COOPERATIVE SPENT FUEL MANAGEMENT PARTNERSHIP IN THE PACIFIC RIM

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Abstract

National decisions about the management of spent nuclear fuel have global consequences for safety, security, and nonproliferation. For the past four years, the Nuclear Threat Initiative (NTI) has been catalyzing a spent fuel management partnership in the Pacific Rim – East Asia, the United States and Canada – a region with more than 230 power reactors and 170,000+ tons of spent fuel as of 2018. In the last year, the Partnership has created three expert working groups to address specific technical and societal challenges identified by the participants in previous workshops. These are: (1) underground research facility research and development; (2) long-term monitored dry cask storage; and (3) technical and non-technical aspects of repository siting. The working groups will meet several times a year to fulfill their objectives and identify additional topics that would benefit from collaborative research and development.

The paper: surveys the status of nuclear power generation, spent fuel accumulation and spent fuel disposal plans in the Pacific Rim; describes the security and nonproliferation implications of accumulating spent fuel stockpiles; details the efforts that led to the development of a Pacific Rim Spent Fuel Management Partnership and subsequent working groups; and discusses the research agendas of each working group. It is hoped that this Partnership will help provide solutions to practical problems faced by waste managers and can serve as a template for future similar cooperation in other parts of the world.

1. BACKGROUND

Thirty-one countries plus Taiwan operate nuclear power plants, although sensitive fuel cycle capabilities are concentrated in fewer than ten countries. Globally, reactors generate about 10,000 metric tons of spent fuel each year, and more than 250,000 metric tons of spent fuel is held in storage worldwide, most at reactor sites, with some at interim storage facilities or stored at reprocessing facilities [1]. Around two-thirds of that spent fuel is stored in pools with the remainder in dry casks. In addition, a significant amount of separated plutonium for eventual fabrication into mixed oxide fuel remains stockpiled internationally; the stockpile grew annually for decades leading up to 2015 but has levelled off in recent years. [2][3] In addition, while decisions about reprocessing are often made to facilitate the recycling of materials in spent fuel, in some cases these decisions are disconnected from use of the recovered products. Geological disposal is the internationally accepted solution for permanently isolating spent nuclear fuel and high-level waste. Political and technical difficulties have so far delayed and, in many cases, prevented the construction of any commercial repositories, though programs in several countries are making significant progress. In most countries, it will be decades before repositories are available to accept waste in sufficient quantities to begin to significantly reduce the inventory. Meanwhile, spent fuel continues to accumulate in cooling pools with limited storage capacity. Dry cask storage is a mid-term but still temporary solution to the problem of limited pool capacity, while significant waste streams that require permanent disposal still exist should countries choose to undertake reprocessing/recycling. Storage and disposal programs are complementary, and both are needed as spent fuel and high level waste should not be stored indefinitely – storage provides the interim solution until the repository is operating while a repository program will provide both a permanent solution and the necessary public and political assurance that the storage site will not become a de facto repository. The lack of functional disposal pathways strains the credibility of the nuclear community and undercuts public and political

acceptance for all nuclear activities. While the technical challenges, financial burdens, and political complexities of spent fuel management are well understood, important security and nonproliferation dimensions are often ignored or minimized.

These problems are no better exemplified than in the Pacific Rim region. Composed of China, Japan, Taiwan, South Korea, the United States, and Canada, there are more than 230 nuclear power reactors spread out across the region that, to date, have generated more than 170,000 tons of spent fuel (see Table 1). With the continued operation of the majority of the existing nuclear power reactors in the region, along with the planned construction of additional reactors, these numbers will only continue to grow. However, these numbers may be tempered by the slow and steady reduction in number of operating reactors in the US along with the attitudes of the current Taiwanese government to nuclear power.

Use of dry cask storage is not widespread throughout the region. China only operates dry cask storage for the pressurized heavy water reactors (PHWR) located at the Qinshan site [4]. Japan has only instituted dry cask storage at two of their reactor sites (Fukushima Daiichi and Tokai 2), instead choosing to move to more compact racks in spent fuel pools at other sites to allow for increased capacity [5]. Taiwan does not use dry cask storage at all. South Korea currently only utilizes dry cask storage for their CANDU reactor fuel – 4 of their 24 operating reactors are CANDUs [6]. This lack of additional storage capacity for PWR fuel is rapidly becoming a serious issue, as many experts estimate their in-situ spent fuel pools will run out of space by the early-mid 2020s. The United States and Canada both use dry cask storage extensively in their nuclear waste programs as an extended interim management step.

The only currently active repository project of the selected countries is in Canada, where a deep geological repository is currently in the site selection process. The estimated timeframe for the opening of this repository is 2040-2045, providing construction begins and proceeds as anticipated [7]. China's nuclear power program is too young for spent fuel volume to have become a major concern. In July 2017, the Ministry of Economy, Trade, and Industry (METI) in Japan released a map mandated by the national Strategic Energy Plan (SEP) that identified areas of the Japanese archipelago that would be favorable or unfavorable for waste transportation and geological disposal [8]. However, post-Fukushima, Japan's storage concerns are less of an immediate issue. The storage situation in Taiwan is dire, as four of the six cooling pools have now reached 99% capacity. In addition, the state-owned electric power company, Taipower has had trouble getting local government approval to operate two planned independent spent fuel storage installations that would help alleviate this capacity issue [9]. Due to the elimination of funding for the Yucca Mountain repository project in the United States, the Department of Energy is in breach of its disposal contract with utilities, resulting in significant and ongoing legal fees for the US government [10].

TABLE 1. REACTORS AND SPENT FUEL INVENTORY IN PACIFIC RIM

	POWER REACTORS	SPENT FUEL INVENTORY (TONS)	DRY CASK STORAGE
CHINA [11] [12]	45 operating, 13 under construction	~6,000 as of December 2017	Yes, but limited
JAPAN [13] [14]	48 total, 9 operating	~17,000 as of March 2017	Yes, but limited
TAIWAN [15]	6 total, 4 operating	~3,700 as of March 2018	No
SOUTH KOREA [16] [17]	24 operating, 5 under construction	~18,000 as of September 2017	Yes, but limited
UNITED STATES [18] [19]	98 operating	~79,000 as of December 2017	Yes
CANADA [20] [21]	19 operating	~55,000 as of December 2017	Yes

After removal from a reactor, spent fuel must be cooled in pools for several years before it can be moved into longer-term storage, reprocessed, etc. The longer spent fuel is stored, the less self-protecting it becomes as the strongly radiating shorter lived isotopes that provide the protection continue to decay, and thus as it becomes less radioactive, the greater security risk it presents[1]. Therefore, high priority should be given to secure spent fuel storage options in program planning. However, the adequacy of the threshold has been called into question in light of terrorists' demonstrated willingness to disregard their self-preservation. In particular, a 2005 ORNL report found that although the current self-protection dose guidance is considered lethal for 50% of recipients, the 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 [22]. And in 2011, INFCIRC/225 Revision 5 counseled that "if the threat assessment or design basis threat includes an adversary who is willing to perform a malicious act, States should carefully consider whether or not to reduce the categorization levels of the material on the basis of radiation levels sufficient to incapacitate the adversary before the malicious act is completed." [23]

China and Japan have chosen to take the reprocessing route for some of their spent nuclear fuel in order to 'close' the fuel cycle. China currently operates a small civilian reprocessing plant at Jiuquan (50 tHM/yr capacity) and is planning to develop additional facilities, while Japan is working to open a reprocessing facility at Rokkasho by early next decade. In the interim, reprocessing of Japanese spent fuel for re-use in mixed oxide fuel has been done in both the United Kingdom and France. The proliferation risks posed by reprocessing spent nuclear fuel have received a great deal of analysis, with the most notable risk being the separation of plutonium during the process. While the Rokkasho facility is under IAEA safeguards, proliferation risks still exist due to the approximately 10.5 tons of separated plutonium stored domestically. A further ~36.8 tons of Japanese-owned separated plutonium is stored in the United Kingdom and France, posing little proliferation risk [24].

2. CREATING A COLLABORATIVE PARTNERSHIP

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. In addressing these challenges, there are many benefits to pursuing a collaborative approach towards spent fuel management and disposition. These include, but are not limited to:

- Providing a wider choice of geological conditions for R&D;
- Enhancing regional transparency and confidence;
- Enabling the integration of engineering, hard science and social science research;
- Building trust through shared R&D;
- Enabling the efficient sharing of costs, resources, knowledge and experience;
- Generating the credibility gained from collaborative work among leading experts in the field;
- Enhancing global security.

This is particularly relevant in the Pacific Rim where disposal pathways are lacking and, in some cases, the lack of spent fuel pool storage capacity is beginning to threaten reactor operations. While some issues are addressed in a bilateral environment with certain Pacific Rim countries, there are no such regional groupings or approaches at present. A regional approach could present a workable path forward, allowing for the safe and effective expansion of nuclear power while simultaneously reducing security and nonproliferation concerns and helping each participating waste management organization to address their specific spent fuel and high-level waste management challenges.

[1] The concept of a self-protecting radiation barrier is that a sufficiently high external radiation level will act as an effective deterrent to the unauthorized removal/use of this material. Like all radioactive materials, as spent nuclear fuel ages the radiation field diminishes. Eventually it is no longer self-protecting. DOE self-protection guidance for radioactive material is 1 gray/hour (100 rem/hour) at one meter unshielded. This is the same threshold that the NRC and IAEA currently use.

The Nuclear Threat Initiative (NTI) organized a workshop in December 2013 in Paris to begin scoping a multinational project. This workshop produced a number of key takeaways that included:

(a) A staged, adaptive approach to siting a repository has allowed several national programs to move forward toward a consistent set of goals while preserving the flexibility necessary to adjust to both changing conditions and opportunities to improve;
(b) Countries that have made progress in developing disposal programs have found this success partly through ensuring the utilities have a stake in making sure the program moves forward;
(c) Safe and secure storage of spent nuclear fuel and/or high-level waste is vital in every nuclear power program for extended periods of time until repositories are operating; and
(d) For regional approaches, cooperation short of final disposition can be helpful starting points, as jumping straight into discussion on final repositories is often a recipe for failure [25].

Taking these ideas into account, NTI decided to focus on a particular region. The Pacific Rim emerged as a natural choice for this work due to the issues discussed previously. Since 2014, NTI has been actively engaging spent fuel and waste management organizations in the region on these issues. Workshops to date have included:

— **Taipei, Taiwan (2014)** – Discussion focused on the status of spent nuclear fuel and high level waste programs in Japan, South Korea, Taiwan, and the United States; nuclear energy plans in Malaysia and Vietnam; and, identification of regional experts to participate in future meetings;
— **Singapore (2015)** – In addition to updates on topics previously discussed, discussion focused on the status of SNF/HLW management in China, Australia's potential interest in multinational spent fuel storage/disposal as well as the mechanics of developing a research agenda;
— **Honolulu, Hawaii (2016**) – The research agenda was refined, and an agreement was reached on the development of an informal Asia Pacific Group on Coordination of Spent Fuel Management. One key activity undertaken in Honolulu was a multinational disposal scenario walkthrough;
— **Tokyo, Japan (2017)** – Co-hosted by the Nuclear Waste Management Organization of Japan (NUMO) and the Japan Atomic Energy Agency (JAEA). Participants provided detailed presentations on underground research laboratories, deep borehole studies, approaches to siting waste management facilities that build public trust and continuity of knowledge/knowledge management;
— **Gyeongju, South Korea (2018)** – Co-hosted by the Korea Radioactive Waste Agency (KORAD), several of the topics discussed at the Tokyo workshop were examined in further detail, and agreement was reached on operationalizing three working groups: (1) long-term monitored dry cask storage; (2) technical and non-technical aspects of siting; and, (3) underground research laboratory (URL) research and development;
— **Planned (2019)** – Three working group meetings will be held in 2019, the first co-hosted by Sandia National Labs in Albuquerque, New Mexico, to operationalize these working groups by developing detailed work agendas and taskings.

International participants in these workshops have included experts from South Korea (KORAD, the Korea Atomic Energy Research Institute and the Ministry of Foreign Affairs), Japan (NUMO and JAEA), Taiwan (Atomic Energy Council, Industrial Technology Research Institute and Taipower), China (China Institute of Atomic Energy), Canada (Nuclear Waste Management Organization), and international organizations such as the IAEA and NEA. Domestically, participants have included the U.S. National Laboratories (Sandia, Idaho, Oak Ridge, and Pacific Northwest), the U.S. Department of Energy's Office of Nuclear Energy, and several independent consultants. Two cask manufacturer companies have also been involved (GNS and Orano), with plans to engage the cask development community more broadly throughout 2019.

3. WORKING GROUP AGENDAS

For the long-term monitored storage & transportation working group, topics identified for further research have included, but are not limited to: developing a better understanding of seal failures; investigating canister cracks and mitigation/repair options, including inspections; investigating cask-to-cask transfers and transfer of spent fuel without a spent fuel pool; studying deformation of seals over time under pressure; examining transportation issues (especially for high burn-up fuel) and licensing; remote monitoring; and, consideration for the interim storage of used enhanced accident tolerant fuel.

At the Gyeongju workshop, participants discussed the utility of creating an information exchange on **non-technical aspects** of siting that would focus initially on lessons learned while acknowledging that each situation is unique and best practices will need to be tailored to the needs of the specific country/host community.

The **underground research facility** working group identified topics including:

- Standards to ensure disposal media characterization is proper and verifiable when applied to repository development
- Extended benchmarks based on the Engineered Barrier Systems (EBS) experiment:
  - Monitor the thermal-hydrological-mechanical-chemical (THMC) behavior after heating;
  - Safety assessment at full saturation;
  - Simulation of transient THMC processes until full saturation in the EBS.
- Dismantling of the EBS experiment
- Tracer experiments:
  - Develop up-scale methods for performance assessments as only small-scale data are now available;
  - Validation of system performance by in-situ experiments;
  - Training and education of tracer experiment technique;
  - Standardization of tracer experiment method to deal with regulation requirements.

4. CONCLUSION

While certain challenges, both technical and political, make progress slow, it is both important and necessary to discuss these topics in a collaborative regional or international forum. The broad objectives of this partnership are:

a) Promote better understanding and improved relationships among key spent fuel and waste management experts so they can have meaningful discussions about key issues facing their programs;
b) Improve understanding among national spent fuel and waste programs about status, plans and challenges and plans of each;
c) Investigate and share information about best practices on topics of mutual interest as identified by the participants;
d) Where useful, develop cooperative research projects on technical and non-technical topics that will complement national programs and are supported by the appropriate government or international agencies;
e) Institutionalize this cooperative research in order to sustain it over the long term; and,
f) Provide output i such as best practice exchanges, cooperative research and development where merited and publications to communicate findings locally, nationally, regionally and internationally.

It is hoped that this project provides a natural link between some of the bilateral work being undertaken, such as the work being undertaken under the auspices of 123 Agreements in place between the United States and Japan/South Korea, and large multilateral or global efforts.

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