Institute for International Science and Technology Policy
Fissile Zero Futures Project

Civil Plutonium Transparency in Asia

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WASHINGTON, DC

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has been Chairman of the Arms Control Association (ACA) since 2017. The ACA is a nonpartisan NGO that analyzes key national security issues and advises the executive branch, Congress and the public on choices that promote global security and reduce risk from weapons of mass destruction. He retired from the Senior Foreign Service in January 2017, after 35 years of service. At that time he served simultaneously as acting Undersecretary of State for Arms Control and International Security and as Assistant Secretary for International Security and Nonproliferation (ISN), a position he held since September 2011. The ISN Bureau leads the U.S. effort to prevent the spread of nuclear, chemical and biological weapons, and their related materials and delivery systems. Previously, he served as Principal Deputy Assistant Secretary for Political-Military Affairs (2009–2010), and as Deputy Assistant Secretary for European Affairs (2010–2011), with responsibility for the Balkans region. He served overseas at U.S. Embassies in Belgrade, Tunis, Cairo, Rome and Athens; and served in the U.S. at the United Nations, the White House and the Pentagon.

Yongsoo Hwang

is Senior Vice President in the Korea Atomic Energy Research Institute (KAERI) in the Republic of Korea. Dr. Hwang is in charge of research for spent fuel management, including the transport, storage and disposal of spent nuclear fuel as well as fundamental research in advanced recycling, such as pyro-processing. In addition, he is leading post-irradiation experiments of spent nuclear fuel. Dr. Hwang has also worked on DPRK nuclear issues during his professional career. He has been in KAERI for more than 25 years in the field of spent fuel management, including the total safety assessment of a deep geologic repository for spent nuclear fuel, and nuclear nonproliferation.

Dr. Hwang also served as the Director General of the Strategic Policy and Research Center in the Korea Institute of Nuclear Non-Proliferation and Control (KINAC), and as a Member of the Advisory Committee for the Korean Nuclear Safety and Security Commission (NSSC) and the first Public and Stakeholder Engagement Task Force Team to solve spent nuclear fuel management issues in the ROK. Dr. Hwang also served as an Advisory Member for the IAEA Director General on multilateral nuclear arrangements between 2004 and 2005 and was a visiting fellow at CSIS in D.C. between 2010 and 2012. Dr. Hwang earned an M.S. and Ph.D. from the University of California Berkeley, in the Department of Nuclear Engineering, and a B.S. from Seoul National University.

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Her work in the government included positions at the Congressional Research Service of the Library of Congress, the State Department and the U.S. Arms Control & Disarmament Agency. She has testified before Congress, and is a frequent commentator on nuclear energy, proliferation and nuclear weapons for U.S. and international print and other media outlets. She is on the Science and Security Board of the Bulletin of Atomic Scientists, Advisory Board for PIR Center and the Board of the Center for Nonproliferation and Arms Control. She earned a B.A. in Political Science from SUNY Albany, an M.P.M. from the University of Maryland School of Public Affairs and an M.P.M. in National Security Strategy from the National War College in 1998.

Tatsujiro Suzuki

is a Director, Professor of Research Center for Nuclear Weapons Abolition (RECNA) at Nagasaki University, Japan. Before joining RECNA, he was a Vice Chairman of Japan Atomic Energy Commission (JAEC) of the Cabinet office from January 2010 to April 2014. Until then, he was an Associate Vice President of the Central Research Institute of Electric Power Industry in Japan (1996–2009) and Visiting Professor at the Graduate School of Public Policy, University of Tokyo (2005–2009), an Associate Director of MIT's International Program on Enhanced Nuclear Power Safety (1988–1993) and a Research Associate at MIT's Center for International Studies (1993–1995). He is now a member of Advisory Panel on Climate Change for Minister of Foreign Affairs since January 2018, and a member of the Advisory Board of Parliament's Special Committee on Nuclear Energy since June 2017. He is also a Council Member of Pugwash Conferences on Science and World Affairs (2007–2009 and from 2014~). Dr. Suzuki has a Ph.D. in Nuclear Engineering from Tokyo University (1988).

SHARON SQUASSONI

Introduction

Experts in nuclear security and proliferation have grappled for decades with the problem of providing enough assurances that the production, use and stockpiling of weapons-usable materials in civilian economies do not increase the risks of proliferation and nuclear terrorism. The series of nuclear security summits held from 2010 to 2016 helped build a norm that the use of highly enriched uranium must be minimized and where possible, eliminated, but there is no similar agreement about the dangers of civilian separated plutonium.[1]

Why is this? Reaching agreement to restrict civilian plutonium is difficult for a few reasons. Plutonium production is itself widespread – it is generated in many research reactors and all nuclear power reactors from the transmutation of uranium. More importantly, as long as plutonium remains in irradiated (spent) nuclear fuel, high radiation barriers make it self-protecting and therefore, less vulnerable. On the scale of proliferation risks, production of plutonium in reactors is generally accepted among experts to be lower than the actual separation effort (spent fuel reprocessing).

[1] When plutonium is contained in irradiated fuel, the radioactivity of the spent fuel provides a barrier to its diversion. The National Academy of Sciences in 1994 called this the "spent fuel standard." See Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Washington, DC: National Academy Press, 1994. Available at: https://www.nap.edu/catalog/2345/management-and-disposition-of-excess-weapons-plutonium Separated plutonium is defined here as plutonium that has been separated from other constituents of spent fuel [or irradiated targets] to the extent that it becomes significantly more vulnerable to diversion or theft than the plutonium contained in light water-reactor spent fuel.

In short, separated plutonium is several steps closer to being usable in a nuclear weapon than is plutonium in spent nuclear fuel. Although many countries and, perhaps, some well-organized non-state actors could conduct the chemical processes to separate small amounts of plutonium, only a few countries have industrial-scale capabilities to separate plutonium from spent fuel. Therefore, the proliferation risks from plutonium are passed off as a question of limiting reprocessing capabilities. The Nuclear Nonproliferation Treaty contains no restrictions on any country acquiring spent fuel reprocessing capabilities, although such facilities and the resultant material would be subject to international monitoring (if the state has joined the treaty as a non-nuclear weapon state). International safeguards are designed really only to detect the diversion from accounting of significant quantities of nuclear material, not to prevent their diversion.

Another technical reason that civilian plutonium is often disregarded as a proliferation risk is the "quality" of the plutonium that is produced in commercial power reactors. Although the U.S. Department of Energy concluded in 1997 that all grades of plutonium can be used in nuclear weapons (and the United States proved this by testing nuclear weapons with so-called "reactor-grade plutonium"), some critics maintain that a country truly interested in making a nuclear weapon with plutonium would not use plutonium produced for other purposes, because it would not have been optimized for weapons use. Uranium irradiated for long periods of time, such as in fuel in civilian power reactors, contains higher levels of other isotopes like Pu-240, which is a poison for fissile yields. Such critics maintain that a country with nuclear power reactors would have the capability to build a clandestine reactor to produce "cleaner" plutonium (irradiated for a shorter time) for a weapon.

Another technical reason that restrictions have not been popular is because plutonium is considered, particularly among technical specialists, to be the key to a perpetual fuel cycle. Once harvested from irradiated nuclear fuel, plutonium can be used as fuel in fast breeder reactors to generate even more plutonium. Although there have been many attempts over the years to discourage future fuel cycles from creating even more plutonium, there is, as yet, no consensus that countries should coordinate their fuel cycle development with that objective.

Overall, the combination of supplier controls and poor economics of commercial spent fuel reprocessing have limited the spread of commercial reprocessing, which has diminished the sense of urgency to put in place measures to prevent widespread proliferation of plutonium separation capabilities. The fact that the Nuclear Non-Proliferation Treaty contains no measures to restrict plutonium separation, use and stockpiling is generally regarded as a manageable risk. Even if countries eventually agree to a treaty to ban the production of fissile material for use in weapons, they may not be able to agree on restricting civilian plutonium use unless nuclear energy falls into disfavor.

In the meantime, then, it could be useful to work towards establishing norms that would in fact diminish the risks of civilian plutonium. These norms could include policies and practices at facilities, by industries, by countries and across countries.

Existing Norms

Nuclear weapon states are not required to submit their stocks of plutonium in civilian use, whether separated or embedded in irradiated nuclear fuel, to international monitoring, including International Atomic Energy Agency (IAEA) safeguards. Twenty years ago, however, the nuclear weapon states and four non-nuclear weapon states (Belgium, Japan, Germany and Switzerland) together established the Guidelines for Management of Plutonium, which were published by the IAEA in an information circular (INFCIRC/549). Nine states publish information on an annual basis about their civil plutonium stocks under the agreed reporting mechanisms of INFCIRC/549. According to INFCIRC/549, however, each government agrees to manage plutonium "in ways which are consistent with its national decisions on the nuclear fuel cycle and which will ensure the peaceful use or the safe and permanent disposal of plutonium." Proliferation risks are taken into account, but so are the following factors: "protecting the environment, workers and the public, the resource value of the material, the costs and benefits involved and budgetary requirements; and the importance of balancing supply and demand, including demand for reasonable working stocks for nuclear operations."[2] This is currently the only example of a multilateral norm on civilian plutonium.

Within industry, AREVA has adopted the equivalent of a "just-in-time" inventory policy, attempting to avoid significant stockpiles of separated plutonium. And Japan, as a

[2] Guidelines for the Management of Plutonium, published as Information Circular (INFCIRC) 549 on March 16, 1998, available at: https://www.iaea.org/sites/default/files/infcirc549.pdf

country, established a "no-surplus plutonium policy" as early as 1991. Japan, the only non-nuclear weapon state now with a domestic reprocessing capability, has taken special steps to allay international concerns about its civilian plutonium stockpile. In 1991, the Japan Atomic Energy Commission (JAEC) specified that Japan would not separate plutonium for which it did not already identify a specific use.[3] Since 1994, Japan has shared information publicly on its separated plutonium and plutonium in spent nuclear fuel, and has reported to the Guidelines for Management of Plutonium (INFCIRC/549) since 1997.

For many years, the Japanese government has relied on the Japanese nuclear industry to specify plutonium consumption plans. Beginning in 2003, the Japan Atomic Energy Agency (then the Japan Nuclear Fuel Cycle Development Institute) participated also in formulating that plan.

Japan's nuclear industry at this point in time, however, is unable to predict with any accuracy when its fleet of nuclear power plants, and particularly the MOX-burning plants will be up and running. The original plan for consuming plutonium relied on at least 16 reactors burning MOX, but at present, the only reactors operating that can burn MOX are Ikata-3, Genkai-3, and Takahama-3 and -4.[4] The continuing disarray that plagues Japan's nuclear industry as a result of the 2011 accident at Fukushima, new regulations and delays in completing and opening the Rokkasho reprocessing plant, and decisions to close the Monju fast breeder reactor, raise questions about the credibility of Japan's plutonium consumption plan. With approximately 10 tons of separated plutonium at home and over 37 tons of separated plutonium at reprocessing plants in the UK and France, Japan's no-surplus plutonium policy looks hollow indeed.

In October 2017, the Japan Atomic Energy Commission released a statement on Plutonium Utilization in Japan. The statement underscored previous policies of not holding plutonium without specific purposes and also Japan's intention to keep a steady state of plutonium through consuming it in light water reactors. The statement reiterated that "It is the intention of the Japanese government (JAEC) to remain engaged to secure appropriate supply-demand balance of plutonium under the current framework of assessing future plutonium consumption by fully grasping the nuclear operators' demand for plutonium and their consumption and verifying its appropriateness."[5] In July 2018, the JAEC released a statement of "Basic Principles on Japan's Utilization of Plutonium." Remarkably, the statement declared that Japan would reduce its plutonium stocks. It then elaborated steps it would take to maintain the balance at current levels. It is worth quoting the operative paragraphs of the statement in full here:

1. Approve reprocessing plans under the Spent Nuclear Fuel Reprocessing Implementation Act so that reprocessing is to be carried out only to an extent necessary for steady pluthermal power generation, reflecting the operational situation of the Rokkasho Reprocessing Plant (RRP), the MOX Fuel Fabrication Plant, and MOX-burning reactors; Instruct the operators and confirm that the produced MOX fuel is to be fully consumed in a timely manner;

2. Instruct the operators so as to secure a balance between demand and supply of plutonium, minimize the feedstock throughout the process between reprocessing and irradiation, and reduce the feedstock to a level necessary for proper operation of the RRP and other facilities;

3. Work on reducing Japan's plutonium stockpile stored overseas through measures including promoting collaboration and cooperation among the operators;

4. Examine all options such as use and disposal of plutonium that is associated with research and development purposes, if there is no concrete plan for its immediate use, while ensuring flexibility depending on the situations; and

5. Steadily promote efforts toward expanding storage capacity for spent fuel.

In addition, in order to enhance transparency, electric utilities and Japan Atomic Energy Agency (JAEA) are expected to develop plutonium utilization plans anew, which describes owners, the amount of plutonium in possession and the purposes of plutonium utilization, and then release them every fiscal year.[6]

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[3] http://www.aec.go.jp/jicst/NC/about/ugoki/geppou/V36/N08/199103V36N08.html

[4] Ikata-3 was under court injunction and should start October 27, 2018; operations see periodic updates from Japan Atomic Industrial Forum's website, https://www.jaif.or.jp/cms_admin/wp-content/uploads/2018/10/jp-npps-operation181002_en.pdf

[5] The October 2017 policy can be found at http://www.aec.go.jp/jicst/NC/about/kettei/kettei171003_e.pdf

[6] The July 31 2018 policy can be found at http://www.aec.go.jp/jicst/NC/iinkai/teirei/3-3set.pdf

The document updated plans for operating the Rokkasho reprocessing plant (construction to be complete in FY 2021) and the MOX fuel fabrication plant (FY 2022).

Without further details, it is difficult to know whether these plans will show anything but slow progress in reducing Japan's plutonium stockpile. The Takahama-3 and -4 reactors were credited with consuming 1 ton of plutonium between 2016 and 2017 and presumably they will remain on-line to continue that steady burning. A significant question is what may occur as a result of the proposed collaboration among operators to reduce Japan's plutonium stockpile stored overseas.

Japan's neighbors, China and South Korea, watch these developments with interest. Although China's growth in nuclear power has slowed a little since 2011, its plans call for considerable expansion, including civilian reprocessing of spent nuclear fuel, as well as work on advanced nuclear reactors.[7] South Korea's current plan, under Moon Jae-In, is to phase out nuclear power, but this policy may only last as long as Moon's one five-year term. Despite some safety scandals a few years ago, South Korea will probably return to a robust nuclear energy program that features exports and a strong push for pyroprocessing, a form of reprocessing for spent fuel.

The essays that follow in this report seek to assess the kinds of additional transparency or restrictions that could strengthen the norm against plutonium stockpiling in Northeast Asia. Is it possible for Japan to do more regarding its no-surplus plutonium policy? Specific questions to consider included:

- What kinds of information would be useful to improve confidence in intentions about the management of civilian plutonium, either separated or in irradiated fuel?
- How much and what kinds of information is shared publicly about spent nuclear fuel and separated civilian plutonium in your country? Has this shifted over time? Are there domestic economic, technical or political hurdles to sharing information?
- Are there domestic, regional or international incentives exist for sharing more information? What potential new best practices or approaches could be useful in other states in the region?
- What barriers exist that might prevent more information-sharing? Do trade/regulatory relationships work for or against greater information-sharing?
- Are there ways in which industry can strengthen confidence? What information can industry share and with whom?
- What constitutes a reasonable level of working stocks for specific reprocessing facilities (based on throughput)? How is that level calculated?

A few themes span the five essays. One is that Japan has an opportunity to play a leadership role in strengthening norms against plutonium stockpiling. In his essay, "Proliferation Risks of Plutonium Production," former Assistant Secretary of State for International Security Tom Countryman suggested that Japan should invest more in medium-term storage (in dry casks) of spent nuclear fuel, and in research on safe and economical methods of permanently storing excess plutonium (with researchers in the US and UK). Making significant progress on identifying a permanent depository for long-term storage of nuclear waste could also be helpful in the region. Countryman proposed that Japan make good on the Joint Atomic Energy Commission's July 31, 2018 pledge to reduce holdings of plutonium by committing "to limiting production when the Rokkasho facility eventually opens to an annual limit matching the realistic consumption capacity of currently existing Japanese reactors." A more far-reaching step would be for Japan to propose a regional moratorium on reprocessing, making a virtue of necessity. In Countryman's view, a moratorium would serve as a confidence-building measure among economic and security rivals, even if it were initially proposed for a limited period, e.g., five years. It could potentially allow the four East Asian states – Japan, China, North Korea and South Korea – to share information on capabilities and risks, and to work together on methods of handling and permanently storing spent nuclear fuel, and of further reducing the cost of LEU for reactor input.

Dr. Tatsujiro Sukuki, former JAEC commissioner and director of the Research Center for Nuclear Weapons Abolition, Nagasaki University (RECNA), suggested four actions that could support efforts to reduce plutonium stockpiles. He recommended first that each country's declaration under the Guidelines for the Management of Plutonium should specify "demand" (consumption/disposition) for the next

[7] See Mark Hibbs, "The Future of Nuclear Power in China," Washington, DC: Carnegie Endowment for International Peace, May 2018, available online at: https://carnegieendowment.org/2018/05/14/future-of-nuclear-power-in-china-pub-76311

three years, restrain "supply" (reprocessing) up to the amount specified by the demand, including the current stockpile, and define what is "excess" stockpile (beyond the quantity defined above). Suzuki recommended that numbers should be in kg rather than tons (per Japan's example), that the report should specify sites where separated plutonium is stored (per Japan's example), should include any stockpiles of highly enriched uranium, and should review the country's national nuclear fuel cycle policy (cost, rationale, environmental impacts, safety etc.).

Another theme was the need for international collaboration to reduce risks from plutonium. In his essay, Suzuki recommended that countries revisit the option of establishing an international plutonium storage concept, cooperate on plutonium disposition, including "swapping" ownership of plutonium to be able to consume it more quickly, and, ultimately, phase out reprocessing. Suzuki specifically proposed that the UK, France, Japan and Russia commit to a moratorium for the foreseeable future until plutonium stocks are substantially reduced.

Dr. Sungyeol Choi, a professor in the Nuclear Fuel Cycle Laboratory at the Korean Advanced Institute of Science and Technology, suggested that potential incentives for regional cooperation might be lower national costs by sharing investment in research and development, shorter timelines for a fuel cycle program, increased public trust (peer review between cooperative countries) and enhanced regional transparency, non-proliferation and security. Regional collaboration could help promote economies of scale, widen the candidate sites for repositories and create multiple options for managing spent nuclear fuel, among other things. However, Choi also cited security concerns, cultural barriers, and economic barriers to sharing information between regional partners in these areas.

On the question of reasonable working stocks for reprocessing plants, Choi noted that inventory optimization is a very common problem in the process, chemical and manufacturing industries. He suggested a crude estimate of working stock as enough to operate reactors for 2-3 years, or roughly 2.5 tons of plutonium per 1 GWe reactor using a one-third core loading. Dr. Jor-Shan Choi, in his essay, echoed the importance of working stocks in reprocessing plants for balancing the supply and demand of plutonium. He noted that industrial operation of fuel fabrication plants in Belgium and France suggested that reasonable working stocks may amount to 1 to 2 years of production throughput, and sufficient for contingencies associated with administrative procedures, transportation logistics and security requirements, etc.

Finally, the role of civil society in promoting transparency about civil plutonium is weak in some countries. For example, in South Korea, as Dr. Yongsoo Hwang points out in his essay, there are only limited universities dedicated to education about the nuclear fuel cycle, nuclear non-proliferation, and public and stakeholder engagement. Although some schools have begun to establish courses on nuclear non-proliferation. it will take some time to see real impact from this educational endeavor.

TATSUJIRO SUZUKI

Possible Options for International Management of Plutonium Stockpile

The growing stockpile of plutonium is one of the most important security risks we face today. A total of 518.6 tons of separated plutonium, which is equivalent to 86,440 Nagasaki bombs (6kg/bomb), exist now (as of the end of 2016), and is still increasing primarily due to civilian reprocessing programs. Roughly 60% of it (roughly 290 tons) is civilian plutonium and about 97% of it are owned by only four countries (UK [110], France [65], Russia [57] and Japan [47]), all of which have on-going civilian reprocessing programs. At the 2014 Nuclear Security Summit, the Hague Communique stated that "we encourage States to keep their stockpile of separated plutonium to the minimum level, both as consistent with national requirements." There are also "excess" military plutonium stockpile, which is roughly 78 tons (US and Russia) which are not yet under international safeguards. Then more than 70% of plutonium stockpile are "non-military purposes" and thus should be kept safety and securely. It is an urgent task for the international community to manage such large stockpile of plutonium and to reduce to minimum level as soon as possible.

This paper addresses possible international management options to deal with such a large stockpile of separated plutonium, especially those of civilian and "excess" military plutonium. There are four possible options: 1) enhanced transparency by strengthening International Plutonium Management Guidelines (INFCIRC/549), 2) International Plutonium Storage (under the custody of IAEA) of "excess" plutonium, 3) International Cooperation on Plutonium Disposition, and 4) Moratorium on commissioning of new reprocessing facilities.

Introduction

Plutonium was once considered a valuable energy resource as it can be recycled from spent nuclear fuel into Fast Breeder Reactor (FBR) fuel, making nuclear energy virtually an unlimited energy resource. However, plutonium was first used as a raw material for the nuclear bomb dropped over Nagasaki City on August 9, 1945. Since then, plutonium is defined by the International Atomic Energy Agency (IAEA) as "special nuclear material" which can be directly used to manufacture nuclear bombs. Another special nuclear material that can be used to make nuclear bomb is Highly Enriched Uranium (HEU) that was used in the bomb dropped over Hiroshima on August 6, 1945. HEU and plutonium are called "weapons-usable materials (WUM)", and now the increasing stockpile of WUM is one of the most important security risks we face today.

The HEU stockpile is declining overall since the end of Cold War as it can be "diluted" to Low Enriched Uranium (LEU) which can be used as nuclear fuel for civilian nuclear power plants. While plutonium can also be mixed with uranium to be used for nuclear fuel (called MOX fuel), its high costs are barriers to using MOX fuel on a large scale. Therefore, disposition of plutonium is more difficult than that of HEU. Meanwhile, civilian reprocessing programs continue in a small number of countries. As a result, the plutonium stockpile, unlike HEU, is increasing steadily. It is a critical moment for international community to consider policy options to deal with increasing plutonium stockpile.

Global Plutonium Stockpile

A total of 518.6 tons of separated plutonium, which is equivalent to 86,440 Nagasaki-type bombs (6kg/bomb), exist now (as of the end of 2016) globally, and is still increasing primarily due to civilian reprocessing programs. For HEU, the total global stockpile is now estimated to be 1,342.5 tons, which is equivalent to 20,977 Hiroshima type bombs (64kg/bomb). Compared with the data published in 2015 (as of the end of 2013), the HEU stockpile was slightly reduced (-7.0 tons) from 1, 349.5 tons, while plutonium stockpile is increasing steadily (+18.2 tons) from 500.4 tons in 2015. The increase in the plutonium stockpile has come primarily from non-military use. The military stockpile has declined from 160.3 tons to 152.3 tons (-8.0 tons), while the non-military stockpile has increased from 340.1 tons to 366.3 tons (+26.2 tons)[1]. Roughly 60% of current stockpile (roughly 290 tons) is civilian plutonium and about 97% of it is owned by only four countries (UK [110], France [65], Russia [57] and Japan [47]), all of which have on-going civilian reprocessing programs. Almost all of the increase in the stockpile actually came from an increase in the civilian plutonium stockpile. For military plutonium, its stockpile increase comes from only three countries -- Israel, India and Pakistan -- although its total amount is about 8.2 tons (India [7.0ton] Israel [0.9ton] and Pakistan [0.3ton]).

Global reprocessing programs

Civilian reprocessing programs are facing critical moments, whether they will continue to expand or they may gradually phase out. So far, ten countries built civilian reprocessing plants (Belgium, China, France, Germany, India, Italy, Japan, Russia, UK, and the US) and another eleven countries (Armenia, Bulgaria, Czechoslovakia, East Germany, Finland, Hungary, Netherland, Spain, Sweden, Switzerland and Ukraine) shipped their spent fuel to France, UK and Russia for reprocessing.[2] As of now, only six countries have significant reprocessing programs and all others have small amounts of plutonium left from past reprocessing activities. There are three categories of these six countries with continuous civilian reprocessing activities.

First is France and Japan. Both have nuclear energy programs with a closed nuclear fuel cycle; France has two operating reprocessing plants while Japan has closed one small reprocessing plant and is completing the safety licensing process for one large reprocessing plant (Rokkasho). Both countries have research and development programs on fast breeder reactors but no large breeder reactor is under construction, and they both plan to consume plutonium in existing light water reactor (LWRs) as MOX fuel. But both countries are facing uncertainties in the future of reprocessing programs. In France, the newest reprocessing plant (UP-3) is now almost 30 years old (operating since 1989) and its new nuclear energy policy is to decrease its share in total electricity production from current 70% to 50%, resulting in fewer reactors to consume MOX fuel. In Japan, the new Rokkasho reprocessing plant has been delayed 24 times and now its planned operation date is March 2021, but the number of

[1] Research Center for Nuclear Weapons Abolition, Nagasaki University (RECNA) Data Base. http://www.recna.nagasaki-u.ac.jp/recna/fms (in Japanese). http://www.recna.nagasaki-u.ac.jp/recna/en-nuclear/a-world-of-potential-bombs-fissle-material-inventory (in English). Non-military stockpile is a total of civilian stockpile and "excess" military stockpile which is declared by nuclear weapon states that is no longer used for military purposes.

[2] International Panel on Fissile Materials (IPFM), "Plutonium Separation in Nuclear Power Programs: Status, Problems, and Prospects of Civilian Reprocessing Around the World", 2015. http://fissilematerials.org/library/rr14.pdf

reactors to burn MOX fuel is only four as of July 2018, much smaller than the planned number of 16-18.

The UK example is different. The UK has decided to end its reprocessing program when its current contracts are fulfilled in 2020. The UK has the largest civilian plutonium stockpile due to past reprocessing activities and is now facing a decision on how to dispose of more than 100 tons of plutonium. In 2011, UK government released its basic program to dispose plutonium, which included MOX fuel as its first choice, but also investigation of a disposal option. The UK government has been willing to take title of foreign owned plutonium stored in the UK as long as it does not have extra financial burden on UK tax payers. The decision on plutonium disposition has been delayed.[3]

The third category includes Russia, India and China. Russia and India have been operating relatively small civilian reprocessing programs and both have on-going breeder R&D programs. Russia and India have already significant plutonium stockpiles, while India's facilities can be dual-purpose. China has also a policy of pursuing the closed fuel cycle and yet has only a small reprocessing plant with an experimental fast reactor. China is now considering building a large reprocessing facility and has signed a memorandum of commercial agreement with French AREVA to build an 800 ton/year reprocessing plant in China[4] despite strong local public opposition at a potential site.[5]

Additionally, the Republic of Korea (ROK) is also interested in reprocessing although such a step would require consent by the United States, which has thus far been denied under the US-ROK bilateral nuclear cooperation agreement[6]. ROK insists that they want similar right which Japan is granted under the 1988 US-Japan bilateral agreement, i.e. "programmatic prior consent" which allows Japan to reprocess without US approval for 30 years since 1988. Now that the US-Japan bilateral agreement has been extended into the future indefinitely, Japan can still continue reprocessing without US approval. Both parties have the right to terminate the agreement with six months' advance notice, leading some observers to suggest that the agreement may become more unstable.[7]

In short, all reprocessing programs are facing critical decision making points regarding whether to continue to expand or to stop and shrink their reprocessing programs. If they continue to reprocess, the global civilian plutonium stockpile will likely to grow, which poses greater security risks to the world.

Civilian Plutonium Management: Need for a new norm

Given the background above, it may be wise to consider a new international norm on management of civilian (and possibly "excess" military) plutonium. At the 2014 Nuclear Security Summit, the Hague Communique stated that "we encourage States to keep their stockpile of separated plutonium to the minimum level, both as consistent with national requirements."[8] This is a positive step in right direction, but it is not clear whether this will eventually reduce plutonium stockpiles as it still allows a minimum level of stockpile for national requirements. There is no clear definition of "minimum" level.

In order to mitigate the risks of increasing stockpile of separated plutonium, John Carlson presented specific proposals for establishing a new norm for civilian plutonium stockpile management[9]. They are:

- Committing to keep separation (reprocessing) in balance with consumption. Ensuring the rate of reprocessing output is consistent with the capacity to consume such output

- Considering mechanism and incentives to encourage states to declare surplus or "excess plutonium" (ex. If there is no plan to use plutonium within a defined period)

[3] UK Department of Energy and Climate Change, "Management of the UK's Plutonium Stocks: A consultation response on the long-term management of UK-owned separated civil plutonium," 1 December 2011.

[4] "French group signs memorandum with Chinese partner on nuclear reprocessing plant", China Daily, January 10, 2018. http://www.chinadaily.com.cn/a/201801/10/WS5a554cbba3102e5b17371b31.html

[5] Jim Green, "Protests against proposed reprocessing plant in China", Nuclear Monitor Issue, August 24, 2016. https://www.wiseinternational.org/nuclear-monitor/829/protests-against-proposed-reprocessing-plant-china

[6] Philip Baxter, "Approaches to Nuclear Cooperation: A Review of the US-ROK Agreement", American Association for Advancement of Science (AAAS), September 2015. http://www.sciencediplomacy.org/files/approaches_to_nuclear_cooperation_science_diplomacy_0.pdf

[7] "US-Japan Nuclear Agreement Extension is Not Cause for Relief", Kyoto Shimbun Editorial, originally published on January 23, 2017, translated and published on Watching America, February 3, 2018. http://watchingamerica.com/WA/2018/02/03/us-japan-nuclear-agreement-extension-is-not-cause-for-relief/

[8] The Hague Nuclear Security Summit Communique, March 25, 2014. https://www.mofa.go.jp/files/000135986.pdf

[9] John Carlson, "Mitigating Security Risks from Separated Plutonium: Some Near-Term Steps", April 2018. http://www.nti.org/media/documents/NTI_Paper_Mitigating_Security_Risks_FINAL-April2018.pdf

- Such "excess plutonium" could be placed under IAEA control or could be made available for consumption elsewhere
- Consider development of regional or multinational plutonium storage schemes
- Take appropriate actions for management and disposition of excess civilian and military plutonium

Carlson also recommended to establish a Forum for addressing separated plutonium issues and to develop a Code of Conduct for separated plutonium, too.

Based on these recommendations, I propose four specific options as near and mid-term steps to reduce and eventually eliminate risks of plutonium stockpile.

Option 1: Enhancement of International Plutonium Management Guidelines (INFCIRC/549)

The first option is to enhance the International Plutonium Management Guidelines (INFCIRC/549)[10] which are voluntary guidelines established in 1997 by nine countries (Belgium, China, France, Germany, Japan, the Russian Federation, Switzerland, the UK, and the US). The guideline is only applicable to civilian plutonium which is under the IAEA safeguards. The guidelines outline general principles of plutonium management strategy including to: 1) ensure the peaceful use of the safe and permanent disposal of plutonium, 2) avoid contributing to the risks of nuclear proliferation, 3) protect the environment, workers and public, 4) take into account the resource value, costs and benefits involved and budgetary requirements, and most importantly, 5) balance supply and demand, including demand for reasonable *working stocks* for nuclear operations.

In order to reduce the plutonium stockpile, the principle of 5) is crucially important, although the definition of "working stocks" is not clear. To enhance the plutonium guidelines, the following can be included. Some of them can just follow Japan's "Status Report of Plutonium Management in Japan"[11] which has higher transparency than the Guideline. The national statement by the government should:

- Specify "Demand" (consumption/disposition) for the next 3 years
- Restrain "Supply" (reprocessing) up to the amount specified by the demand, including current stockpile
- Define "excess" stockpile (beyond the quantity defined above)
- Numbers should be in kg rather than tons (following Japan's example)
- Specify sites where separated plutonium is stored (following Japan's example)
- Include HEU stockpile, if any
- Review of national nuclear fuel cycle policy (cost, rationale, environmental impacts, safety etc.)

It is reported that a similar policy may be introduced by the Japan Atomic Energy Commission (JAEC) soon. The report says that JAEC will "cap" the stockpile and restrains the pace of reprocessing in order to match specific plutonium demand specified in a certain time period.[12]

Option 2: International Plutonium Storage (IPS) revisited

Linked to the Option 1, an international plutonium storage concept can and should be considered as a reasonable option to enhance the transparency of a growing plutonium stockpile. Article XII of the IAEA Statute provides that the IAEA has the right to "require deposit with Agency of any excess of any fissionable materials recovered or produced as a by-product over what is needed for…in order to prevent stockpiling of these materials…at the request of the member of members concerned special fissionable materials so deposited with the Agency shall be returned promptly to the member or members concerned."[13] This is the basis of IPS concept, which was once considered in 1980s and again in 1990s.

More recently, Fred McGoldrick proposed that Japan should consider an agreement with the IAEA for a custodial regime for its excess

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[10] International Plutonium Management Guideline, INFCIRC/549. https://www.iaea.org/sites/default/files/infcirc549.pdf

[11] Office of Atomic Energy Policy, Cabinet Office, "The Status Report of Plutonium Management in Japan 2016", August 1, 2017. http://www.aec.go.jp/jicst/NC/about/kettei/170801_e.pdf Japan's status report show the quantities in kg rather than ton, and specifies specific sites of plutonium storage.

[12] "Japan nuclear agency urges measures to cut plutonium stocks," The Japan Times, July 6, 2018. https://www.japantimes.co.jp/news/2018/07/06/national/japan-nuclear-agency-urges-measures-cut-plutonium-stocks/#.W0CBXfZuK5h

[13] The Statute of International Atomic Energy Agency (IAEA). Article XII. https://www.iaea.org/about/statute#a1-12

plutonium. He suggested that the following broad characteristics should be included, although the details of such an agreement must be negotiated between IAEA and Japan.[14]

- Japan would determine the amount of plutonium to be placed under IAEA custody, but there would be a presumption that material not being used or not designated for use within a specified period of time would be excess and be deposited with the agency.

- Japan and the IAEA would agree on the location of storage sites, presumably co-located with Japanese reprocessing and MOX fuel fabrication facilities.

- The agency would retain custody of the excess plutonium until the Japanese government requests its release for a specified peaceful use, for example, in a MOX fuel fabrication plant, a nuclear power plant, a vitrification facility, or a direct disposal site.

- Japan could not remove the materials from IAEA custody until it submitted to the IAEA a request for release of a specified quantity accompanied by an end-use certificate. The certificate of use would contain the following assurances and information:

    - an assurance that the material would be used for exclusively peaceful, nonexplosive purposes;

    - an assurance that the plutonium would be subject to continuing IAEA safeguards in accordance with the provisions of the IAEA-Japanese safeguards agreement or, if the material were to be exported to another country, that it would be subject to the safeguards agreement between the IAEA and that country;

    - an assurance that the material would remain under effective physical protection in accordance with accepted international standards;

This could be a good example to be followed by other countries who own plutonium stocks and can be adopted as a part of International Plutonium Management Guidelines if all members agreed. But voluntary efforts by any plutonium stockholder would enhance transparency and international confidence.

Option 3: International Cooperation on Plutonium Disposition

The above two options are good measures to improve transparency and international confidence, and may help "capping" the plutonium stockpile but may not contribute to significant "reduction" of plutonium stockpile. In order to reduce plutonium stocks effectively, international cooperation could and should be considered more seriously.

One option is "swapping" the ownership of plutonium to consume plutonium more quickly and effectively. International commercial transactions have already helped to reduce plutonium stocks. For example, in March 2013, the Tokyo Electric Power reported that it "swapped" its 434 kg of plutonium kept in France for the same amount in Britain owned by a German utility, following a proposal by a British and French nuclear authority.[15] The swap was a "win-win" deal for all parties in Japan/Germany/UK/France. The German utility wanted to manufacture MOX fuel kept in UK but UK did not have MOX fabrication plant. So the Germans swapped the plutonium owned by TEPCO in France so that the German utility was able to quickly convert its plutonium in the French MOX fabrication plant. MOX fuel fabricated in France can be shipped to Germany LWR to consume, which cuts the need for plutonium shipments from UK to Germany which would have been necessary if the swap did not take place.

A second option is the one proposed by the UK government which is willing to take "title" of foreign-owned plutonium stored in the UK, subject to commercial terms that are acceptable to the UK Government. The UK government would treat such plutonium as UK-owned plutonium. There are already several cases under this proposal. The UK Nuclear Decommissioning Authority (NDA) has agreed to:

- Take ownership of about 800 kg of material owned by Swedish utility

- Take ownership of about 140 kg of material owned by a German research organization

[14] Fred McGoldrick, "IAEA Custody of Japanese Plutonium Stocks: Strengthening Confidence and Transparency", Arms Control Today, September 29, 2014. https://www.armscontrol.org/node/6555

[15] "Tepco Swaps Plutonium Kept in France for German Utility's Fuel", Japan Update, April 24, 2013. https://www.japanbullet.com/news/update-tepco-swaps-plutonium-kept-in-france-for-german-utilitys-fuel

These transactions, which were agreed by the EURATOM Supply Agency, would not result in any new plutonium brought into the UK and would not increase the overall amount of plutonium in the UK, but could eliminate plutonium shipments from the UK to original owner countries. So these transactions have also entailed win-win cooperation among participating parties.

Japan has the largest foreign-owned stockpile in the UK and naturally it would be great if UK and Japan agreed to eliminate the need for plutonium shipments from the UK to Japan. Japan also can reduce its plutonium stockpile quickly, although the global plutonium stockpile would not change until the UK eventually disposes of such plutonium. Japan previously agreed to give up ownership of 331kg of weapon-grade plutonium stored as fuel in Fast Critical Assembly (FCA) in 2014 and plutonium will be eventually disposed of instead of being used as nuclear fuel.[16] Such international transactions between plutonium owners or countries who are willing to take foreign owned plutonium for their disposition programs. It would be ideal the nuclear weapon states will take titles of plutonium owned by non-nuclear weapon states.

A third option is called "virtual reprocessing." Under this option, customer utilities ship spent nuclear fuel for a "reprocessing contract" but the plutonium can be drawn from the existing stockpile rather than from new reprocessing. Although this may reduce the plutonium stockpile, it may encourage utility companies to ship spent fuel and plutonium back to the original customer. It then may be useful to consider this option with combination of IPS concept so that plutonium can be stored until the customer proves its specific demand for plutonium.

Finally, international cooperation on R&D of plutonium disposition can be encouraged. For example, the US and UK are conducting an R&D program on plutonium disposition technologies as an alternative to the MOX program. Given the failure to proceed with MOX fuel in the US, the Department of Energy (DOE) is now conducting a direct disposal of excess plutonium from dismantlement of nuclear weapons. DOE's plutonium disposition working group is now focused on the simplest possible direct-disposal strategy -- down-blending the plutonium and packaging it in drums to be deposited in an already operating underground waste-plutonium depository, called the Waste Isolation Pilot Plant.

There are other options, such as can-in-canister disposal and packaging for disposal in a geological disposal, or deep borehole disposal.[17] The UK government is also searching for alternatives to a MOX program. The UK National Nuclear Laboratory is setting up a plutonium "immobilization" process at the Sellafield reprocessing site where contaminated plutonium oxide is to be immobilized. The process creates a solid composite using "hot isostatic pressing". The UK may have to use an "immobilization" strategy for about 14-21 tons of its 140 tons of plutonium, which may be too impure to be fabricated into MOX.[18]

International R&D on such plutonium disposition programs can be quite useful to share technology and possibly share the financial burden. Japan, France or Russia may join such international R&D efforts to explore alternatives to MOX programs.

Option 4: Moratorium and phasing out reprocessing for all purposes

Lastly, but not least, in order to eliminate plutonium stocks, reprocessing activities must be phased out eventually. The Pugwash Council made a statement in 2015 on this issues, saying; "Reprocessing to separate plutonium should end in all countries, including all nuclear weapon countries, whether for energy or weapon purposes…In view of the international security consequences of fuel cycle decisions, countries need to mutually agree to restrictions on their national sovereignty in making nuclear fuel cycle decisions."[19]

In Japan, about 20 experts and policy makers made a series of recommendations on plutonium management after the conference on this subject in 2017, in particular to the government of Japan, saying; "Commit to a reprocessing moratorium in order to prevent the further accumulation of separated plutonium in the Northeast Asian region. Japan's government should lead the way by indefinitely postponing the startup of

[16] "US-Japan Joint Statement on Nuclear Security Cooperation", Japan Ministry of Foreign Affairs, March 2014. https://www.mofa.go.jp/files/000144984.pdf See also "Plutonium from Japan to be disposed of underground in New Mexico", The Japan Times, April 2, 2016. https://www.japantimes.co.jp/news/2016/04/02/national/politics-diplomacy/plutonium-japan-disposed-underground-new-mexico/#.W0GhUtL7Rdg

[17] Frank von Hippel and Gordon MacKerron, "Alternatives to MOX: Direct-disposal options for stockpiles of separated plutonium", IPFM report, April 2015. http://fissilematerials.org/library/rr13.pdf

[18] Frank von Hippel and Gordon McKerron, ibid.

[19] Statement of the Pugwash Council, November 2015. https://pugwashconferences.files.wordpress.com/2015/10/20151125_council-statement.pdf

the Rokkasho reprocessing plant since Japan has already accumulated 48 tons of separated plutonium. Other governments in the region should follow this example by committing to suspend all activities and future plans to separate plutonium through reprocessing." [20]

Based on these recommendations, I would propose that four countries (UK, France, Japan and Russia) could agree not to commit to further reprocessing while transferring ownership of plutonium among four countries if necessary. There is enough plutonium for energy use for decades to come and no further separation of plutonium is needed for a foreseeable future. In order to realize such a plan, it is essential that spent fuel storage capacity should be secured. Besides, it may be a good time to establish a new norm for reprocessing -- commitment to no new reprocessing facilities and placing existing ones under multinational control. This may take more time, but we have enough time to discuss these proposals until existing plutonium stocks will be substantially reduced.

Conclusion

Increasing plutonium stocks is a global security issue and needs to be addressed under an international framework. Japan is unique as a non-nuclear weapon state with a large plutonium stockpile. But the issue of plutonium management and disposition is common to all plutonium owner countries. They need to collaborate further to solve this complex issue. It is time to establish a new international norm on plutonium management and disposition.

[20] PuP 2017 Statement, 24 February 2017. http://www.cnic.jp/7348

THOMAS COUNTRYMAN

The Proliferation Risk Of Plutonium Production

The continued commitment of Japan to a closed fuel cycle, and the Republic of Korea's interest in establishing a closed cycle, raise serious concerns about increased risk of proliferation of nuclear weapons. The two nations and the two cases are not identical, but they raise the same difficult questions. This paper focuses on Japan, because its decisions, or its failure to decide, will have significant consequences in Asia and beyond.

This comment focuses on the nonproliferation challenges in its broadest meaning. For some advocates of reprocessing, for example in Japan and ROK, nonproliferation has a narrow meaning: adherence to the security and safety policies and guidelines, and the safeguards against diversion of fissile material, established and enforced by the International Atomic Energy Agency (IAEA). I mean it in the larger sense, of reducing the incentives and risks of new nations developing or acquiring nuclear weapons.

In a closed fuel cycle, plutonium is separated from spent nuclear fuel. Separated plutonium is inherently a proliferation risk, regardless of the process employed. Research in US laboratories has demonstrated that the distinction between 'weapons-grade' and 'reactor-grade' plutonium is not significant. Either can be used to fabricate a nuclear weapon of the type that destroyed Nagasaki. With less than ten kilograms of plutonium required for such a weapon, the world's accumulation of more than 500 tons of separated plutonium should demand a greater effort to securely manage, and eventually eliminate, this dangerous stockpile.

Background

As a nation almost totally dependent upon imported energy, Japan (like several other countries at the time) began pursuing the technology for reprocessing in the 1950s. Two oil shocks in the 1970s gave strong impetus to the national project. Although Japan has encountered the same difficulties in developing fast breeder reactors that other countries have faced (recently closing definitely its flagship project at Monju), it has focused instead on fabricating mixed-oxide fuel (MOX, a mixture of plutonium and low-enriched uranium, LEU) that can be used in place of LEU in the more standardized light water reactors. For years, it has shipped spent fuel to reprocessing plants in the UK and France which then return MOX fuel elements to Japan.

Construction of a reprocessing facility at Rokkasho, in the Aomori prefecture, and an accompanying MOX fabrication plant, has proceeded fitfully and slowly. This – and the fact that only four of Japan's reactors were using MOX fuel - led gradually to Japanese ownership of a stockpile of some 47 tons of separated plutonium, of which ten tons is located in Japan. The Fukushima accident in 2011 led to the closing of many Japanese reactors, including some of those capable of consuming MOX, and the indefinite postponement of the construction of new MOX-consuming reactors. As justification for the continuation of its policy, Japanese officials continue to project the future operation of fourteen to eighteen MOX-capable reactors, an optimistic forecast which few observers judge to be politically acceptable to voters.

The experience of those nations (US, UK, Germany, Belgium and others) that have abandoned long-standing efforts to close the fuel cycle should be instructive for Japan, providing a number of sound and sufficient reasons for Japan to reconsider its policy.

The economic justification for moving to a once-through fuel cycle is particularly compelling. Even the cost studies by the advocates of reprocessing conclude that it adds to the total cost of electricity generation, as compared to the 'once-through' disposal of spent fuel which is now pursued by most of the world's civil nuclear powers.[1] The most recent scientific studies cast doubt – indeed refute – the claim that reprocessing will reduce the cost of ultimate fuel disposition. This additional cost in electricity generation is passed on to consumers, and to Japanese manufacturers struggling to compete in the world market.

In Europe (Germany and Belgium), the production and transport of plutonium in itself generated significant public protest against the entire nuclear industry. Advocates of nuclear energy in Japan harm their own cause by insisting on production of plutonium. [2]

Plutonium will always be a safety risk. Its high chemical toxicity (compared to enriched uranium) means that more expensive systems must be built to protect workers. (Note the fatal explosion at the Marcoule reprocessing facility in France in 2011).

Any stock of separated plutonium will always be a tempting target for criminals and terrorists. Japan's security measures at the Rokkasho facility are impressive, but even the most expensive measures will never completely eliminate this risk.

Proliferation Concerns

Beyond these reasons, broad nonproliferation concerns argue for a change to Japan's policy regarding plutonium.

At the most general level, Japan's holding of 47 tons of plutonium has eroded its international reputation as a leader in disarmament and nonproliferation. The United States has had few partners in the world so steadfastly committed to using the tools of diplomacy to slow the spread of nuclear weapons technology. As both a victim of nuclear weapons, and a beneficiary of the US 'nuclear umbrella', Japan has been particularly valuable in building bridges between the nuclear weapons states and the strongest advocates of more rapid disarmament. Any diminution of its standing negatively affects both US security interests and the general strength of the nonproliferation regime. But even nations friendly to Tokyo see an inconsistency between this stockpile and Japan's prominent voice on nonproliferation issues.

Criticism from Beijing that Japan itself poses a proliferation risk can be dismissed as part of the standard propaganda Beijing regularly directs toward Tokyo. There is little reason for the world to be concerned that Japan retains its plutonium stockpile to maintain 'nuclear latency' i.e., as a contingency in case of a future decision to pursue nuclear weapons. No matter what the rhetoric, it is not conceivable that the Japanese

[1] See Masafumi Takubo and Frank von Hippel, *Ending Reprocessing in Japan: An alternative approach to managing Japan's spent nuclear fuel and separated plutonium* (International Panel on Fissile Materials, 2013). Fissile Materials.org/library/rr12.pdf

[2] Forthcoming publication by Alan Kuperman on comparative study of MOX use in several countries, to be published by University of Texas, 2019

public, which cannot forget the horrors of Hiroshima and Nagasaki, would tolerate such a decision.

Yet, like much successful political propaganda today, there is a seed of truth contained. Japanese officials have been disciplined in insisting that Japan has no intention ever to build nuclear weapons, and in pointing to public opposition to the idea. However, the need for a "latent deterrent" was cited by the Defense Minister as an argument for maintaining civil nuclear capacity following Fukushima. There is a political taboo against suggesting that Japan develop nuclear weapons, but few in political circles question the desirability of maintaining the necessary technical skills. Without doubt, Japan has the technical capability to rapidly produce a nuclear weapon, regardless of the size of its plutonium stockpile. Chinese (and Korean) apprehension about Japanese acquisition of nuclear weapons runs as deeply as the historic Russian apprehension about Germany following the same path.

Regional Implications For East Asia

Although Japan's policy has proven to be a bad bet economically, it has advanced among its neighbors the perception that reprocessing and advanced reactor technology are an area of strategic competition. Both China and South Korea are likely in the future to outstrip Japan as a supplier of reactors to the global market. Both believe that their sales can be enhanced if they are able to offer new customers an alternative to constructing a permanent spent fuel depository on their own territory, i.e., to reprocess spent fuel and consume MOX in advanced reactors.

But in the tough neighborhood where Japan lies, strategic economic competition rapidly overlaps with security competition. What is true for Japan is also true for its neighbors: the economic justification to pursue a closed fuel cycle is equally lacking. An analysis of the economic and security interests of its neighbors provides additional nonproliferation and security reasons for Tokyo to reassess its policy.

North Korea: At the Singapore Summit, the DPRK committed (for the third time) to the complete denuclearization of the Korean Peninsula. Despite previous commitments, it has developed an arsenal of dozens of nuclear weapons primarily through reprocessing spent fuel into plutonium. The current US negotiation with the DPRK has as one of its goals the cessation of fissile material production in the North. This target is far from being realized; even if North Korea reduces or eliminates its weapons, it would require several negotiating steps beyond that before it accepts restrictions on enrichment and reprocessing. Achieving that goal will be more difficult if the DPRK can point to continued US acquiescence in Japan's reprocessing program. Conversely, the US negotiating demand, to end reprocessing in North Korea, will be stronger if none of the DPRK's neighbors are pursuing reprocessing. At this early point in US-DPRK negotiations, this situation is speculative, but would fall into the category of "a good problem to have." The prospect of ending North Korea's capability to produce fissile material would add another strong reason for Tokyo to change its approach.

South Korea: When I led the US side in the negotiations (2011-2015) for a new ROK-US civil nuclear cooperation agreement ("123 agreement"), ROK negotiators made frequent reference to the fact that Seoul wanted the US to recognize the same "rights" the US had recognized in its 123 agreement with Japan, i.e. providing advance consent for using US-provided materials for enrichment and reprocessing. The ROK sees itself as a future world leader in pyroprocessing (a form of reprocessing), offering reprocessing services to help other countries manage their spent nuclear fuel.

Of course, Japan and the ROK, despite the fact that both are close allies of the US, are two very different cases. The original US agreement to allow Japan to reprocess US-origin materials was made after Japan had already demonstrated an indigenously developed capability, and before the US adopted a stronger policy of discouraging the spread of ENR (enrichment and reprocessing) technology, a point US negotiators made repeatedly in Seoul. No matter: throughout the negotiations, it was clear that the ROK demand for advance consent was driven to a large extent by a sense of strategic political and economic competition with Japan.

The primary technical rationale advanced by the South Korean negotiators for pursuing reprocessing was that it would ease the problem of storing spent fuel. They also were unimpressed by the economic difficulties experienced by Japan and were convinced that Korean researchers and engineers could economically outperform the Japanese. They resisted including economic outcomes of the Joint Fuel Cycle Study as one of the criteria for a future joint decision about US consent for moving forward with pyroprocessing, arguing that it should be Seoul's exclusive decision whether economic costs justified moving ahead. They also advanced the same argument about energy self-sufficiency as Tokyo.

Despite the constant reassurance from officials in Seoul that the ROK will not develop nuclear weapons, South Korea's history has to raise serious concerns among objective observers of nonproliferation. First, the taboo against the development of nuclear weapons is much less strong in the ROK than in Japan, where the direct experience of nuclear warfare remains in the public consciousness. The ROK previously began a covert nuclear weapons program, with the US stepping in to force a stop, and the IAEA has also reported on 'anomalies' in the ROK's nuclear program. Leading political voices in Seoul advocate development of a weapons program to counter the North's capability, and the 'latent deterrent' argument heard in Tokyo is voiced more openly and frequently in Seoul. And in a consistent series of public opinion surveys, a majority of South Korean voters say they would support a nuclear weapons program.

The US interest in ending North Korea's production of fissile material raises the same issues for the ROK as it does for Japan. Achieving that ideal outcome is likely to require that the ROK agree to the same prohibition on enrichment and reprocessing as the US seeks from the DPRK.

China: China has demonstrated an interest in civilian reprocessing. Like the ROK, China sees mastering this technology, and the reactors that go with it, as an area of strategic competition. Having the ability to offer reprocessing of spent fuel to global customers would make it easier to sell its reactors abroad. But there are risks associated.

Beijing has shown greater restraint in expanding its nuclear arsenal than have Washington and Moscow. Its current military reprocessing capacity would allow it to expand that arsenal if it so chose. However, it is still possible to foresee a scenario in which a surplus of production from a civilian facility could create a temptation to use the excess in weapons, particularly if Beijing proceeds to begin massive production of plutonium before the reactors to consume it are actually built.

As a nuclear-weapons-state recognized by the NPT, China denies that there are any nonproliferation implications of its ultimate decision on reprocessing. In 2016, it deferred suggestions from Washington for a bilateral dialogue about the economic, environmental, safety and nonproliferation implications of pursuing civilian reprocessing. It is unlikely to be moved by the argument that entering this field will further spur the strategic competition from its neighbors that – conceivably – could create a security risk for Beijing. Still, it would be valuable to emphasize to Beijing that it will be contributing to a "plutonium race" that carries economic, safety and national security risks for China, just as surely as the same risks are playing out in Japan and will affect the ROK.

Reinforcing The Global Nonproliferation Regime

Japan can make a major contribution to a safer world, in which the risk of nuclear weapons use is reduced, by changing its policy. Such a shift would contribute both to Japan's national security and to that of the Asian region and the world.

There are a number of steps Japan should consider, beginning with those that do not require a complete reversal of its current policy. 3

Japan can contribute to establishing a higher set of standards for the management of separated plutonium. Concerns about such stockpiles are not limited to Japan; significant quantities of civil plutonium also exist in India and Russia. Japan participates with other countries in formulating and assiduously following the 'International Plutonium Management Guidelines' (IAEA INFCIRC 549). Elevating these voluntary measures into a more rigorous 'code of conduct', with enhanced transparency measures, would give the world greater assurance about the safety and security of these stockpiles.

Japan should invest in additional research, in cooperation with the US and other civil nuclear states, in three key areas:

- Medium-term storage (in dry casks) of spent nuclear fuel. Japan must increasingly rely on this established technology, regardless of its ultimate decisions on Rokkasho.
- Safe and economical methods of permanently storing excess plutonium. Japan ought to be an enthusiastic co-researcher with the US and UK.

[3] See also: John Carlson, Nuclear Threat Initiative paper on "Mitigating Security Risks from Separated Plutonium: Some Near Term Steps," available at http://www.nti.org/media/documents/NTI_Paper_Mitigating_Security_Risks_FINAL-April2018.pdf

- Identification of a permanent depository for long-term storage of nuclear waste, both spent fuel and separated plutonium. Japan has long postponed a decision – or even movement toward a decision – on building a geological depository for permanent, safe storage of plutonium, spent nuclear fuel and other radioactive waste. Dreaming that another country might offer its territory for a geologic depository is not a realistic option for Japan. (We cannot completely discard the idea of some ROK officials, that a peace agreement with the DPRK could lead to North Korea hosting a nuclear waste disposal site in return for financial incentives, but it is too speculative at this time for either Japan, the ROK or Taiwan to delay further work on their own national depositories).

Tokyo can take steps to put into practice the commitment made by the Atomic Energy Commission on July 31 to reduce its holding of plutonium. This statement was a step in the right direction, and stated explicitly an objective that Washington had encouraged Tokyo to set. However, it did not present a credible path forward for achieving the goal of a reduction in the stockpile. As documented elsewhere, this cannot be accomplished solely by using current reactors, which could – at best – consume only about 1.5 tons of plutonium per year, which is a fraction of the planned production capacity for Rokkasho . A first step would be for Japan to commit to limiting production, when the Rokkasho facility eventually opens, to an annual limit matching the realistic consumption capacity of currently existing Japanese reactors.

A significant reduction in the stockpile could be made more immediately by transferring ownership to the UK of the plutonium (22 tons) Japan currently holds there. Germany and Belgium have already followed this approach (for a much smaller quantity) by paying the UK to take plutonium off their hands.

This would not be easy. For Japan to pay the UK to take ownership would be an explicit acknowledgment of something the rest of the world knows and that the Japanese nuclear industry has long denied: that plutonium is properly seen to be a waste product and not an economic asset. The impact on the balance sheets of Japanese utilities would be significant, and is one reason for the bureaucratic and policy inertia that prevents a serious re-examination of the policy.

An alternative approach would be for Japan to transfer legal custody of excess plutonium currently at Rokkasho to the International Atomic Energy Agency. This is not required under IAEA policy guidelines, but it would be a highly convincing demonstration to the world of Japan's purely peaceful intent.

The Japanese Diet should commission an objective study of the true costs of the closed fuel cycle, and compel the government to move more forcefully on the need to construct a permanent geological depository. Like the US and ROK, Japan continues to move only slowly and fitfully toward a decision that should have been made at the very outset of the civil nuclear era.

The successive postponements – more than twenty – of initiation of operations at Rokkasho have both technical and political reasons. They have allowed time for Japan to consider, post-Fukushima, how to consume plutonium without the full fleet of MOX-burning reactors on which it had counted. A political decision to continue to postpone (beyond the currently projected 2021 date), even if explained on technical grounds, would continue to provide the same benefit. If the Rokkasho Reprocessing Plant does open in 2021, despite a continued lack of demand for its output, it would focus the world's attention more sharply on Japan's stockpile.

An end to the reprocessing approach would have immediate economic, safety and security benefits for Japan. The simple fact is that spent nuclear fuel will always be a lesser health threat, and less attractive to terrorists and criminals, than separated plutonium.

Making a virtue of necessity, Tokyo could re-establish its global leadership in nonproliferation by taking the initiative to establish a regional moratorium on civilian reprocessing. This would be an important confidence-building measure among economic and security rivals, even if it were initially proposed for a limited period, e.g., five years. It would allow the four East Asian states – Japan, China, North Korea and South Korea – to share information on capabilities and risks, and to work together on methods of handling and permanently storing spent nuclear fuel, and of further reducing the cost of LEU for reactor input.

In terms of national security, Japan has the most to gain from a regional moratorium, as well as from greater transparency among Asian states. Exchanging information on utilization and (particularly) disposal of plutonium would in itself be a confidence-building measure among four nations suspicious of each other's nuclear intentions.

Going further, Japan could lead the way in establishing a global norm: no production of separated plutonium. This might be resisted by Iran, Egypt and others who have always objected to any restriction on the 'right to enrich (or reprocess)'. But it would be the most significant step forward in decades in narrowing the path by which India and North Korea have developed nuclear weapons.

When the Nuclear Nonproliferation Treaty was written, it did not include a prohibition on reprocessing spent fuel for civilian purposes. In the years since, the global stockpile of plutonium has grown to more than 500 tons, with no current economically viable options for its full consumption in energy production. The conclusion that plutonium is an economic liability, a waste product, rather than an asset, is gaining strength among the world's nuclear scientists and engineers. Given its lack of economic viability as a fuel source, and its inherent danger, plutonium production will increasingly provoke suspicions that it masks either a nuclear weapons program or a desire for nuclear latency. It would be consistent with wide global support for a Fissile Material Cutoff Treaty, as well as the momentum behind the nuclear "ban treaty," for the world to pay closer attention to plutonium as a specific nonproliferation challenge. While it would add further contention to an already disharmonious discussion in the global community, the time is approaching when the world's leaders need to consider whether and how to establish a global norm for, first a moratorium, and then a prohibition on production of plutonium for either civilian or military purposes. In my view, the world is reaching a point of consensus: that production of plutonium is not justified for commercial purposes, given its inherent risks.

YONGSOO HWANG

The Norm of Managing Special Nuclear Materials in Spent Nuclear Fuel in the ROK

Recent Changes in the Energy Policy in the Republic of Korea

South Korea has been devoted to promoting nuclear power generation since its first nuclear power plant, Kori, began operating. Kori recently ceased operations on June 19, 2017. But from the middle of the last May in 2017, the Moon Administration has implemented the so called "Energy Transition Policy" which clearly stipulates two policies:

1. No more "New Build" on the nuclear power generation and
2. No life time extension of existing nuclear installations.

The 8th Electricity supply plan followed by the 3rd National Basic Energy Plan claims the cancellation of two new nuclear power plant sites. These new policies limit the number of nuclear power plants quite strictly. At this moment some new power plants are still under construction. The New Kori Unit 4 and the New Ulchin Units 7 and 8 will join the grid network soon. And the New Kori Units 5 and 6 which were under the national deliberative consultation last fall will be completed after several years of the construction.

Different Nuclear Power Plant Fleets

There are three different streams of power reactors in Korea: the conventional pressurized water reactors (PWRs), the newly designed advanced pressurized water reactors, (APWRs), and the Canada Deuterium-Uranium, (CANDU) reactors. All four CANDU reactors are located at Wolsong in Gyungbuk Province. The Wolsong Unit 1 was refurbished for the 10 year life extension. But the national utility KHNP last week decided to terminate the operation of the unit. In fact, many reactors will be out of the service within 10 years. This will raise the question of how to manage spent nuclear fuel in shut-down reactors in the ROK.

Concerns from the General Public on Spent Nuclear Fuel Management: SNF Storage & Final Disposal

Even though the general public in the ROK has supported the utilization of nuclear power generation, the proper management of spent nuclear fuel has been one of the major national concerns in the civilian society of the ROK. There has been series of new policies followed by the postponing of those policies in the ROK. The Government of the ROK firstly announced the national policy at the end of 1980's stressing the implementation of the centralized spent nuclear fuel storage pool. The initial project implemented by KAERI at that time did not specify the measure for the final management. The so called "Wait and See Policy" had been there for many decades. It created the uncertainty over the potential reprocessing and recycling of the spent nuclear fuel even though the Korean Government proclaimed a strict no enrichment or reprocessing policy to promote the reunification in 1991 stipulated in the statement of the Joint Declaration by both North and South Koreas.

The Role of KAERI on the Fundamental Research

The Korean Atomic Energy Research Institute, KAERI, has been the sole national laboratory for the research over the nuclear issues. Its role changed significantly in 1997 followed by the restructuring of the nuclear industry in the ROK. The responsibility of managing spent nuclear fuel was transferred to the utility company KHNP. NETEC, the subsidiary of KHNP, and now KORAD, has been the major power to manage the spent nuclear fuel in the ROK. Since then, the role of KAERI has been limited to the fundamental R&D of safe and secure management of spent nuclear fuels. KAERI has started the pyro processing technology development since then while the KHNP had been assigned to the role of the sole implementation body.

Transparency in the National Programs

All the information from the research programs performed by KAERI has been in the public domain including all research reports. The Government policy to promote transparency on all research projects have been strengthened following the incident of the 2004 AVILIS uranium enrichment program. To ensure transparency, the newly established national entity KINAC has worked on the safeguardability of all concerned nuclear research programs and the concerned industrial activities over fresh and spent nuclear fuel. The national regulatory entity, the Nuclear Safety and Security Commission (NSSC), in association with its daughter institute, KINAC, has rigorously worked with the IAEA and the United States to fully implement the national framework assuring comprehensive nuclear non-proliferation in Korea. The so-called *three pillars* of nuclear non-proliferation, Safeguards, Export Control, and Physical Protection have been fully implemented in the ROK. The principal and secondary measures for safeguards -- material accountability and containment and surveillance – are used to fully monitor the relevant activities at reactor sites, research institutes, fuel manufacturing companies, radioactive waste management companies, and academic schools.

Through this national framework, the ROK Government fully shares core information over the special nuclear materials such as plutonium with the international watchdog IAEA, the United States, and the other relevant entities.

Hard to Reach the Civilian Societies

But it does not mean that the appropriate information is fully exposed to the general public in the ROK. Even though there is open information from the national utility KHNP and the governmental bodies, it may be still difficult for the civilian society to exactly understand the nature of special nuclear materials in spent nuclear fuel.

The general public in the ROK can find information on the spent nuclear fuel arising as listed in Tables 1 and 2 through a careful internet search. But such a search would not give a comprehensive picture on the special nuclear material inventories and etc. The inventory itself is related to the burn-up. The information of the burn-up of spent nuclear fuel is not open to the public clearly even though limited information is available in a certain degree.

In addition, the detailed information over the nature of plutonium isotopes such as Pu-239, Pu-240, Pu-241, and others is not available for the public.

Weak Civilian Watch Actions

In fact, even though the general public is largely supporting a nuclear-weapon-free society, there is no independent civilian entity to fully check the detailed actions over the spent fuel management in the ROK. There are many reasons for it.

1. No Solid Independent Think Tank

The first reason is that there is no solid think tank for the nuclear non-proliferation in the ROK. Many prominent entities in the ROK are not fully independent of the national government and political parties. The continuous financial support to promote the independent watch over all special nuclear materials is not realized in the ROK yet even though quite recently there has been a series of proactive movement to support it.

2. No Academia to Support the Civilian Actions

The second reason is that there is no good practical academic system supporting civilian actions over the full spectrum of the nuclear fuel cycles in the ROK yet. The prominent schools in the ROK provide world-class courses in reactor technology development. But there are limited universities dedicated to the education of the nuclear fuel cycle, the nuclear non-proliferation, and the public and stakeholder engagement. Recently, certain schools began to establish the dedicated works on the nuclear non-proliferation. But it will take some time to see the real impact from this endeavor in education.

Still Bright Future throughout the People's Participation

The ROK has been experiencing the full blossom of the full degree of the democratic society quite recently. The strong and sincere movement for the "*Nuclear Weapon Free Korean Peninsula*" in association with various pro-environmental activities is becoming a major force to assure the power of the civilian society for preventing illicit actions for nuclear proliferation. The will from the civilian activists to promote the nuclear non-proliferation has been very strong since the beginning of the current government.

Still Transition Period

There is still strong debate over the role of the fundamental research programs such as the full pyro-processing. The more active actions from the civil societies and the strong support from the national congress will act as a cornerstone to curb the rogue action while supporting the transparent study to properly manage the civilian spent nuclear fuel in the ROK.

Real Taste of the Two Way Dialogue

The Korean Government has implemented the so called two-way dialogue for the management of spent nuclear fuel. The new government plans to revitalize the new round of the Public and Stakeholder Engagement (PSE) program from the second part of the year 2018. All key issues for the peaceful, safe, and secure management of the spent nuclear fuel along with proactive involvement of the general public will be implemented throughout the engagement program.

Table 1: SNF Arising in the ROK at the end of 2017

NPP Complex	# Units in Operation	Type of UNF	Cumulative Amount at Pools [Bundles]	Cumulative Amount at Pools [tons]	Saturated Capacity [bundles]	Pool/Dry Storagel Saturation [%]
Wolsong	4	CANDU	436,112	9,594	490,512	88.9
New Wolsong	2	PWR	317	143	1,046	30.3*
Kori	5 (1 Shut downed in June 2017)	PWR	6,024	2,711	8,115	74.2
New Kori (Saewool)	1 (3 are under construction)	PWR	0	0	780	0*
Yonggwang (Hanbit)	6	PWR	6,103	2,746	9,017	67.7
Wulchin (Hanwul)	6 (2 are under construction)	PWR	5,263	2,368 17,563	7,066 26,024	74.5

*New pool capacity shall be added throughout the new construction.

The total cumulative arising will be 37,700 composed of 26,000 from PWRs and 11,700 from CANDUs

The annual arising will be increasing up to 2026.

After that the annual arising drops significantly due to the new energy policy not to extend the lifetime of the existing NPPs and no new build

One CANDU Bundles 22 kg for CANDU

One PWR Bundles 450 kg for PWR

Table 2: Spent Fuel Arising in the ROK at the end of the 1st quarter of 2018

Kori	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	PWR	485		218	562	86	*Shut down/ transfer to New Kori
Unit 2		668		301	799	84	* transfer to New Kori
Unit 3		1,915		862	2,103	91	
Unit 4		1,997	57	899	2,105	95	
Total		5,065		2,279	5,569	91	

(New Kori Saewool)	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	PWR	495		223	1,273	39	* transfer from Kori Units
Unit 2	PWR	521		234	1,273	41	* transfer from Kori Units
Unit 3	PWR	100	100	45	780	13	* transfer from Kori Units
Total		1,116		502	3,326	34	
2018 Q1	**Net Increase in Kori + New Kori**	**157**	**157**	**71**			

Yonggwang (Hanbit)	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	PWR	1,648		742	2,105	78	
Unit 2	PWR	1,274		573	2,100	61	
Unit 3	PWR	842		379	1,125	75	
Unit 4	PWR	914		411	1,125	81	
Unit 5	PWR	712		320	1,281	56	
Unit 6	PWR	713		321	1,281	56	
Total		6,103		2,746	9,017	68	No Change during the 1st Quarter in 2018
2018 Q1	**Net Increase in Hanbit**	0		0	0		

Table 2: Spent Fuel Arising in the ROK As of the end of the 1st quarter of 2018 (continued)

Wulchin (Hanwul)	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	PWR	936		421	957	98	
Unit 2	PWR	819		369	905	90	
Unit 3	PWR	1,139		513	1,321	86	
Unit 4	PWR	1,025		461	1,321	78	
Unit 5	PWR	752		338	1,281	59	
Unit 6	PWR	592		266	1,281	46	
Total		5,263		2,368	7,066	74	No Change during the 1st Quarter in 2018
2018 Q1	**Net increase in Hanwul**	0		0	0		

Wolsong	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	CANDU	28,168		620	42,408	66	At pool
Unit 2	CANDU	29,768	1,064	655	42,408	70	At pool
Unit 3	CANDU	33,048	1,080	727	42,408	78	At pool
Unit 4	CANDU	34,496	424	759	42,408	81	At pool
Total at Pools		125,480		2,761	169,632	74	At Total pools
Total at Dry Storage		313,200		6,890	330,000	95	At Dry Storage
Total		438,680		9,651	499,632	88	
2018 Q1	**Net Increase in Wolsong**	2,568	2,568	56	9,120	28	**Small increase in Storage Capacity at Pools**

New Wolsong	Type of UNF	Cumulative Bundles at Pools	New Arising 2018 Q1	Cumulative Tons at Pools	Saturated Capacity [bundles]	Percent Saturation	Notes
Unit 1	PWR	193		87	523	37	
Unit 2	PWR	124		56	523	24	
Total		317		143	1,046	30	No Change during the 1st Quarter in 2018
2018 Q1	**Net Increase in New Wolsong**	0		0	0		
By the end of the 1st quarter Total Cumulative SNF [tons] in 2018				**17,690**			
Additional UNF arising during the quarter [tons]				**127**			

JOR-SHAN CHOI

Reasonable Working Stocks At Reprocessing Plants

Plutonium is generated as a by-product in today's uranium-fuelled nuclear reactors. To be utilized, it must first be separated by chemical reprocessing from other radionuclides in used nuclear fuel discharged from the reactors, then fabricated into a new fuel element such as mixed-oxide (MOX) fuel, and recycled back into the reactors. If plutonium is not utilized, it should not be reprocessed and separated from other radioactive elements in used fuel. For some used fuel, reprocessing is required for safety reasons, such as the used Magnox fuel in the United Kingdom (UK) [1]. If there is no practical use for the separated plutonium (Pu) recovered from reprocessing, it can be processed into suitable disposition forms, such as borosilicate glass or Synroc, and disposed of in a geologic repository when it is available.

The Imbalance of Separated Civil Plutonium

There is at present a substantial global stock of separated civil plutonium, resulted from the imbalance between the Pu sources and Pu sinks [2,3]. The Pu sources result mainly from the operation of the reprocessing plants, but also from plutonium recuperated from un-irradiated remnants, such as from those terminated R&D activities (i.e., critical experiment) and fresh MOX fuel left over from shut-downed nuclear power plants (NPPs, i.e., Fugen, Pheonix, Monju, etc.). The United States (US) and the Russian Federation (RF) also declared an excess of 50 t of weapons-grade plutonium (WPu) each from their dismantled nuclear-weapons stockpiles [4]. The US declares the ex-defense Pu as civil plutonium [5]. The Pu sinks can be considered either at:

- Fabrication plants where plutonium is intimately admixed with another constituent, such as UO2 and fabricated into MOX fuel;

- End users, mainly NPPs where plutonium-bearing fuel such as MOX fuel is irradiated;

- Disposition facilities where plutonium is processed and made into chemical forms suitable for geologic disposal.

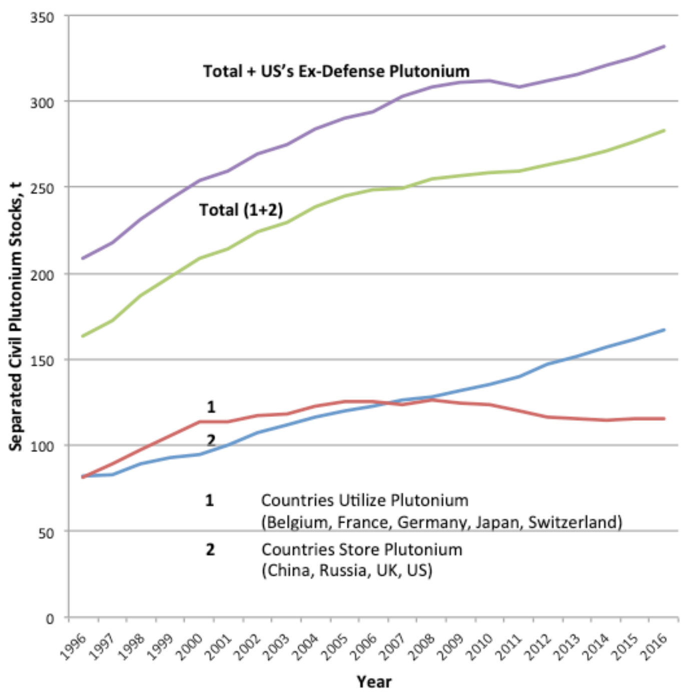
As both fabrication plants and disposition facilities involve plutonium being progressively converted into MOX fuel and disposition forms, respectively with internal recycle of plutonium scrap and recuperation of plutonium from waste streams, they are not in the same manner as "sinks" as that in the end-users (i.e., NPPs) or in the geologic disposal media.

The imbalance of separated civil plutonium is dominated by the operation of reprocessing plants in a few countries where there is no utilization (or disposition), or not sufficient capacity of Pu moxification (i.e., fabrication of plutonium into MOX fuel, the primary chemical form of plutonium-bearing fuel used in today's nuclear reactors). The stocks of separated plutonium in these countries are simply stored and accumulated. There are also countries, notably France, which are actively recycling the separated plutonium recovered from reprocessing as MOX fuel in light-water reactors (LWRs). Nevertheless, the growing stock of global separated plutonium poses a concern for nuclear proliferation [6].

The Guidelines for the Management of Plutonium

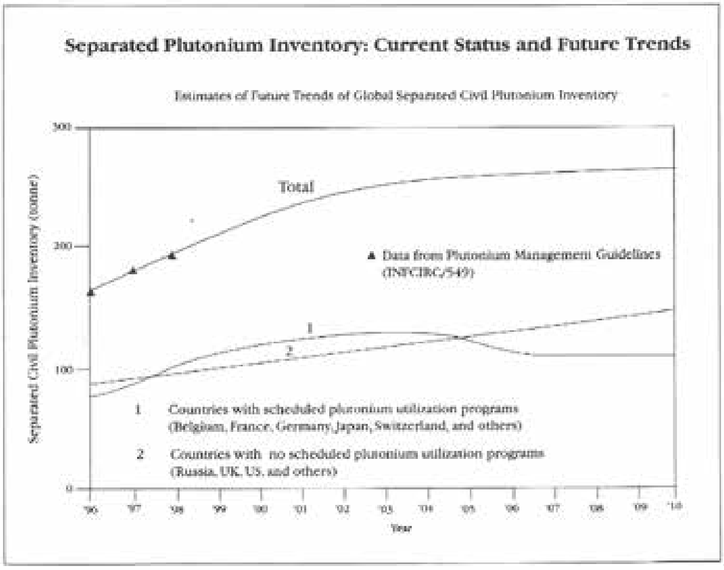
To allay such concern and to promote transparency, the Guidelines for the Management of Plutonium were formed in 1998 where nine countries holding separated plutonium stocks would declare their annual holdings to the International Atomic Energy Agency (IAEA, INFCIRC549) [7]. Over 20 years of declarations from 1996 to 2016, the total separated civil plutonium stocks in these nine countries has risen from 160 t (in 1996) to 330 t in 2016. Figure 1 shows the status of civil plutonium stocks from 1996 to 2016 in these nine countries reporting to the INFCIRC549. The figure draws a distinction between countries with reprocessing but no (or not sufficient) utilization programs (shown as Group 1) and countries with plutonium utilization programs (shown as Group 2). It shows the plutonium stock in Group 1 continues to grow, and in Group 2, it passes the peak (around 2005-6) and levels off (around 2012). Although not all countries holding separated civil plutonium adhere to the Guidelines, the declarations disclose more than 90% of the total global civil plutonium stock.

Figure 1: Declared Separated Civil Plutonium Stocks in Plutonium Management Guidelines



Source: Calculated and plotted by J. Choi, using data from INFCIRC/549

Figure 2: Separated Plutonium Stock Reported to Plutonium 2000 in Brussels



Source: Briefing slide presented at Plutonium 2000 Conference in Brussels, Presenter: J. Choi

Results in Figure 1 deviate from those in Figure 2, which were results presented at the Plutonium 2000 Conference in October 2000 in Brussels, Belgium [8] that the plutonium in Group 2 has peaked later (as compared to 2004 in Figure 2) and leveled off at a higher stock level (by approximately 20 tPu). This is because the plutonium utilization program in Japan has not proceeded as previously planned, due to the falsification of MOX fuel assembly data by BNFL in 1999 [9], and the shut down of NPPs in the wake of the Fukushima nuclear accident in 2011 [10].

In addition to the total, which is the sum of Groups 1 and 2 stocks, Figure 1 also shows a total plus the ex-defense plutonium stock declared by the US. Previously in Figure 2, the US civil stock included in Group 2 were those stored in West Valley, the now- dismantled commercial reprocessing plant.

In addition to their declarations of civil plutonium stocks, each of the governments of the nine countries within the Guidelines is committed to management of plutonium in ways which are consistent with its national decisions on the nuclear fuel cycle and which will ensure the peaceful use or the safe and permanent disposal of plutonium. The formulation of that strategy will take into account the:

- Need to avoid contributing to the risks of nuclear proliferation, especially during any period of storage before the plutonium is either irradiated as fuel in a reactor or permanently disposed of;
- Need to protect the environment, workers and the public;
- Resource value of the material, the costs and benefits involved and budgetary requirements; and
- Importance of balancing supply and demand, including demand for reasonable working stocks for nuclear operations, as soon as practical.

The Guidelines stated the importance of maintaining a balance of supply and demand of separated plutonium for nuclear operations. This importance is more profound in the aftermath of the 9/11 terrorists attack in 2001 in the US, as stocks of separated plutonium would surely be targets of terrorists seeking to acquire the improvised nuclear devices (INDs).

A key factor in balancing the supply and demand of plutonium for nuclear operations in countries actively reprocessing used fuel, fabricating MOX fuel and recycling MOX fuel into NPPs is the working stock required for these operations. As plutonium produced by aqueous reprocessing[1] and MOX fuel assemblies sent to the NPPs

[1] Japan's reprocessing in Tokai-mura involves a blending of Pu nitrate with Uranyl nitrate to produce a 50-50 mix of PuO_2-UO_2, but the blending is conducted in aqueous and the dry Pu-bearing product is stored. It is presumed that the same process would be employed at the Rokkasho-mura Reprocessing Plant (RRP) when and if it is operated.

usually involve just storage, there is no active processing of the separated plutonium and hence, there wouldn't be a need for working stocks of plutonium in these operations[2]. The operation in the current reprocessing and recycling fuel cycle that need to have a working stock of plutonium is the MOX fuel fabrication plant where plutonium is progressively converted into the MOX fuel, with internal recycle of plutonium scrap and recuperation of plutonium from waste streams.

How much separated plutonium is required as working stock in the MOX fuel fabrication plant to keep a supply-and-demand balance? In other word, what amount of plutonium constitutes a reasonable working stock for MOX fuel fabrication? These questions are explored below.

Working Stock of Plutonium for MOX Fuel Fabrication

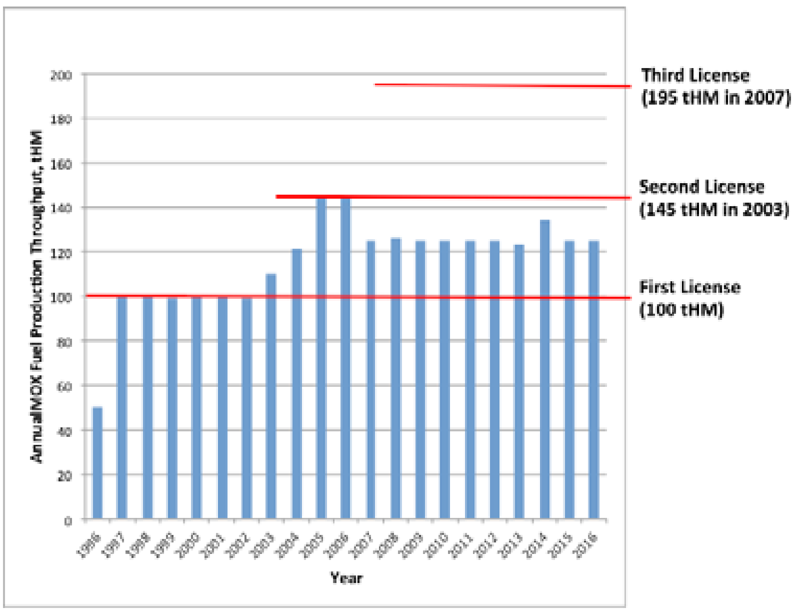
The working stock, or "the running process inventory" of plutonium for an industrial-scale MOX fuel fabrication plant is the amount of plutonium sufficient to support the annual throughput of the plant, plus contingencies for unexpected events happening, which affect the operation. The amount of plutonium for contingencies should be able to take into account:

- The uncertainties associated with the time and administrative procedures in transporting the plutonium from the re-processor to the fuel fabricator,
- The uncertainties associated with the quality control and the allocation of plutonium to various customers,
- The buffer store of plutonium at the fabrication plant before moxification, and
- The buffer store of MOX fuel assemblies at the fabrication plant before transport to the NPPs.

Melox, an industrial-scale MOX fuel fabrication plant in Marcoule, France, which started up in 1995, began its first year of production at licensed capacity of 100 tHM in 1997. It increased its capacity to 145 tHM in 2003 following the closure of the Cadarache Plant, and again increased it to 195 tHM in 2007 after the closure of the Dessel Po Plant in Belgium [11]. Figure 3 shows the annual throughputs of the Melox Plant [12].

Melox/Marcoule is located thousand kilometers away from the La Hague Reprocessing Plant, the source of its plutonium, and has multiple customers, both domestic and international. Before 2007, Melox operated at or near its licensed capacity. Since 2007, its annual throughput had maintained at the level of about 65% of licensed capacity, serving primarily the need of its domestic customer, EdF (which is

Figure 3: Annual MOX Fuel Production Throughput of the Melox Plant



Source: from www.areva_melox_2005.pdf and Uranium Red Books, dated 2009, 2011, 2014, and 2016

[2] This may not be true for a pyro-chemical reprocessing as it involves series of dry processes with Pu-bearing salts and ingots in dry process streams.

about 120 tHM/y for 20 PWRs). To deal with the many possible contingencies for its operation (such as worker strikes in transportation, logistical and security difficulties in international transport of MOX fuel assemblies, etc.) it is likely that Melox would operate with a reasonable working stock of plutonium equivalent to 2 years of fabrication capacity [13]. For a plant with smaller capacity, co-located reprocessor, dedicated customer and less contingencies, like the now-dismantled Dessel Po Plant (capacity factor of 35 tHM), its working stock of plutonium was close to its annual throughput, which is about 2 tPu (MOX fuel contained 5.5% Pu /tHM) [14].

To shed some light on how a plant's capacity factor (or throughput) relates to the working stock the plant needs for operation, Figure 4 compares the plutonium used in Melox's MOX fuel production (i.e., throughput) and the French declaration to the Guidelines (INFCIRC/549) of separated plutonium in the course of fabrication, and plutonium contained in un-irradiated semi-fabricated, or unfinished products at fuel fabricating plants or elsewhere. Figure 4 does not directly show the working stocks of Melox (as the declarations shown before 2003 included both production in Melox and Cadarache) but merely shows the relationship between annual throughputs and the amount of plutonium resided at the fabrication plant(s).

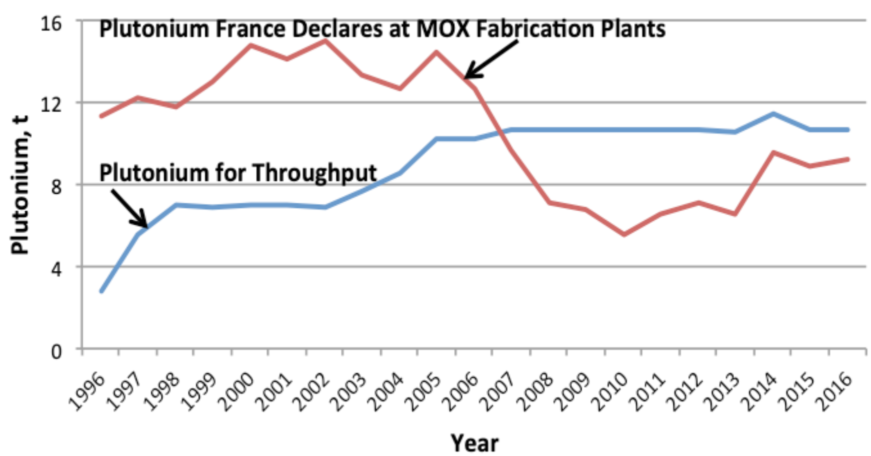
Figure 4 shows that before 2007, the French declared plutonium residing at its MOX fuel fabrication plants (both Melox and Cadarache before 2003) are about 2 times that of the production throughput at Melox. After 2007, the declared amount at Melox is below or near its production throughput. The declared plutonium at Melox is not its working stock because some of the finished MOX fuel assemblies may have transported out to NPPs during the year before the accounting is taken for declaration. Nevertheless, it shows that after 2007 when Melox is primarily serving its domestic customers, its production may encounter fewer contingencies than in previous years involving both domestic and international customers.

Beside the contingencies associated with administrative controls, logistics, and buffer storage requirements, there are also contingencies on quality control and allocation of plutonium to various customers, which may involve the adjustments of plutonium isotopic compositions needed to account for the loss of fissile content and growth of 241Am, as well as technological constraints with reprocessing and MOX fuel fabrication.

Plutonium Isotopic Compositions

The origin of the used nuclear fuel (PWR, BWR, AGR, etc.), the discharge burn-up, the storage time before reprocessing, the storage time after reprocessing and many other secondary factors affect the isotopic composition of each plutonium batch to be processed. An example of the variety of isotopic compositions is given in Table 1.

Figure 4: Comparison of Plutonium France Declares at MOX Fabrication Plants and Plutonium for Production Throughput at the Melox Plant



Source: Calculated and plotted by J. Choi, using INFCIRC/549 data and Figure 3 throughputs

Table 1 shows a combine of 241Pu and 241Am, in which the 241Am results from the beta decay of 241Pu, with a half-life of 14.4 years. This is the only way to maintain a constant of any given quantity of plutonium during storage and fabrication periods, during which the Am is not removed. Stripping of Am takes place only during reprocessing of the used fuel. Therefore, it must be taken into account in the bookkeeping of plutonium quantities that 38% of 241Pu would be converted into 241Am 10 years after reprocessing.

It is important to take this into account. For instance, if the plutonium issued from reprocessing used PWR fuel discharged at 33 GWd/tU were introduced as MOX fuel in a PWR 10 years after reprocessing, it would have lost 22% of its equivalent fissile value. In other words, either the 241Am would need to be removed or the (Pu +Am) content of the MOX fuel would need to be increased by a factor of about 1.28 to compensate for the additional americium. If such plutonium would be issued from used fuel discharged at 50 GWd/tU, the loss would have been 29% and the compensation factor of about 1.4. This is an effect frequently overlooked in evaluating the future evolution of the separated plutonium stock. This effect is of course negligible for weapons-grade plutonium and minor for plutonium discharged from Magnox reactors.

Reprocessing and fabrication constraints

Core management calculations performed by (or on behalf of) the utility define the plutonium content and isotopic composition of each fuel assembly or each group of four or eight fuel assemblies positioned symmetrically in the reactor core. It provides the input of plutonium content and isotopic composition of each batch of used fuel sent to reprocessing. Although symmetrically positioned fuel assemblies do not evolve identically (due to the adjacent fuel assemblies, to slight differences in coolant temperature or void fractions, to movement of control rods, etc.), the differences are small and those assemblies can be considered as sibling. Even in the most optimistic case of eight sibling PWR fuel assemblies, a uniform plutonium batch at this stage is thus involved only about 34 to 43 kg of Pu.[3]

For the La Hague Reprocessing Plant, which handles multiple domestic and international customers, the reprocessing schedule for used fuel assemblies is considered as commercial information disclosed only to the customers. Each individual customer has his own policy about the release of this part of the information. At the reprocessing plant, each batch of used fuel is fed to the shear in an uninterrupted sequence determined by the necessity of optimizing the operation of the reprocessing plant. As such, the first homogenization of the plutonium isotopic takes place at the shearing and dissolving stage. A further blending of the individual plutonium sources occurs at the finishing stage, where plutonium is purified, converted to oxide and packaged into containers. This final stage is purposely utilized to constitute homogeneous batches of typically 90 kg Pu.

Table 1: Typical Isotopic Composition of Plutonium (rounded w/o)

Type GWd/ tU[1]	WPu[2] -	GCR[3] 5 - 6	AGR[4] 18 – 24	PWR[5] 33	PWR 50	BWR[6] 30
Pu in Used Fuel, %, tPu/tHM	-	0.24	0.45	0.9 – 1.0	~1.2[7]	0.8 – 0.9
^{238}Pu	0.0	0.3	0.6	1.6	2.6	2.8
^{239}Pu	94.0	69.0	54.0	58.0	50.0	55.0
^{240}Pu	5.5	25.0	31.0	25.0	28.0	23.0
^{241}Pu + ^{241}Am	0.5	4.2	10.0	10.0	11.0	14.0
^{242}Pu	0.02	1.1	5.0	5.5	8.0	5.0

Sources: Table values cited from notes by H. Bairiot [13] for:

1 – Burn-up value, in unit of GWd/tU
2 – Weapons-grade plutonium
3 – Gas-cooled reactor, i.e., Magnox
4 – Advance gas-cooled reactor
5 – Pressurized water reactor
6 – Boiling water reactor
7 – estimated value

3 This is calculated as follows: A used PWR fuel assembly contains 465 kgHM and roughly 0.9 to 1.1% plutonium, 465kg x 0.011 x 8 = 41 kg.

At the fabrication plant, a MOX reload to be delivered consists typically of 7 to 9 tHM, containing some 400 to 600 kg of plutonium. Several reloads may even be manufactured in one single fabrication campaign. As a result, depending on the average Pu content of the MOX fuel and on the campaign size, anywhere from 3 to 11 Pu batches are involved in each fabrication campaign (Melox can operate 90 tHM fabrication campaign). For each reload, the customer requests the fuel assemblies to be interchangeable. It requires the isotopic composition of the plutonium within a MOX reload to be uniform, as far as reasonably achievable. To meet this specification, the manufacturing processes have been optimized to incorporate in each pellet batch of up to 5 adequately selected Pu containers (each contains typically 3 kg Pu from La Hague). It results in the uniformity of Pu isotopic composition within a MOX reload meeting specifications. The inter-changeability of Pu holdings within the fabrication plant is beneficial for both customer and manufacturer in other respects, including the reduction of the cost related to separate storage of the various scrap streams and to timely transportation of the Pu feed.

For the MOX fuel fabrication facility (MFFF) the US is building for its ex-defense plutonium disposition, the plutonium is weapons-grade and the MOX is for domestic NPPs, and hence, there are few contingencies associated with plutonium quality and customer allocation. However, the source of the plutonium, i.e., where and how the pits are converted into PuO2 may be challenging [16]. MFFF may require a reasonable working stock to support its annual throughput of 3.5 tPu plus a reasonable amount for contingency. As of this writing, the US Department of Energy (DOE) had cancelled the MFFF program on May 16, 2018, due to high costs in completing the plant [15]. The DOE will now pursue the "dilute and dispose" option for disposing of the 34 tPu. Under this option the MFFF may be used as a disposition plant to dilute plutonium and the disposition products will be sent to the Waste Isolation Pilot Plant (WIPP) in New Mexico for disposal. Under this mission change, the disposition plant would require a working stock of WPu in support of its 3.5 tPu annual throughput plus a reasonable amount for an increase in contingencies, including:

- Where and how the pits are converted into PuO2
- Processes, chemicals, diluents, etc. involved in diluting the WPu
- State legislations associated with WIPP acceptance of diluted WPu
- Transportation variants due to possible increase in sizes and volumes of the disposition products (as compared to MOX fuel assemblies)

Conclusion

There is at present a substantial and growing global stock of separated civil plutonium. To reduce the global civil plutonium stocks, countries holding these stocks are encouraged to reduce or stop their reprocessing activities, and increase their utilization or disposition of separated plutonium,

A key factor in balancing the supply and demand of plutonium for nuclear operations in countries pursing utilization or disposition is the working stock of plutonium required for these operations. Based on industrial operation of fuel fabrication plants (in Belgium and France), a reasonable working stocks may be an equivalence of 1 to 2 years of production throughput, and sufficient for contingencies associated with administrative procedures, transportation logistics and security requirement, buffer storage for source receipt and products sent, as well as quality controls and customer allocations, if multiple clienteles are involved,

The US and the Russia declared an excess of 50 t weapons-grade plutonium each from their dismantled nuclear-weapons stockpiles. They pledged to each disposition of 34 t as MOX fuel in NPPs. The US now decided to forego the MOX fuel option. Instead, it would pursue a "dilute and dispose" option with possibly an increase of contingencies associated with its operation of the disposition plant.

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SUNGYEOL CHOI

Responses to "Norms for Civilian Plutonium"

1. What kinds of information would be useful to improve confidence in intentions about the management of civilian plutonium, either separated or in irradiated fuel?

One must have good reasons to justify the use of plutonium. Two kinds of information are required to ensure that civilian plutonium will not be diverted to military programs or other purposes other than civilian uses. One is a specific plan to use separated civilian plutonium with detailed timeline, if possible, before the separation of civilian plutonium from spent nuclear fuel. Another is information about amounts of civilian plutonium that were produced, separated, stored, and used previously with reliable quantitative errors. This may allow us to prevent large stocks of surplus separated plutonium and verify activities against original plans. Plutonium in spent nuclear fuel is more proliferation-resistant than separated plutonium. Reports submitted from 9 countries based on INFCIRC/549 do not include the two kinds of information, but only present the current amounts of civilian plutonium [1-1]. Surplus separated plutonium can be an easier target of thefts by insiders or terrorists compared to plutonium in irradiated fuel. Once it is stolen and sold to the black market, there is almost no way to track and retrieve it. Tons of surplus separated plutonium without short-term plans for use, which could be used for thousands of atomic bombs in that quantity, would be vulnerable.

First, detailed plans with timeline to use civilian plutonium before its separation from spent nuclear fuel could be very useful information to ensure that Pu is not going to be diverted or stored for a long period. Plutonium should not be separated and stored to just keep running the reprocessing plant already built. It has to be associated with a follow-up plan – fabricating mixed oxide fuels (MOX) using the separated plutonium and burning them in a nuclear reactor. In fact, there are very limited applications which require or accept civilian plutonium. To date, the only significant application is to run nuclear reactors like PWR, BWR, or fast reactors. Sometimes, fast reactors accept reprocessed fuels in forms of metals, carbides, and nitrides, but they are not available for commercial purposes yet. In addition, the radioactive decay of plutonium in metallic form is useful to produce heat and electricity for deep-space missions. Pu-238 enriched mixtures are used for space missions, but they are not weapon-useable and are exempt from the IAEA safeguards.

The fast reactor program in Japan is facing serious difficulties and significant delays after the accident and shutdown of the Monju reactor, a demonstration reactor for commercial sodium-cooled fast reactors. Monju experienced several incidents including one that occurred on August 26, 2010 when a 3.3-tonne in-vessel transfer machine fell into the reactor vessel after a scheduled fuel replacement operation. Operators were unable to retrieve the machine until June 23, 2011. After the Fukushima accident, a series of studies and reviews on the continuous operation of the Monju reactor recommended the shutdown and decommissioning of the reactor on December 21, 2016 [1-2]. In addition, the construction of MOX plant in the United States was not successful. The lifecycle cost estimate to make MOX fuel was expected to be less than $2 billion but it increased to over $30 billion. The MOX program in the United States aims at turning the excess plutonium from dismantled nuclear weapons into fuel for commercial nuclear reactors [1-3].

Nowadays, PWR burns fuels for about 5 years (3 batches, each roughly 18 months) after it accepts fresh fuel. When fresh MOX fuels are loaded into a reactor, it certainly requires new MOX fuels (roughly 1/3) after 5 years later. Then, it is the time to reprocess spent nuclear fuel for extracting plutonium and fabricating MOX for specific purposes – loading MOX fuels for the target reactor. The 5 years is good enough time to process spent nuclear fuel and make fuels. The amount and composition of plutonium and MOX fuels required is already given since the core design of nuclear reactors is given too. This might reduce the necessary stockpile of civilian plutonium storing without detailed plans to use.

Second, annual plutonium balance could be reported too. According to INFCIRC/549, Japan, Germany, Belgium, Switzerland, France, the United States, China, the United Kingdom, and Russia annually declare the current stockpiles of plutonium. India is missing among countries with separated plutonium. Netherlands, Italy, and spain have separated plutonium abroad. These reports all do not include why there is more or less plutonium compared to the plutonium stock of the last year. For example, in 2016, France reported having 81.7 tons of separated unirradiated plutonium in its custody (among them, 16.3 tons belong to foreign countries). This indicates that France separated 2 tons of plutonium in the last year. However, it did not explicitly provide information like how much spent nuclear fuel was processed, which types of spent nuclear fuel were processed, how much plutonium was in spent nuclear fuel, and how much plutonium was lost to produce the separated plutonium. The last two pieces of information might be difficult to predict accurately. Regarding the first comment, there is also no information about how and when the separated plutonium is going to be used.

Table 1.1: The Status of Separated Plutonium Management in Japan as of 2015, 2016 [1-4].

<Units : t Pu>

	As of the end of the year 2015	As of the end of the year 2016
Total	47.9	46.9
Held in Japan	10.8	9.8
Held abroad (total)	37.1	37.1
Breakdown | U.K. | France	20.9 16.2	20.8 16.2

Third, the results of IAEA safeguards must be shared. It is not necessarily very detailed information, but it is important to share that all the nuclear material remain in peaceful activities. For example, Japan's report on August 1, 2017 includes the conclusion of the safeguards in 2016. If there are incidents or indications of undeclared nuclear materials nor activities, these should be also reported as well.

Forth, in addition to nonproliferation concerns, it might be useful to share the results of nuclear security performance on separated or irradiated plutonium. It is important to test the integrity of security systems by conducting realistic exercises of nuclear security systems to defeat insiders or outsiders. Actual cases of unclassified security-related incidents can be shared too. This will enhance other countries' confidence in the security management of the plutonium.

2. How much and what kinds of information is shared publicly about spent nuclear fuel and separated civilian plutonium in your country? Has this shifted over time? Are there domestic economic, technical or political hurdles to sharing information?

Since the Fukushima accident, public opinion on nuclear energy in ROK is very sensitive. Nowadays, such excessive concern against nuclear industry has evolved into an anti-nuclear policy in South Korea (ROK). This political trend in ROK would come from the public fear of spent nuclear fuel (SNF). To keep momentum of SNF management in ROK, it is highly necessary to shape public opinion.

Under such an atmosphere in the ROK, information related to SNF should be shared publicly as much as possible unless such information sharing significantly harms nuclear security, or industry. During past forty years, the policy, and the plan for SNF have been driven by the ROK governments. Not only public engagement but also public information sharing was absent. Several administrations confidentially tried to select the sites for facilities related with SNF. Every attempt failed due to strong demonstrations by local communities, and civic groups against governments' decision.

The decision making on nuclear energy in the early years of ROK was led by the government. Due to strong administrative enforcement, the only thing that government needed for nuclear policy was a scientific basis. The government's decision on SNF in the past was also established based on scientific, and technical review. Both scientific committees and the government, however, failed to persuade the public. What we can learn from this is that convincing the public after the decision does not work for SNF management. The most important principal for SNF management should be 'information sharing before decision making' [2-1].

Figure 2.2: Public trust on various organization related with nuclear policy in ROK and US. [2-1]

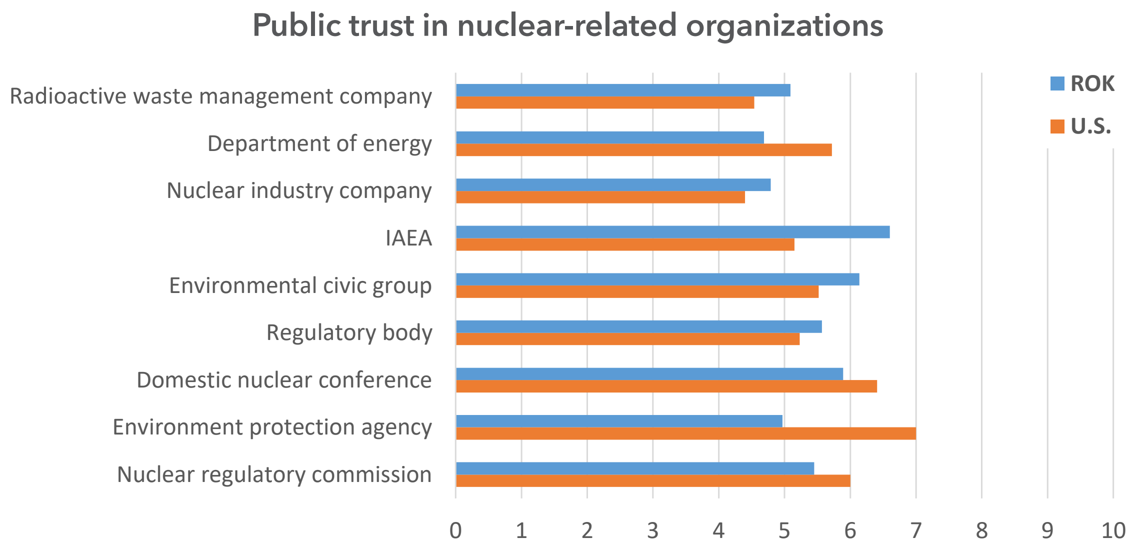
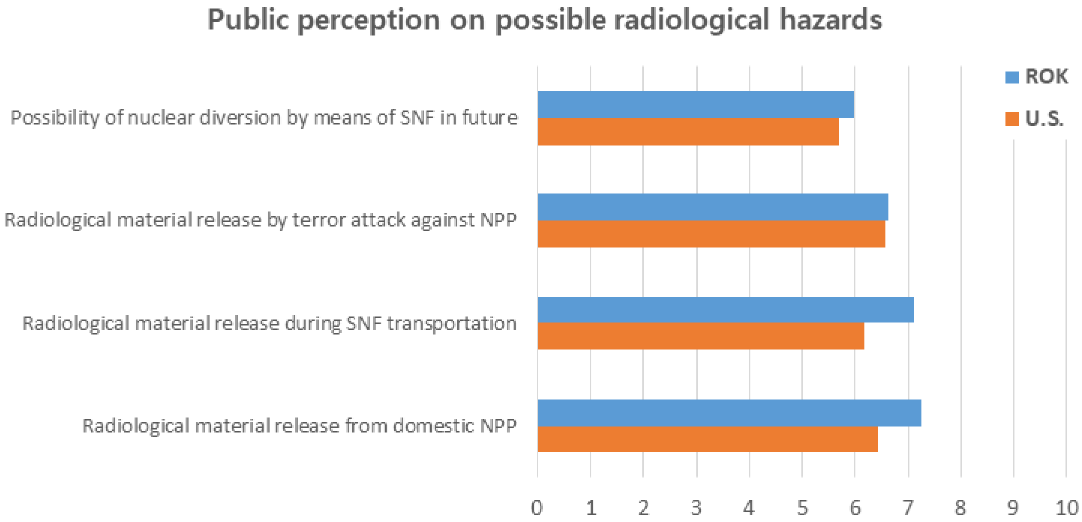


Figure 2.3: The risk of radiological hazards perceived by the public in ROK and US. ROK people are more sensitive on the risk of SNF management than US people [2-1]



The significance of such a principle was shown in the public survey on ROK SNF management by Public Engagement Commission on Spent Nuclear Fuel Management (PECOS) in 2014 (Figure 2.1.) [2-1]. The objective of PECOS was to gather the public opinion on domestic SNF management. The survey results showed that the absence of information sharing before decision making is closely related to the public trust in a government's decision.

Figure 2.2 shows the degree of public trust in domestic and international organizations related with SNF management in ROK, and US. It showed that ROK people trust more the international agency (IAEA) than government organizations, or domestic scientific committee while US people are opposite. Such a difference between two countries comes from the degree of information sharing. It was estimated that ROK public are more sensitive than US public (Figure 2.3). In other words, publicly perceived risk of SNF in ROK is higher than in the US. Based on this, one can normally expect that ROK public are more interested in information about domestic SNF management. It was counted, however, that the portion of ROK public who mis-understand their government's policy on SNF is 10 %p higher than the US. This means that dialogue on SNF management policy has failed in ROK.

The lesson we learned from the PECOS's experience is that both the government and scientific committee should try to share their knowledge with the public and stakeholders prior to decision. Nowadays, the ROK government is sharing information about SNF through various communication channels. Most of the information about SNF is shared through websites of administrative institutions, or national companies. Table 2.1 summarizes the current information sharing status in ROK. Information about legislation regarding safety and security of SNF is offered by Nuclear Safety and Security Commission (NSSC), Korea Institute of Nuclear Safety (KINS), or Korea Institute of Nuclear Nonproliferation and Control (KINAC). The basic plan for SNF management was drafted by PECOS in 2015. Currently, the Ministry of Trade, Industry, and Energy (MOSTIE) is sharing updated information about the national plan for SNF management. The policy on SNF management in ROK is 'wait and see'. Therefore, a geological repository for SNF, or HLW from pyro-process is absent yet. The information about a repository for radioactive wastes will be shared by Korea Radioactive Waste Agency (KORAD). The information about stockpile, and location of SNF is being updated by Korea Hydro Nuclear Power (KHNP). The ROK also has consultant processes for the public: public engagement commission, and experts review committee.

Still, many hurdles exist regarding public opinion, and information sharing. The political situation in ROK is especially in a bad mood. The nuclear industry in ROK is a government-managed system. Accordingly, concentrated dialogue on SNF is hardly made under nuclear-phobic administration. Actually, the timeline for basic plan for SNF management plan has been delayed due to the loss of momentum of the administration. Moreover, fake news defaming

Table 2.1: Status of SNF information sharing in ROK

Information	Implementation sector
Legislation	NSSC, KINS, KINAC
Basic plan of SNF management	MOSTIE, PECOS
SNF stockpile	KHNP
Location of SNF storage	KHNP
Operation of repository (ILLW)	KORAD
Public consultant	Public engagement commission Experts review committee

nuclear communities is destroying public trust in experts of nuclear engineering. In such an environment, delivering correct information is very difficult now.

Nonetheless, continuous efforts on information sharing is leading to some productive results little by little. In 2017 the Public Deliberation Committee on Shin-Gori nuclear reactor No. 5 and 6 recommended to resume the construction of Shin Gori Unit 5 and 6 despite the president's strong enforcement to nullify the new NPP project [2-2]. Similarly, the administration and the ruling party tried to stop R&D on pyro-processing. The external and independent review committee was launched and recommended not to halt the R&D [2-3]. It is obvious that the public with sufficient information is reasonable. Therefore we should keep trying to share our information transparently with the public.

Figure 2.4: Final report of the Public Deliberation Committee on Shin-Gori Nuclear Reactor (left). Webpage of the Public Deliberation Committee. General public can participate in the debate through this webpage (right)

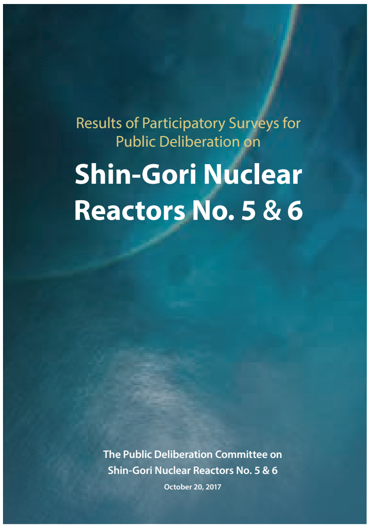
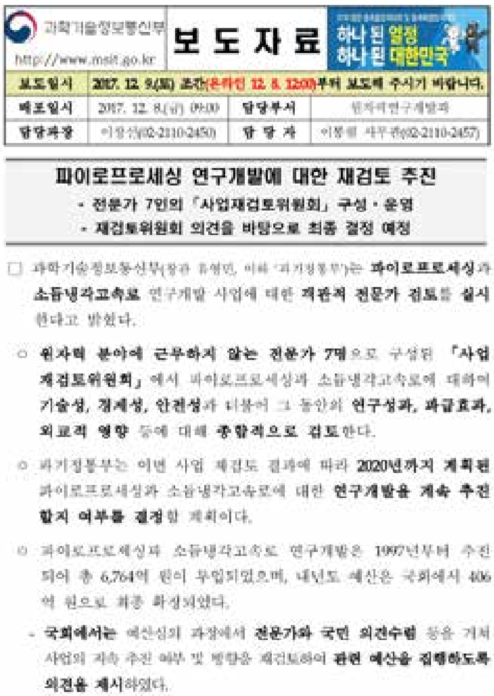


Figure 2.5: Press release on external and independent review on pyro-processing R&D (left). Review report by the committee (right)



과학기술정보통신부
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보 도 자 료

하나 된 열정 하나 된 대한민국

보도일시	2017. 12. 9.(토) 조간(온라인 12. 8. 12:00)부터 보도해 주시기 바랍니다.		
배포일시	2017. 12. 8.(금) 09:00	담당부서	원자력연구개발과
담당과장	이창선(02-2110-2450)	담 당 자	이봉재 사무관(02-2110-2457)

파이로프로세싱 연구개발에 대한 재검토 추진

- 전문가 7인의 「사업재검토위원회」 구성·운영
- 재검토위원회 의견을 바탕으로 최종 결정 예정

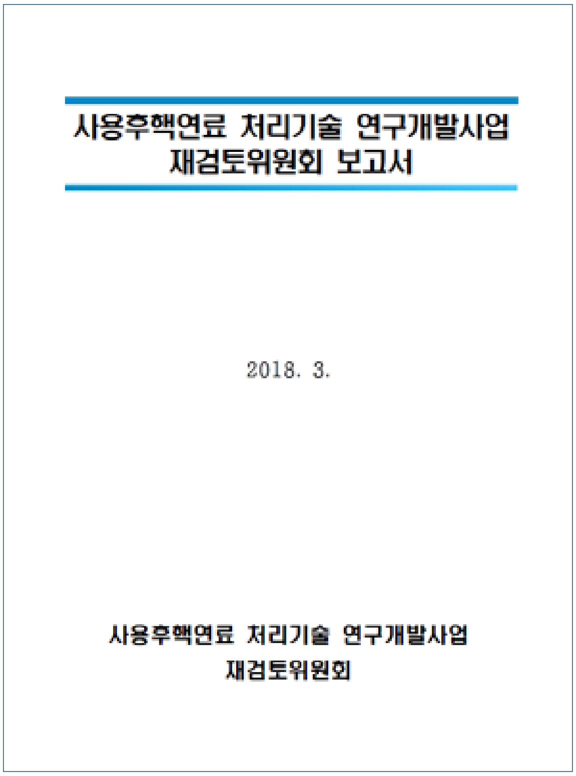
□ 과학기술정보통신부(장관 유영민, 이하 '과기정통부')는 **파이로프로세싱**과 **소듐냉각고속로** 연구개발 사업에 대한 **객관적 전문가 검토**를 **실시**한다고 밝혔다.

○ **원자력 분야에 근무하지 않는 전문가 7명**으로 구성된 **「사업재검토위원회」**에서 파이로프로세싱과 소듐냉각고속로에 대하여 **기술성, 경제성, 안전성**과 더불어 그 동안의 **연구성과, 파급효과, 외교적 영향** 등에 대해 **종합적으로 검토**한다.

○ 과기정통부는 이번 사업 재검토 결과에 따라 **2020년까지 계획된** 파이로프로세싱과 소듐냉각고속로에 대한 **연구개발을 계속 추진할지 여부를 결정**할 계획이다.

○ 파이로프로세싱과 소듐냉각고속로 연구개발은 1997년부터 추진되어 총 6,764억 원이 투입되었으며, 내년도 예산은 국회에서 406억 원으로 최종 확정되었다.

- **국회에서는** 예산심의 과정에서 **전문가와 국민 의견수렴** 등을 거쳐 사업의 지속 추진 여부 및 방향을 재검토하여 **관련 예산을 집행하도록 의견을 제시**하였다.



사용후핵연료 처리기술 연구개발사업 재검토위원회 보고서

2018. 3.

사용후핵연료 처리기술 연구개발사업 재검토위원회

3. In your view, are there domestic, regional or international incentives exist for sharing more information? What potential new best practices or approaches would you like to see in place in other states in the region?

In my opinion, sharing information is essential not only to keep national momentum for SNF management but also to cooperate with regional countries having the same problem. Many North-East Asian countries with nuclear energy are struggling with SNF challenge. Having their own national well-defined SNF program would require billions of dollars to develop and to implement. At this point, a cooperative approach to SNF management would be necessary especially for countries where the accumulation of SNF is becoming acute. For regional cooperation, information must be shared between cooperative countries.

Potential incentives of domestic information sharing would include:

- Support of stakeholders (local community, the public)
- High degree of confidence for the SNF business
- Enhancing transparency
- Continuous, and stable SNF management

Potential incentives of regional cooperation would be:

- Sharing R&D investment (lowering national cost burden)
- Shortening the timeline for fuel cycle program
- Intensifying public trust (peer review between cooperative countries)
- Enhancing regional transparency, non-proliferation and security
- Promoting economies of scale (regional economic growth)
- Win-win business model
- Large site candidate group for a repository

- Multiple SNF options
- Job opportunities for a hosting country
- Regional facilities (incentive for country with small land area)

One of the best practices of domestic information sharing is Swedish nuclear fuel management program. Swedish Nuclear Fuel and Waste Management Company (SKB) has communicated with the public and local communities where facilities related with SNF management have been located since the 1980s. The whole information of RD&D (research, development, and demonstration) for SNF management has been shared with local administrations, politicians, and the public (figure 3.1). The Swedish government will decide upon the SNF program suggested by SKB soon. SKB's continuous efforts for keeping communication have shown successful results. Figure 3.2 and 3.3 show how much public trust on SKB's SNF program is accomplished by domestic information sharing. The survey results show that high support by local communities has been maintained.

The case for EU radioactive waste and SNF management would be regional information sharing practice [3-2]. The proposed EU's directive on management of spent fuel and radioactive waste makes member states legally bound to share regional information on SNF programs with other states. The proposed directive requires the member states to have periodical international peer reviews between them. The more specific information of such

Figure 3.1: The structure of domestic information sharing of SKB [1]

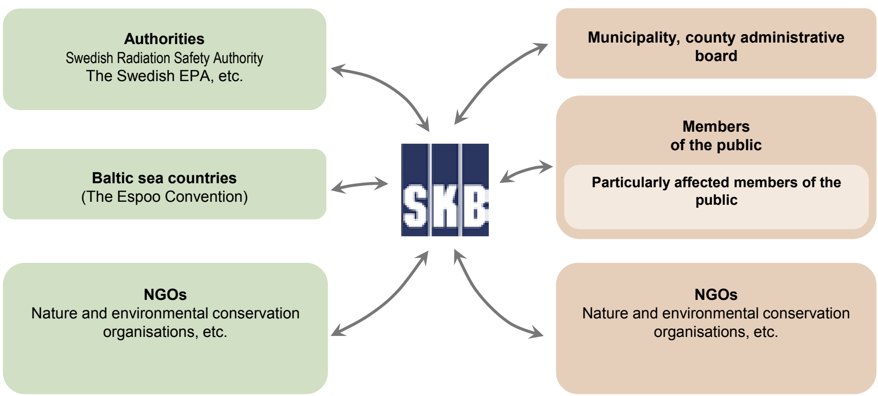


Figure 3.2: Degree of confidence in SKB activities in local community [3-1]. .

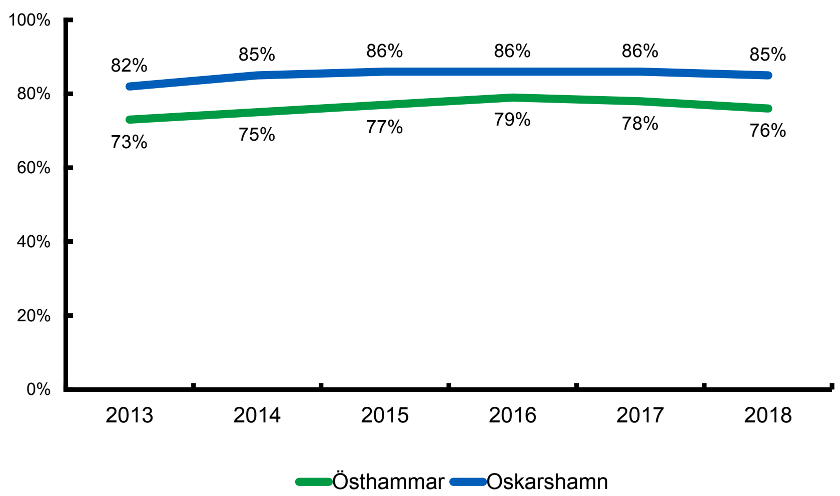
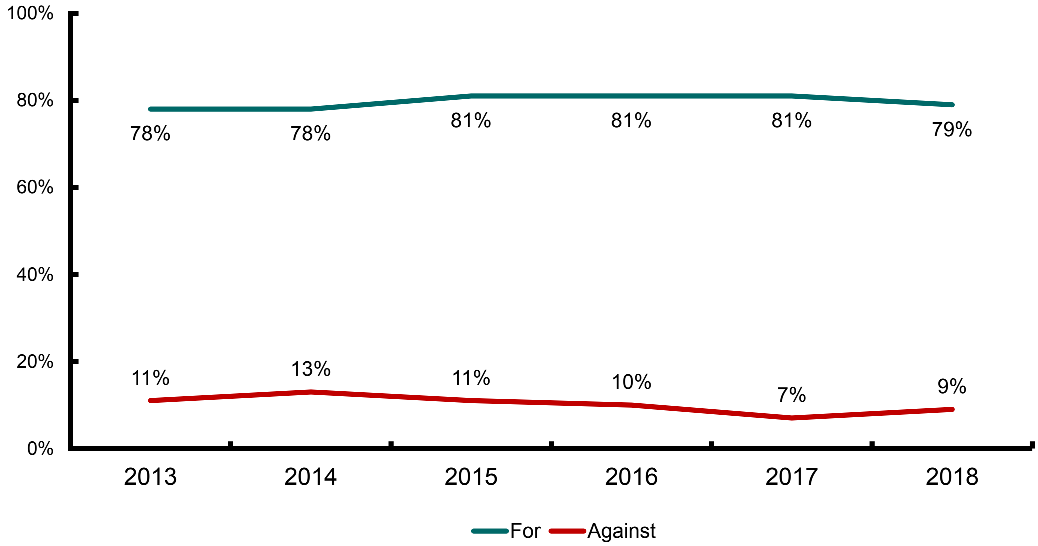


Figure 3.3: Local community's opinions on the final repository Forsmark in Östhammar [3-1].



regional cooperation is collaboration, and information exchange between SKB in Sweden and Posiva in Finland.

4. What barriers exist that might prevent more information-sharing? Do trade/ regulatory relationships work for or against greater information-sharing?

The biggest barrier to information-sharing regionally and internationally is security concerns. In the security field, a culture of confidentiality exists due to national responsibility and sovereignty considerations. In addition, more information sharing might lead to critical information fallen into the wrong hands. The security related information on spent nuclear fuel management and separated plutonium cannot be shared – design basis threats, detailed processes of security incidents, and detailed results of system reliability against potential security incidents.

In addition to the security barrier, there might be additional barriers such as:

- No clear short-term incentives recognized to share more information
- Cultural barriers to information sharing within government, regulatory, and industry activities; different communication styles
- Economic barriers critical to share information among industries since Korea, Japan, China are potential competitors in nuclear export markets
- No legally binding agreements but degree of information sharing only relies on political decisions
- Lack of coordination and follow-up for information sharing among several countries
- Many other conflicting issues in addition to nuclear programs (North Korea – the most recent one)

5. Are there ways in which industry can strengthen confidence? What information can industry share and with whom?

In Korea, the industry, Korean Nuclear & Hydro Power (KHNP) is asked to release information related to spent nuclear fuel. The information includes the number of assemblies of spent nuclear fuel in each nuclear power plant site (both PWR and CANDU). The information also contains the limit of storage capacity and the degree of saturation.

One way to strengthen confidence in industry is an external expert review for on-site verification of spent nuclear fuel management. Up to now, if the industry releases the information to the public, there is no way to verify the information through on-site visits and an independent scrutiny process. According to Figure 2.1, the

Korean public has the least confidence in Korea's nuclear industry, while the public has higher confidence in the IAEA and in the regulatory body. In the recent discussion in spent nuclear fuel management policy, Korea is considering such a mechanism. A group of people from universities, regulatory bodies, and research institutes will be selected for reviewing the information of KHNP.

The information that can be shared with the public:

- Amount of spent nuclear fuel in the storage currently (the number of assemblies)
- Capacity limit of the storage for spent nuclear fuel
- Expected amounts of spent nuclear fuel to be produced for a couple of years
- Results of countermeasures and enhancements for safety issues
- Key conclusions of countermeasures and enhancements for security issues
- Key conclusions of real cases or exercises against potential security incidents
- Management of damaged spent nuclear fuel
- Information related to emergency preparedness
- Key conclusions of final safety analysis report for spent nuclear fuel related facilities
- Intermediate options to manage spent nuclear fuel (i.e., interim storage)
- Long-term options to manage spent nuclear fuel (i.e., disposal, recycling)
- Reports on external and independent expert review committee on nuclear fuel cycle options (beyond industry-level; with multiple stakeholders?)

The information that can be shared with the neighboring countries:

- Amount of spent nuclear fuel in the storage currently (the number of assemblies)
- Results of countermeasures and enhancements for safety issues

  International Reporting System for Operating Experience (IRS)

  Fuel Incident Notification and Analysis System (FINAS)

- Information related to emergency preparedness

  Emergency Notification and Assistance Convention Website

- Key conclusions of real cases or exercises against potential security incidents

  ITDB; Illicit trafficking database system

- Results of IAEA safeguards on spent nuclear fuel related facilities (government-level)

The information that cannot be shared with the public and the neighboring countries but can be shared with the regulatory body and other authorities:

- Design basis threats of spent nuclear fuel storage
- Detailed results of final safety analysis report for spent nuclear fuel related facilities
- Results of countermeasures and enhancements for security issues
- Results of real cases or exercises against potential security incidents

6. What constitutes a reasonable level of working stocks for specific reprocessing facilities (based on throughput)? How is that level calculated?

To determine a reasonable level of working stocks for specific reprocessing facilities, it is important to clearly define whether to use separated plutonium and when it is going to be used. Without such information, there is no way to determine a “reasonable” level. Once how much separated plutonium is required and when it is required, the capacity factor of the plant and the failure probability of the plant will determine the working stocks. This is so called “inventory optimization.” The throughput of the chemical plant will be determined to meet the peak demand. Each plant differs in terms of refueling cycles, and the amount of fresh fuels, and the plutonium ration of MOX fuels. Producing separated plutonium based on throughput and based on the peak demand might not be the best option to run the reprocessing plant and this will lead to surplus plutonium stocks.

In fact, inventory optimization is a very common problem and is heavily addressed in most process, chemical, and manufacturing industries. Determining working stocks is extremely important for them in order to prevent overinvestment while achieving maximum efficiency of all equipment and the whole plant.

This will closely link with a rate determining step of all processes in the plant and the malfunction probabilities of equipment. Higher separated plutonium inventories can ensure sustained operation of nuclear reactors using MOX. The continuous operation of the reprocessing plant will also mean stable profits of companies and workers if it is paid based on the production of separated plutonium.

This analysis must be done by dynamic simulation, not static simulation. The static simulation does not tell us working stocks in buffers; there are no buffer materials considered in the static analysis. The common dynamic simulation method to determine the best optimal working stocks is a discrete event system modeling technique since the optimization needs to consider a series of complicated unit processes using multiple equipment, complex supply chains, and dynamic materials flow. It also needs to consider demand uncertainty (i.e., the operation of MOX fuel fabrication plant and the operation of nuclear reactors) and uncontrollable events like random failures or external events. It is important to understand overall system reliability by assessing critical bottlenecks of the processes.

In the below examples of pyroprocessing [6-1, 6-2], a batch type operation was considered using an integrated operation model constructed in a discrete event system. A simulation of dynamic material flow – input, output, loss – was implemented. Chemical reactions in the unit process were considered as well. All data were recorded in database. The operation efficiency as well as random failure can be included in the modeling. Still, this model considers the constant throughput of the plant, which means that all processes work to produce the same of TRU ingots. This model can be modified to consider varying output requirements based on separated fissile materials required for running nuclear reactors by coupling discrete event system modeling of the pyroproccesing plant with that of nuclear reactor fleets. The coupled model can be used to analyze "what-if scenarios" and determine a reasonable level of working stocks.

Another simple but crude way to determine a reasonable level of working stocks for separated plutonium is to roughly estimate the amount of plutonium required for the next 2~3 years to operate nuclear reactors. Commonly, 1/3 of the core in PWR is loaded with MOX. Also, each MOX fuel contains about 7-11% plutonium mixed with depleted uranium. It is plant-specific. With the number and design of nuclear reactors using MOX, one can roughly estimate the amount of separated plutonium required as annual basis. Roughly, 1 GWe PWR requires 25 tons of fresh fuel in one refueling cycle and, if plutonium ratio in MOX is assumed to be 10% of weight, the amount of plutonium required is 2.5 tons.

Figure 6.1: Unit Process Diagram for Discrete Event System – Oxide Reduction in Pyroprocessing [6-1]

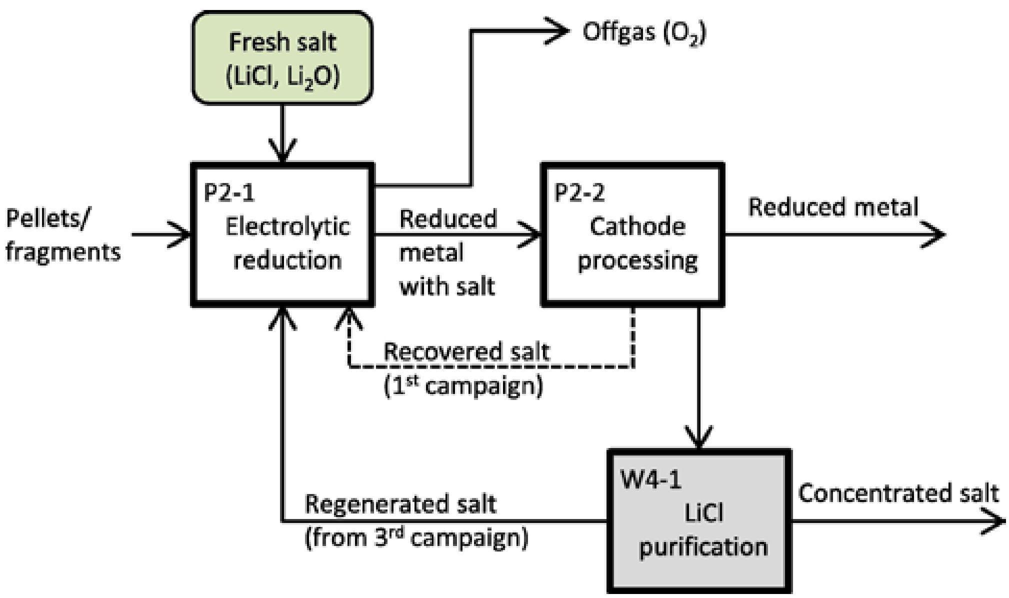


Figure 6.2: Example of Whole Pyroprocessing Process Diagram for Discrete Event System Modeling [6-1]

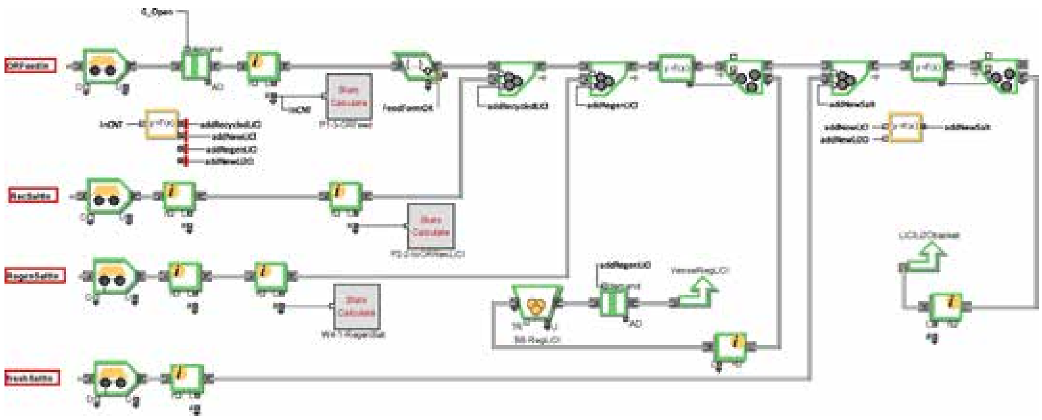
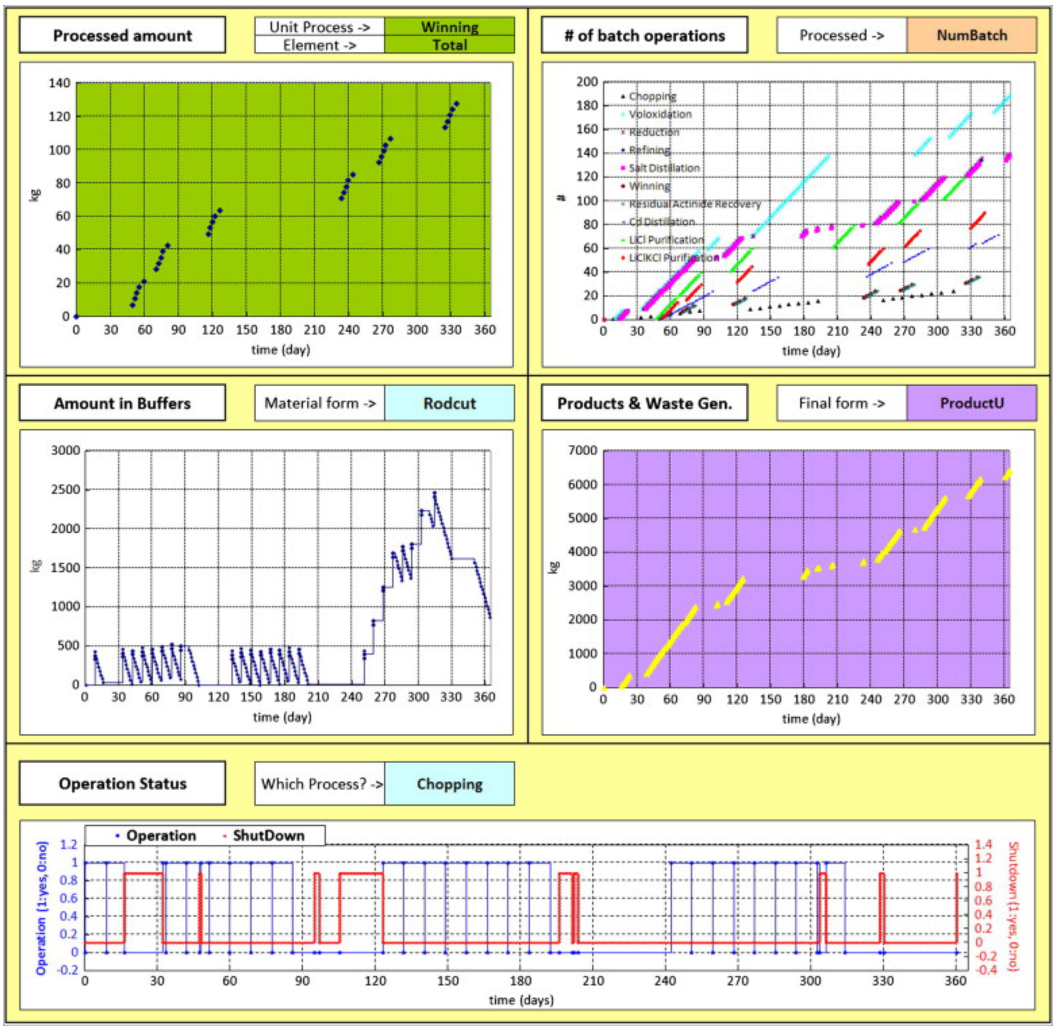


Figure 6.3: Example of material flows and inventory in buffers in pyroprocessing [6-2]



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