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A Step-by-Step Approach to Regional Spent Fuel Management Cooperation in the Pacific Rim

SUMMARY

The inability of the vast majority of countries with nuclear energy programs to implement sustainable spent fuel disposal pathways raises security concerns and undercuts public and political acceptance for all nuclear activities. This report addresses the security and proliferation implications of accumulating spent fuel stockpiles, describes the benefits of regional cooperation, and lays out a three-step process to institutionalize and operationalize a research and development agenda for spent fuel management in the Pacific Rim.

Andrew Newman, Alina Constantin, and Thomas Isaacs

NTI

BUILDING A SAFER WORLD

Contents

Introduction

Thirty countries plus Taiwan operate nuclear power plants, and their reactors generate roughly 10,000 metric tons of spent nuclear fuel each year. According to the International Atomic Energy Agency (IAEA), although 120,000 metric tons of spent nuclear fuel have been reprocessed, more than 250,000 tons remain held in storage worldwide. Most of this storage is at reactor sites—about 77 percent in storage pools and the remainder in dry casks.[1]

The global lack of spent fuel disposal options exacerbates security and proliferation risks, has sometimes led to ill-conceived or short-sighted waste management decisions, and undercuts public and political acceptance for all nuclear activities. Continuing along this path is ultimately unsustainable. Meanwhile, spent fuel continues to accumulate in cooling pools with limited storage capacity. On-site dry cask storage is a vital but non-permanent solution, and reprocessing/recycling does not solve the waste problem because those activities still generate significant waste streams that require disposal.

The global lack of spent fuel disposal options exacerbates security and proliferation risks, has sometimes led to ill-conceived or short-sighted waste management decisions, and undercuts public and political acceptance for all nuclear activities.

Finding suitable sites with appropriate geological conditions and available real estate to dispose of this large and accumulating stockpile is a challenge. Locating and characterizing a repository site is a complex, expensive, and time-consuming task, requiring political commitment by all levels of government, sustained over decades. Finding a willing host community, and securing acceptance from multiple levels of government, including those local entities along presumptive transportation routes, has proven the most intractable problem of all.

Despite well-developed programs in Finland, Sweden, and France, and encouraging progress in Canada, political and technical difficulties have delayed and, in many cases, prevented the construction and operation of commercial spent fuel repositories.[2] As a result, most waste management organizations continue to struggle to establish sustainable disposal pathways. The problem is particularly acute in South Korea and Taiwan, where spent fuel pools are almost full.

Over the past five years, the Nuclear Threat Initiative (NTI) has been working with waste management experts in the Pacific Rim to develop collaborative solutions to shared spent fuel management problems. This report contains the following:

- A description of the often-overlooked security and proliferation risks inherent in spent nuclear fuel management, the prevention of which are central to NTI's mission
- An outline of the benefits of regional cooperation and explanation of how the emergent Pacific Rim Spent Fuel Management Partnership offers a path forward to obtaining these benefits while avoiding the pitfalls that come with an exclusive focus on siting a multinational repository
- A comprehensive summary of the commercial nuclear power and spent fuel management programs in China, Japan, South Korea, and the United States plus Taiwan.

A note on scope: This report focuses on activities only related to long-term storage and disposal of spent nuclear fuel in a geological repository. A host of alternatives has been proposed or studied, including reprocessing, partitioning and transmutation; burning in fast reactors; emplacement in boreholes; direct injection into deep rock; rock melting; subseabed or deep ocean disposal; disposal in ice sheets or subduction zones; dilution and ocean dispersion; and ejection into outer space.

Nuclear Security and Proliferation

Although the financial burdens and political complexities of spent fuel management are well understood, if not always acted upon expeditiously,[3] the important security and proliferation dimensions often are ignored or minimized.[4] Spent fuel contains plutonium—approximately 1 percent by weight—that can be separated and used to make nuclear weapons. Spent fuel also needs to be securely stored for extended periods of time until it has cooled sufficiently for repositories to begin accepting it. In addition, because the allowable thermal and radiation limits for transportation often are substantially lower than the limits for storage, increasingly high burnup fuel and large dry storage canisters require an extended period of aging before the canisters have cooled down enough to be moved.[5]

In most countries, decades will pass before repositories are open and able to accept waste in sufficient quantities to begin significantly drawing down the global inventory. The longer spent fuel is stored, the less "self-protecting" it becomes as the strongly radiating shorter-lived isotopes that would harm a person attempting to handle or process the material continue to decay. Thus, as it becomes less radioactive, it presents an even greater security risk (see The Spent Fuel Radiation Barrier). In addition, lack of disposal options has led some countries to conclude that recycling spent fuel for use as mixed oxide (MOX) fuel is an alternative to long-term spent fuel storage, at least in the short-to-medium term. However, even a mature and efficient recycling program does not obviate the need for a repository, and reprocessing can produce separated plutonium that might be diverted to a nuclear weapons program or be acquired by non-state actors for use in nuclear explosive devices.

A spent fuel take-back service could be an effective solution for many nuclear waste generators (from security, safety, technical, financial, and social perspectives) if an appropriate supplier country—or countries—were willing to offer this service. The IAEA quoted a 2007 U.S. National Academies–Russian Academy of Sciences workshop report: "arrangements that would provide assured return of spent nuclear fuel could provide a much more powerful incentive for countries to rely on international nuclear fuel supply than would assured supply of fresh fuel, because assured take-back could mean that countries would not need to incur the cost and uncertainty of trying to establish their own repositories for spent nuclear fuel or nuclear waste."[6] The United States and Russia have been providing this service for research reactor fuel for years, and Russia is promising to take back spent fuel as part of its nuclear reactor deals with Bangladesh, Belarus, Egypt, Hungary, Iran, Jordan (for the first 10 years), Kazakhstan, and Turkey. Russia also was reportedly offering the same service to Vietnam until Vietnam's National Assembly voted in November 2016 to cancel its nuclear power program.[7] As long as the host country can ensure state-of-the-art competence and facilities, the international community should support any and all such offers, recognizing that they enhance regional and global safety and security.

The Spent Fuel Radiation Barrier

The concept of a self-protecting radiation barrier is that the immediate health consequences of high radiation serve as an effective deterrent to the unauthorized removal and use of spent fuel. But, like all radioactive materials, the radiation field diminishes as spent fuel ages, and eventually it is no longer self-protecting. A 2005 Oak Ridge National Laboratory (ORNL) report defined "self-protection" as "the incapacitation [an inability to function effectively] inflicted upon a recipient from inherent radiation emissions in a time frame that prevents the recipient from completing an intended task."[8] The U.S. Department of Energy self-protection guidance for radioactive material is 1 gray/hour (100 rem/hour) at one meter unshielded. This is the same threshold the U.S. Nuclear Regulatory Commission (NRC) and the International Atomic Energy Agency currently use.[9] However, the adequacy of the threshold has been called into question in light of some terrorists' demonstrated willingness to kill themselves in the pursuit of their objectives. The 2005 ORNL report also noted that although the current self-protection dose guidance is considered lethal for 50 percent of recipients, immediate health effects are minimal (onset sometime between 30 minutes and 16 hours), allowing substantial time for exposed persons to function and complete a task. The authors determined that a dose rate of 100 grays/hour at one meter was "the level that significantly affected performance and offered limited self-protection."[10] In 2015, the NRC advised that "the continued use of the existing external radiation dose-rate threshold as a security feature might not be prudent or realistic since, in some cases, the adversary may fulfill their goal prior to succumbing to the effects of radiation that may include death." As a result, the NRC has initiated rulemaking to revise the threshold.[11]

Through a combination of natural (geological) and human-made (engineered) barriers deep underground, mined repositories permanently isolate spent fuel from the biosphere, rendering the security need for a protective radiation barrier redundant. Some analysts have suggested that such structures could eventually serve as "plutonium mines"—that is, accessible and affordable sources of plutonium for nuclear weapons—for future generations.[12] Although theoretically true, there are reasons why this approach is not practical. First, repositories are easier to safeguard than other methods of eliminating plutonium, and those alternatives, such as reprocessing, "are associated with greater proliferation risks and would require much more extensive and costly safeguards."[13] Second, drilling back into a repository to retrieve spent fuel is expensive, complex, time-consuming, and extremely difficult to conceal.

The Benefits of Spent Fuel Management Cooperation

Multinational storage and disposal are worthwhile ultimate goals to complement well-established individual or national programs. The benefits are evident. For storage in particular, multinational options would enable spent nuclear fuel to be consolidated more quickly, creating "breathing room" while disposal programs are developed. They also demonstrate that spent fuel can be stored safely and securely and, as a result, help build public trust for disposal operations. For storage and disposal, collaborative options would consolidate spent fuel from many sites to a few facilities with high levels of security; promote economies of scale; lower environmental impacts; provide a wider variety of geological conditions for siting; enhance transparency and confidence, which will increase regional security; offer a business opportunity for the host country or countries; and, through the provision of a spent fuel pathway, incentivize customers not to acquire domestic reprocessing technology. The precise structure (technical, financial, and legal and regulatory) of any potential multinational storage facility or repository will depend on the requirements of both the host and the customers.[14]

By adopting a step-by-step approach rather than trying to solve everything at once, parties can make real progress and build trust. The objective is to integrate engineering, hard science, and social science research to address challenges that are common to all spent nuclear fuel generators.

Step-by-Step Approach Needed

At the same time, there are real concerns, for both those with mature repository programs and those struggling with disposal options, that multinational work will undermine domestic momentum and that "multinational" is really code for imposing hosting duties on one of the partners. This issue is why multinational storage or disposal proposals often are greeted with caution, indifference, suspicion, or outright hostility by some countries and international organizations that might otherwise be expected to strongly support such initiatives. By adopting a step-by-step approach rather than trying to solve everything at once, parties can make real progress and build trust. The objective is to integrate engineering, hard science, and social science research to address challenges that are common to all spent nuclear fuel generators. Such integrated research and development (R&D) is expensive, complex, and time-consuming; a multinational setting can be an efficient way to accomplish these sorts of tasks. This cooperation would also enhance transparency and confidence, thus increasing regional security and, over time, creating a much more favorable environment for any future regional storage or disposal negotiations.

Importantly, the back end of the fuel cycle is more conducive to multinational cooperation than the front end of the fuel cycle. Uranium enrichment and fuel fabrication, as well as spent fuel reprocessing, have traditionally been competitive commercial fields. In addition, the proliferation risks associated with enrichment and reprocessing mitigate against technology transfer. However, sharing information and working collaboratively to solve the universal waste disposal problem have generally been seen as more important than trying to exploit technological advances for commercial gain.[15]

Regional Cooperation Underway

Regional cooperation at the back end of the fuel cycle is already taking place. For example, the European Repository Development Organization (ERDO) Working Group is studying the feasibility of establishing an organization that would implement one or more shared geological repositories in Europe.[16] The creation of cooperative networks and regional frameworks to address specific sets of technical, political, and regulatory challenges would be a productive way forward in the Pacific Rim where the production of spent fuel, high-level waste, and plutonium is outpacing storage capacity; disposal pathways are lacking; and common understandings of basic concepts as well as agreed regulatory frameworks do not exist. Regional approaches could present a "win-win-win" path forward by allowing for the safe and effective expansion of nuclear power while reducing security and proliferation concerns (future multinational facilities would most likely have to operate under IAEA safeguards) and helping solve the spent fuel and high-level waste dilemma. However, sensitivity to the mutual impacts of both tracks is vital: the possibility of multinational options arising should not be used as an excuse to neglect domestic responsibilities. Likewise, individual programs should not oppose multinational approaches.

A Three-Step Approach to Building a Sustainable Pacific Rim Spent Nuclear Fuel Management Network

Step 1: Form a Cadre of Regional Technical Experts, and Scope the Mission

The network would consist of technical experts from regional waste management (or nuclear technology) organizations who can identify topics that are not currently being addressed in multilateral fora. The R&D projects should add value to existing national and international work, not replicate or compete with ongoing activities.[17] This network will enable the efficient sharing of costs, resources, knowledge, and experience, and it will generate the credibility that is gained from collaborative work among the leading experts in the field.[18] Over the past five years, NTI's Developing Spent Fuel Strategies project has brought this network together. Waste managers from Canada, China, Japan, South Korea, and the United States plus Taiwan have participated in some or all of the seven workshops that have taken place so far: Taipei (2014), Singapore (2015), Honolulu (2016), Tokyo (2017, co-hosted with NUMO [Nuclear Waste Management Organization]), Gyeongju (2018, co-hosted with KORAD [Korea Radioactive Waste Agency]), Albuquerque (2019, co-hosted with Sandia National Laboratories), and Suwon (2019, co-hosted with Kyung Hee University).[19]

Step 2: Develop and Operationalize a Practical Research Agenda

Trying to find a community to host a storage or disposal facility should not be the first step in any national or regional spent fuel management strategy; rather, it should be the eventual outgrowth of an adaptive, staged approach. The same principle applies to the network. Types of cooperation short of repository siting can be helpful starting points for discussions aimed at regional approaches to spent fuel management. Many topics can be studied collaboratively by a regional partnership. During the seven workshops, participants identified just such a topic catalogue and from that long list have selected three issues to address in the first phase of work:

- Underground research facility R&D
- Long-term monitored dry cask storage
- Technical and non-technical aspects of siting

The next step is to select working group leads and members and then devise work plans with defined areas of responsibility and agreed timelines. Every member does not need to participate in every project. Smaller working groups can and should be created on an ad hoc basis to tackle problems for which members have a particular interest or expertise, the results of which can then be shared with the network. In Albuquerque, the siting working group was the first to operationalize by agreeing to develop a "common framework for the safe, secure and socially acceptable long-term management of spent fuel."

The establishment of a "virtual multinational laboratory" to support this agenda would be one way to foster technical and institutional collaboration based in one or more underground research labs. Japan has two such labs (Mizunami and Horonobe), South Korea has the KAERI (Korea Atomic Energy Research Institute) Underground Research Tunnel (KURT) and is planning for the construction of an underground research lab, and China is developing one as well. The Nuclear Security Centers of Excellence in China (State Nuclear Security Technology Center), Japan (Integrated Support Center for Nuclear Nonproliferation and Nuclear Security), and South Korea (International Nuclear Non-proliferation and Security Academy) also could make an important contribution to the network by highlighting the importance of waste management to a comprehensive nuclear security system.[20]

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Step 3: Build Sustainability

The purpose of the network is to complement ongoing work in national waste management programs so that technical experts do not need to take time away from their regular employment, but a modest financial commitment will be required to support network activities such as hosting periodic workshops, participating in some international travel, and so forth. The creation of a secretariat consisting of one member from most, if not all, participating organizations to coordinate the network's work, assist with meeting and working group logistics, and ensure the timely flow of information to all stakeholders would be a valuable first step. More broadly, this collaboration needs to be institutionalized, which will require modest but sustained political and funding support from higher levels of government.[21] This support would send a powerful signal of commitment to solving the spent nuclear fuel and high-level waste problem at the national, regional, and international levels. Whether this solution would be best achieved by creating a new organization or by embedding the network in an existing regional association (which runs the risk of politicization) will be for the partners to determine. Institutional support is increasing. For example, the past four workshops have been co-hosted: May 2017 in Tokyo with Japan's Nuclear Waste Management Organization; September 2018 in Gyeongju with the Korea Radioactive Waste Agency; February 2019 in Albuquerque with Sandia National Laboratories; and August 2019 in Suwon with Kyung Hee University. The United States must play a role because U.S.-supplied fuel powers much of the region. In addition, there are strong climate change, security, and non-proliferation reasons for Washington, D.C., to galvanize such an initiative. Over time, if the core group agrees, new members who can contribute to the research agenda might be added to the network. Indeed, this has already occurred; Canada's Nuclear Waste Management Organization was a key contributor to both of the 2019 workshops. As envisioned, this cooperation is limited only to what the members are willing and able to support; there are no international legal or political restrictions on such work.[22]

Beyond the Rim

About half of the countries currently operating nuclear power plants have fewer than five reactors, meaning they do not accumulate spent fuel very quickly. For likely nuclear newcomers, including Bangladesh, Belarus, Egypt, Jordan, Poland, Saudi Arabia, and Turkey, this aggregation will be even slower. As a result, spent fuel management becomes proportionately a very expensive component of their nuclear programs. Ultimately, access to a disposal pathway that limits responsibility for spent fuel management may make more sense financially and politically for many of these countries. For example, the United Arab Emirates (UAE), which has contracted with a Korea Electric Power Corporation–led consortium for four APR-1400 reactors that are expected to begin operation by 2020, is already thinking along these lines. Whereas the Swedish Nuclear Fuel and Waste Management Company (SKB) is helping the UAE government determine the feasibility of a national geologic repository, in 2013 then-director of radiation safety at the UAE Federal Authority for Nuclear Regulation, John Loy, observed: "Options that may be considered for the National Strategy on Nuclear Waste Disposal would be either regional or international repositories operating in different countries."[23] But like UAE, all of the countries with small programs and newcomers must have national spent nuclear fuel management pathways in place because they cannot rely on third parties to relieve them of their responsibilities as these international options may not materialize. The Gulf Cooperation Council (which has already cooperated on regional nuclear energy studies) and the African Commission on Nuclear Energy could form the basis for cooperative networks among nuclear newcomers in the Middle East and Africa.

Countries with small programs and newcomers must have national spent nuclear fuel management pathways in place because they cannot rely on third parties to relieve them of their responsibilities as these international options may not materialize.

Toward Solutions

All nuclear power programs produce spent fuel. Current storage practices are safe, but the long-term nature of the hazard poses unique scientific and societal challenges for permanently disposing of this material. Although the precise details vary, many of the underlying problems are common. The Pacific Rim Spent Fuel Management Partnership has been exploring the potential for enhanced cooperation to address common technical, political, institutional, and social challenges of spent fuel management. Through a series of regional workshops, a substantial, but by no means exhaustive, list of topics that would benefit from multinational collaboration has been identified. The participants also have acknowledged several areas where joint research would likely be of more limited value. As a result, an ongoing R&D program is being operationalized that will provide solutions to practical problems, increasing understanding among participants and thus building trust. The first phase of work from 2019 to 2020 will focus on underground research facility R&D, long-term monitored dry cask storage, and the public and stakeholder engagement and technical aspects of siting long-term storage and disposal facilities. Also, this process possibly could lead to more far-reaching forms of cooperation including shared storage and disposal facilities. To ensure the long-term viability of the network, the partners will need to create an institutional framework or embed the partnership within an existing high-level regional network that would provide the necessary political support and an enduring funding stream. The need for action is urgent, but history is littered with attempts to site spent fuel storage or disposal facilities that have foundered owing to technical, political, or social complications. Although the network's first steps might be considered modest, they are concrete, emphasizing technical problem-solving, transparency, and confidence-building, and they are the result of direct input from the national waste management organizations in the region that will be carrying out the work.

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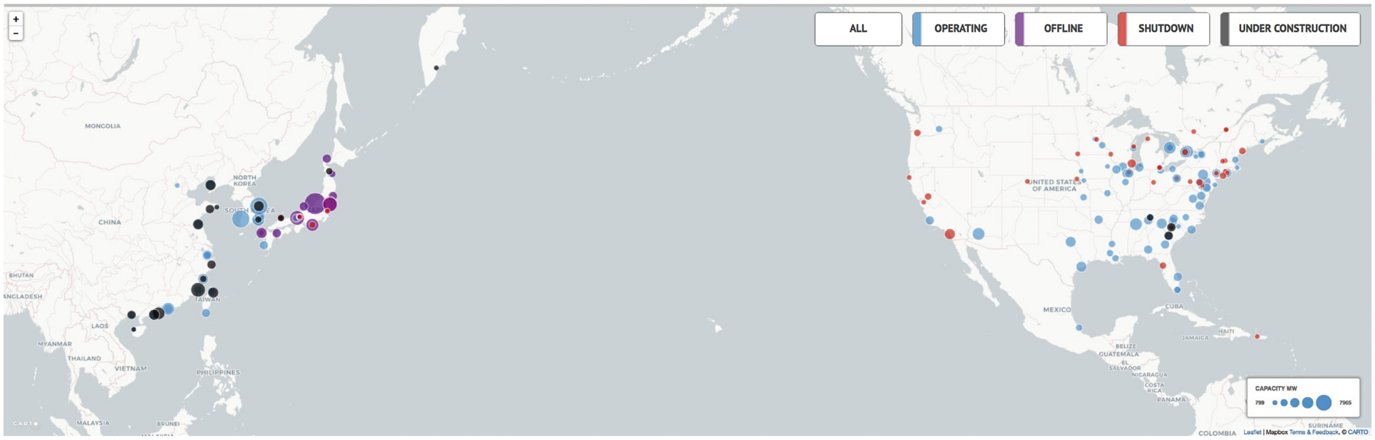
Country Case Studies

Pacific Rim Nuclear Power and Spent Fuel Snapshot



Nuclear Power Plants in the Pacific Rim[24]

CHINA

Nuclear Power

There are currently 47 operating power reactors producing 45,688 megawatts electric (MWe) at 12 sites: Daya Bay, including Ling Ao Phase I and II (six reactors); Qinshan Phase I–III, including Fangjiashan (nine reactors); Tianwan (four reactors); Yangjiang (six reactors); Hongyanhe (four reactors); Fangchenggang (two reactors); Changjiang (two reactors); Ningde (four reactors); Fuqing (four reactors); Taishan (two reactors); Sanmen (two reactors); and Haiyang (two reactors). China has 11 additional reactors under construction and plans for 43 more.[25]

Spent Fuel Storage

By mid-2019, more than 7,000 tons of spent fuel had accumulated at the plant sites.[26] China's reactors generate roughly 1,062 tons of spent fuel annually.[27] There is a limited amount of dry storage at the Qinshan site, but plans for expansion are being made.

Spent Fuel Disposal

China has one centralized 550-ton-capacity storage pool at the Lanzhou Nuclear Fuel Complex in Gansu Province. This pool is almost full but can be expanded to 1,300 tons. The complex also houses an enrichment plant and a pilot reprocessing plant.[28] China has plans to close the fuel cycle by reprocessing its spent fuel to recover and reuse the plutonium in MOX fuel.[29] Its disposal plan for the high-level waste (HLW) generated by reprocessing is broken into three phases:

1. From today through 2020: Construct an underground research laboratory at Beishan.
2. From 2021 to 2040: Conduct research and development, as well as testing, at the underground laboratory; conduct feasibility studies of a prototype facility; and conduct a preliminary safety assessment.
3. From 2041 to 2050: Conduct demonstration work at the prototype facility, and then construct and begin operation of the repository.[30]

JAPAN

Nuclear Power

Before the March 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Ōkuma, 56 power reactors produced 47,500 MWe with two reactors (2,756 MWe) under construction and 12 reactors (16,532 MWe) planned. Today, only nine reactors (Sendai 1 and 2, Ikata 3, Takahama 3 and 4, Ohi 3 and 4, and Genkai 3 and 4) have restarted.[31] The government hopes to restart enough reactors by 2020 to reach 60 percent of the 2010 output.[32]

Spent Fuel Storage

As of November 2017, 18,398 tons of spent fuel had accumulated, of which 3,393 tons are in pools at the Japan Nuclear Fuel Limited reprocessing facility and 15,005 tons are in pools at reactor sites. A proportion of this latter total is in dry storage casks at Tokai 2 and Fukushima Daiichi, but the exact quantity has not been made public.[33] In addition, there are plans for 400 tons of dry cask storage at Chubu Electric Power Company's Hamaoka Nuclear Power Plant and 5,000 tons of consolidated interim dry cask storage in Mutsu City, Aomori Prefecture.[34] Japan's nine operating reactors generate roughly 145 tons of spent fuel annually.

Spent Fuel Disposal

Japan has all of the infrastructure to close its fuel cycle, but technical problems have plagued its reprocessing, MOX fuel fabrication, and vitrification facilities.[35] As a result, a large plutonium stockpile has accumulated: 10.5 tons in country and 36.7 tons stored in France and the United Kingdom.[36] In May 2000, the Radioactive Waste Final Disposal Act mandating deep geological disposal of HLW became law.[37] In 1995, the Vitrified Waste Storage Center at the then-under-construction (and still not operating) Rokkasho Reprocessing Plant Site in Honshu's northernmost prefecture of Aomori began receiving HLW from Japanese fuel reprocessed at La Hague, France; the center also received reprocessed HLW from Sellafield in the United Kingdom.[38] It has a 2,880-canister capacity and is more than half full. In addition, in 2010 a Tokyo Electric Power Company and Japan Atomic Power Company consortium received approval to store spent fuel in dry casks in Mutsu (Aomori Prefecture) for 50 years in preparation for reprocessing. A facility with an initial 3,000-

ton capacity was constructed by October 2013, but the associated Nuclear Regulation Authority review of earthquake and tsunami countermeasures has not been completed, so it is not operational.[39]

In October 2000, the Nuclear Waste Management Organization (NUMO) was created to implement the Radioactive Waste Final Disposal Act. NUMO commenced its siting process in 2002 with the announcement of an open solicitation to all municipalities to explore the feasibility of hosting a repository. Initially, 10 expressed interest, but the program soon stalled, and the 2011 Fukushima accident effectively halted any further progress. In 2013, the Ministry of Economy, Trade and Industry (METI) created a working group to review the state of the art in geological disposal technology and Minister Toshimitsu Motegi declared: "The government will play an active role in choosing a permanent place. We'll abandon the current system of waiting for volunteers to raise their hands."[40] In April 2014, the latest Strategic Energy Plan (SEP) was adopted. The SEP requires the government to promote the site selection process by identifying "scientifically preferable disposal areas" around the country. In May 2015, the Japanese Cabinet endorsed this approach. NUMO is preparing a Generic Safety Case Report on the feasibility of deep geological disposal, and in July 2017, METI released the SEP-mandated map identifying areas of the Japanese archipelago that would be favorable or unfavorable for waste transportation and geological disposal.[41]

SOUTH KOREA

Nuclear Power

There are currently 24 operating power reactors producing a little more than 23,231 MWe at four sites: Hanbit (six reactors); Hanul (six reactors); Kori and Shin Kori (seven reactors[42]); and Wolsong and Shin Wolsong (five reactors[43]). Construction of Shin Hanul 1 and 2 has been delayed because of strengthened safety requirements prompted by two earthquakes in nearby cities in 2017.[44] South Korean President Moon Jae-in, elected in May 2017, pledged not to renew the licenses of the currently operating fleet and to cancel construction of new reactors, specifically Shin Kori 5 and 6. In response, Korea Hydro and Nuclear Power suspended construction of those units in July 2017. However, as a result of a Citizens' Jury that voted 59.5 percent in favor of completing construction, the Presidential Office announced in October that work on Shin Kori 5 and 6 would resume.[45] Despite this announcement, the government currently remains committed to the cancellation of six planned reactors.[46]

Spent Fuel Storage

As of June 30, 2019, 20,429 tons of spent fuel had accumulated at the four sites. All 9,322 tons of the pressured water reactor (PWR) spent fuel is located in pools at the reactors; there is no dry storage yet.[47] All 11,107 tons of pressurized heavy water reactor (Canada Deuterium Uranium, or CANDU) spent fuel is also at reactor sites, less than one-third (3,421 tons) sits in pools while the remainder (7,686 tons) is in dry storage—60 percent of the tonnage in dry storage is in silos (which have reached capacity), and 40 percent is in Modular Air-Cooled Storage (MACSTOR) cylinders.[48]

Korea's 24 reactors generate more than 700 tons of spent fuel annually. Like Taiwan discussed later, lack of storage space in spent fuel pools may soon threaten reactor operations. For example, the Kori 3 pool is 94 percent full, the Kori 4 pool is 95 percent full and the Hanul 1 and 2 pools are 90 percent full. High-density racks have been installed in the pools at 11 units (including Kori 3/4 and Hanul 1/2) to increase storage capacity and racks are being installed at Hanul 5 and 6.[49]

Spent Fuel Disposal

Nine times between 1986 and 2004, the South Korean government tried and failed to secure a disposal site for the country's low-, intermediate-, and high-level waste, including spent fuel. Then in December 2004, the government separated low- and intermediate-level waste (LILW) from the spent fuel disposal effort. After implementing a consent-based site selection process and offering a large package of financial benefits to a willing host community, in November 2005 it selected Gyeongju as the host of the country's first LILW disposal site. Although the law guarantees that Gyeongju will not be considered as a site for future spent fuel storage, the 2008 Radioactive Waste Management Act brought LILW, HLW, and spent fuel management back under the same agency—the Korea Radioactive Waste Management Corporation, which was renamed the Korean Radioactive Waste Agency (KORAD) in 2013—that is operating the LILW disposal facility.[50] Therefore, if KORAD runs its LILW disposal operation safely, the organization may be able to build public trust and goodwill that can be leveraged to help in siting spent fuel storage and, eventually, disposal facilities. In July 2015, a Public Engagement Commission on Spent Nuclear Fuel Management (PECOS), established by the Ministry of Trade, Industry and Energy (MOTIE) two years earlier, submitted its report recommending that the government select an underground research laboratory (URL) site by 2020, begin operating the URL and centralized interim storage by 2030, and complete construction of a repository by 2051.[51] Given the lack of progress since the PECOS report, MOTIE now hopes that a consent-based process will lead to the selection of a repository site by about 2028, and KORAD plans to have a centralized interim storage facility operational by 2035.[52]

UNITED STATES

Nuclear Power

There are currently 96 operating power reactors producing 97,896 MWe in 30 states and two reactors under construction in Georgia.[53]

Spent Fuel Storage

As of the end of 2017, approximately 79,389 metric tons (MT) of spent fuel had accumulated at reactor sites across the country—52,471 tons from PWRs and 26,918 tons from boiling water reactors (BWRs). Those totals comprise the following:

- 32,373 MT: PWR spent fuel in pools
- 20,098 MT: PWR spent fuel in dry casks
- 17,081 MT: BWR spent fuel in pools
- 9,837 MT: BWR spent fuel in dry casks[54]

U.S. nuclear power plants generate between 2,000 and 2,300 metric tons of spent fuel annually.[55] Recently, steps have been taken toward potentially providing utilities with a spent fuel storage option in the private sector. In April 2016, Waste Control Specialists (WCS) and Orano USA submitted a license application for a consolidated interim storage facility in Andrews, Texas.[56] Similarly, in March 2017, Holtec submitted a license application for a consolidated interim storage facility in southeastern New Mexico.[57]

Spent Fuel Disposal

The 1982 Nuclear Waste Policy Act committed the U.S. Department of Energy (DOE), in return for nuclear energy generators' regular payment of a fee into the Nuclear Waste Fund, to begin disposing of spent fuel not later than January 31, 1998, and a 1987 amendment to the act directed DOE to exclusively study Yucca Mountain in Nevada as the site for a potential repository.[58] However, political opposition has prevented the licensing process from being completed, leaving DOE in breach of contract. As a result of the government's inability to provide that disposal pathway, utilities have sued DOE for the costs of storing their spent fuel at each plant, and, as of June 2019, utilities had received more than $7 billion in payments from the U.S. Department of the Treasury's Judgment Fund.[59] Despite the fact that the federal government had spent more than $11 billion on siting activities, the administration of President Barack Obama in 2010 eliminated all funding for Yucca Mountain in its DOE fiscal year 2011 budget request, and then–Secretary of Energy, Steven Chu, attempted to terminate the licensing proceeding.[60] Thirty years after the Nuclear Waste Policy Act was signed into law mandating the operation of a geologic repository, there is no active U.S. repository program.[61] There is, however, recent movement to restart it; President Donald Trump's administration requested $120 million for fiscal year 2018 to resume the U.S. Nuclear Regulatory Commission's Yucca Mountain license review process and the same amount for fiscal year 2019 to resume the licensing process and support interim storage of spent fuel.[62]

TAIWAN

Nuclear Power

There are six power reactors that produced just over 4,900 MWe at three sites: Chinshan (two reactors) in New Taipei City; Kuosheng (two reactors) in New Taipei City; and Maanshan (two reactors) in Pingtung County.[63] At present, only four—Kuosheng 1 and 2 and Maanshan 1 and 2—are operating.[64] The Democratic Progressive Party, which took control of the presidency and the Legislative Yuan in January 2016, announced its intention to phase out nuclear power. However, a public referendum proposal to drop the government's language from the Electricity Act—"all nuclear energy–based power-generating facilities shall completely cease operations by 2025"—passed in November 2018.[65]

Spent Fuel Storage

As of September 2019, approximately 3,825 tons of spent fuel sit in pools at reactor sites (see Table 1).[66] There is no dry cask storage at present. Taiwan's four operating reactors generate about 85 tons of spent fuel (39 tons from the Kuosheng BWRs and 46 tons from the Maanshan PWRs) annually.[67] Taiwan Power Company (Taipower) is endeavoring to begin operation of two independent spent fuel storage installations (ISFSIs):

- Construction of the Chinshan ISFSI (1,680 fuel assembly capacity) began in 2010, and pre-operational tests were carried out in 2013. However, because the New Taipei City government has not approved the soil and water reservation facility, hot testing has been delayed.
- The soil and water reservation plan and construction license for the Kuosheng ISFSI (2,400 fuel assembly capacity) were approved by the Taiwan Atomic Energy Council in 2015, but other approvals have been blocked by the New Taipei City government.[68]

Storage space shortages in Taiwan's pools are acute. As the table below shows, if one compares fuel assembly capacity to inventory, the Chinshan pools are more than 99 percent full and the Kuosheng pools are 96 and 94 percent full.[69]

Spent Fuel Storage in Taiwan, September 2019

	Fuel Assemblies	
Reactor	Capacity	Inventory
Chinshan 1	3,083	3,074
Chinshan 2	3,083	3,076
Kuosheng 1	4,838	4,688
Kuosheng 2	4,838	4,540
Maanshan 1	2,160	1,516
Maanshan 2	2,160	1,528

In an attempt to avoid pool saturation at Chinshan and Kuosheng, which would threaten continued operation of the reactors, Taipower (supported by the Ministry of Economic Affairs) put out a request for bids in February 2015 to reprocess 1,200 fuel assemblies from the two plants.[70] However, four months later, the Legislative Yuan froze the reprocessing budget owing to concerns about the price of the contract and lack of legislative oversight.[71]

Spent Fuel Disposal

In 2009, Taipower completed, and in 2010 the Taiwan Atomic Energy Council approved, a Preliminary Feasibility Report for Final Disposal of Spent Nuclear Fuel. The report concluded that granite would be given priority as the host rock; potentially suitable sites on Taiwan Island might exist but require further research; rock formations in offshore islands offer long-term geological stability; and the reference design (Sweden's KBS-3 concept) adopted by Taipower enables the research team to conduct localized studies. In March 2017, Taipower completed a Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal that presented three key findings: Taiwan has granite formations considered a "scientifically hopeful" candidate for a deep geological repository; proposed engineered barriers and construction technology are feasible; and long-term safety assessment work continues to be developed by actual applications with the reference case.[72] As a result, a speculative timeline has been laid out: candidate site confirmation by 2028; detailed site investigation and testing by 2038; repository design and license application by 2044; and repository construction by 2055.[73]

About the Authors

Andrew Newman is Senior Director for Nuclear Fuel Cycle Activities at the Nuclear Threat Initiative (NTI), where he leads the Developing Spent Fuel Strategies project. Before joining NTI, he was a research associate with Harvard University's Project on Managing the Atom. Previous to his post at Harvard, Andrew spent three years with the Nuclear Science and Technology Office at the Australian Embassy in Washington, D.C. Before that, he worked with RANSAC (now the Partnership for Global Security) in Washington, D.C., and in the Office of the Emergency Services Commissioner, Department of Justice, Victoria, Australia. He holds a PhD in political science from Monash University in Australia, is the lead author of *Decision-making and Radioactive Waste Disposal* (Routledge, 2016), and is a Senior Non-Resident Scholar with the Institute for International Science and Technology Policy at George Washington University's Elliott School of International Affairs.

Alina Constantin is a consultant with NTI's Developing Spent Fuel Strategies project. From June 2018 to January 2019, she served as acting staff director for the World Nuclear Association's Waste Management and Decommissioning Working Group and has consulted for the International Atomic Energy Agency since January 2019. Alina is a former Fellow of the World Nuclear University Summer Institute's Nuclear Leadership Development Program and has served as an organizer of that program since 2017. Alina has a PhD in chemical engineering from the University Politehnica of Bucharest, Romania. Her thesis focused on modeling mass transport for a nuclear waste repository.

Thomas Isaacs is a well-recognized leader in nuclear energy, nuclear waste management, nuclear security, repository siting, and public trust and confidence. Tom is a senior advisor to NTI's Developing Spent Fuel Strategies project, an advisor to the Canadian Nuclear Waste Management Organization, and chairman of the Experts Team established by Southern California Edison to provide advice on the management and options for removing the spent fuel from the shutdown San Onofre Nuclear Generating Station. Previously, Tom served as the lead advisor to the Blue Ribbon Commission on America's Nuclear Future and earlier led the national comparative siting evaluation that led to the designation of Yucca Mountain as the candidate for the first U.S. spent fuel and high-level radioactive waste repository. He has served on the Nuclear and Radiation Studies Board of the National Academy of Sciences, Engineering, and Medicine and has engineering degrees from Harvard University and the University of Pennsylvania.

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[67] This volume is calculated using spent fuel assemblies-to-tons conversion ratios provided by Yan-Hong Li, Geological Survey Subsection, HWL Disposal Section, Department of Nuclear Back-end Management, Taiwan Power Company, communication with the authors, June 7, 2017.

[68] World Nuclear Association, "Nuclear Power in Taiwan," updated July 2019, www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx; Taiwan Atomic Energy Council, "Dry Storage Management in Taiwan," September 25, 2017, www.aec.gov.tw/english/radwaste/article05.php.

[69] Taiwan Atomic Energy Council, "Spent Fuel Management."

[70] In October 2014, a government task force had recommended reprocessing Chinshan and Kuosheng spent fuel. "Taipower Launches Overseas Reprocessing Tender," *World Nuclear News*, February 19, 2015, www.world-nuclear-news.org/WR-Taipower-launches-overseas-reprocessing-tender-1902155.html.

[71] Milly Lin and Ted Chen, "Lawmakers Block Taipower Offshore Nuclear Waste Reprocessing Plan," *Focus Taiwan*, March 16, 2015, focustaiwan.tw/news/aeco/201503160026.aspx.

[72] The report also considered project management strengths and gaps in terms of labor, material, machinery, method, and money. Taiwan Power Company, "The Spent Nuclear Fuel Final Disposal Program, Potential Host Rock Characterization and Evaluation Stage—The Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal: Main Report," March 2017, pp. S-1–S-7, 1-1–1-2, www.aec.gov.tw/webpage/control/waste/files/index_06_f1.pdf.

[73] Yan-Hong Li, "Brief of the Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal in Taiwan," NUMO-NTI Developing Spent Fuel Strategies Regional Workshop, Tokyo, May 29, 2017.

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The Nuclear Threat Initiative works to protect our lives, environment, and quality of life now and for future generations. We work to prevent catastrophic attacks with weapons of mass destruction and disruption (WMDD)—nuclear, biological, radiological, chemical, and cyber.

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