Innovations in U.S. nuclear decommissioning and waste storage and their potential application in Taiwan

15 September 2020

The field of nuclear decommissioning is in the midst of a major transformation, led by innovations in the United States. Since 1964, 36 nuclear reactors have shut down,[1] 21 reactors are currently undergoing decommissioning,[2] and 10 reactors have been successfully decommissioned.[3] The lessons learned from extensive experience in nuclear decommissioning and waste management in the U.S. could help enhance this process abroad. While the regulatory and practical realities differ across countries and reactors, there are innovations in safe and efficient decommissioning and in the disposal of nuclear waste that are broadly applicable. Our team has experience not only within the U.S., but also in Europe and Asia, handling decommissioning issues such as licensing and waste storage. We are experienced in overcoming nuclear regulatory hurdles and helping companies find sound solutions to complex decommissioning matters.

This article encourages thought-leadership on this topic by discussing U.S. experiences in nuclear decommissioning and positing how these experiences can be applied to countries like Taiwan that already have many of the resources necessary to successfully decommission plants, but may benefit from leveraging global experience and insights. In particular, we discuss (i) innovations in decommissioning models, (ii) innovations in waste storage, and (iii) U.S. application of licensing and waste storage in Taiwan.

(i) U.S. innovations in decommissioning

Starting in the late 2000s and continuing into the last decade, decommissioning technology and processes have greatly advanced. For example, decommissioning vendors in the U.S. created new tools such as diamond wire saws and robotics, and developed new processes for faster decommissioning, including innovations in reactor segmentation. These non-utility vendors also

[1] Nuclear Energy Institute, *Decommissioning Status for Shutdown U.S. Nuclear Plants* (Apr. 2016), https://www.nei.org/resources/statistics/decommissioning-status-for-shutdown-us-plants.

[2] U.S. Nuclear Regulatory Commission, *Locations of Power Reactor Sites Undergoing Decommissioning* (May 4, 2020), https://www.nrc.gov/info-finder/decommissioning/power-reactor/.

[3] U.S. Energy Information Administration, *Decommissioning nuclear reactors is a long-term and costly process (Nov. 17, 2017)*, https://www.eia.gov/todayinenergy/detail.php?id=33792#:~:text=As%20of%202017%2C%20a%20total,stages%20of%20the%20decommissioning%20process.

worked with regulators to develop and implement new decommissioning models that reduced doses to workers and more effectively transferred waste offsite to disposal facilities. These models allowed for a more efficient and streamlined process and greater interaction with decommissioning experts. While utilities had expertise in the operation of reactors, they did not necessarily have expertise specific to decommissioning. The models allowed the utilities in many states to leverage the expertise of decommissioning companies, while still maintaining sufficient regulatory and contractual controls to protect ratepayers as well as the environment and public health and safety.[4]

Traditionally, owners/operators of nuclear plants engaged with specialized decommissioning contractors, but still largely controlled the details of the decommissioning process, including interactions with regulators and control of decommissioning funding assets. However, in 2008 a novel decommissioning model was introduced by Energy*Solutions* in the decommissioning of the Zion nuclear power plant. The "License Stewardship" model promised certain benefits for the decommissioning contractor, utility operator, and the public. Under this new approach, the contractor takes over as the power plant licensee and assumes the legal and technical responsibilities traditionally held by the utility owner/operator. These responsibilities include adhering to nuclear regulatory liabilities, ensuring Nuclear Decommissioning Trust (NDT) funding is adequate, and returning the site to the owner/operator upon completion.[5] The License Stewardship model allows for the regulator to interact directly with the decommissioning vendor, which encourages transparency of the decommissioning process.

Since its initial use in the Zion project, the License Stewardship model has taken off along with other innovative decommissioning models created in the U.S. under what is called the "Acquisition" model, contractors are now able to acquire nuclear power plants in the U.S. for purposes of decommissioning. The contractor would also generally acquire title over the spent nuclear fuel and purchase the real estate at the reactor site. In general, the License Stewardship and Acquisition models have improved decommissioning timelines and efficiency in the U.S., while protecting public safety. The regulatory framework under the U.S. Nuclear Regulatory Commission (NRC) supports flexibility of license transfers and requires that funds are set aside for decommissioning. Countries like Taiwan that may have a less flexible or established regulatory framework may wish to follow a more traditional decommissioning model, such as the plant operator hiring a contractor to support decommissioning activities at the plant, and discuss with counsel how best to utilize lessons learned from decommissioning experience in the U.S. and elsewhere to adjust that model within its unique regulatory constraints.

In the U.S., the planned decommissioning of Three Mile Island, Unit 2 (TMI-2) may be another example of a successful application of decommissioning innovations. In 1979, a minor malfunction in the secondary cooling circuit caused part of the TMI-2 reactor core to melt[6] in what became known as the worst nuclear reactor accident in U.S. history.[7] The recent development in license transfers will drive the long-awaited restoration forward. Last year, Energy*Solutions*, the company that led decommissioning at the Zion plant, agreed to acquire TMI-2 to decommission the site.[8] Energy*Solutions* is expected to acquire TMI-2 from the owner/operator through a license transfer process and proceed to dismantle the plant and

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[4] Energy Solutions, *Ken Robuck: The D&D business model* (Dec. 2017), https://www.energysolutions.com/wp-content/uploads/2018/01/Dec-2017-NN-EnergySolutions-Reprint-1.pdf.

[5] *Id.*

[6] World Nuclear Association, *Three Mile Island Accident (Mar. 2020)*, https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/three-mile-island-accident.aspx.

[7] U.S. Nuclear Regulatory Commission, *Backgrounder on the Three Mile Island Accident* (June 21, 2018), https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html.

[8] First Energy, *FirstEnergy Subsidiaries to Transfer TMI-2 to a Subsidiary of EnergySolutions* (Oct. 15, 2019), https://firstenergycorp.com/newsroom/news_articles/firstenergy-subsidiaries-to-transfer-tmi-2-to-a-subsidiary-of-en.html.

remove the remaining nuclear waste.[9] The TMI-2 experience will provide further insights on decommissioning highly complex nuclear power plant accident sites.

(ii) U.S. innovations in waste storage

Determining who is responsible for spent nuclear fuel (SNF) disposal and how that process is undertaken is a large part of the decommissioning process. SNF storage and management requires long-term planning and creative solutions, with the private sector leading the way with innovative new approaches. One such solution has been the development of consolidated interim storage facilities (CISFs). CISFs are intended to acquire SNF from power plants across the country to store in a centralized location. Utilizing CISFs facilitates site decommissioning and aids decommissioning contractors to better manage SNF long-term. In 2016 and 2017, multiple companies in the U.S. submitted applications to construct CISFs. After considering environmental implications of the various CISF applications, the NRC staff recently recommended the issuance of a license for Interim Storage Partners (ISP) to construct and operate a CISF to store up to 5,000 metric tons of spent nuclear fuel for a licensing period of 40 years.[10] According to ISP, the CISF will help address the growing need to decommission reactors across the country.[11]

There has also been notable technical progress in long-term disposal, despite the failure to reach a political consensus. The original plan called for long-term SNF disposal at the Yucca Mountain site in Nevada, but this ran into strident political opposition and is currently unable to move forward. However, other storage options, such as deep borehole disposal (DBD), are being explored. DBD involves drilling holes 5,000 meters underground and sealing canisters filled with nuclear waste in those boreholes.[12] While there remain outstanding engineering questions, DBD technology has been developed in other countries such as Denmark, Sweden, and Switzerland.[13] The U.S. Department of Energy (DOE) funded research and development of DBD and previously selected sites for field testing. While these efforts stalled in 2016,[14] a more recent push by the private sector is propelling the concept into reality. For example, a company called Deep Isolation is working with contractors to utilize horizontal wells to store nuclear waste deep underground where it would be protected by the earth's shale rock.[15]

In addition to disposal of SNF, disposal of low-level waste is of increasing importance, given the challenge of finding appropriate disposal facilities. Here, innovations in the decommissioning process, including solidification, sorting, and compaction can reduce overall generation of radioactive waste, and post-removal treatment can lower the quantity of radioactive waste

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[9] Energy Solutions, *EnergySolutions in Negotiations to Acquire and Complete the Decommissioning of the Historic Three Mile Island Unit-2 Nuclear Power Plant* (July 23, 2019), https://www.globenewswire.com/news-release/2019/07/23/1886703/0/en/EnergySolutions-in-Negotiations-to-Acquire-and-Complete-the-Decommissioning-of-the-Historic-Three-Mile-Island-Unit-2-Nuclear-Power-Plant.html.

[10] U.S. Nuclear Regulatory Commission, *Environmental Impact Statement for Interim Storage Partners LLC's License Application for a Consolidated Interim Storage Facility for Spent Nuclear Fuel in Andrews County, Texas – Draft Report for Comment (NUREG-2239)* (May 2020), https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2239/.

[11] Orano USA, *Interim Storage Partners submits renewed NRC license application for used nuclear fuel consolidated interim storage facility in West Texas* (June 11, 2018), http://us.areva.com/EN/home-4216/orano-orano-usa--interim-storage-partners-submits-renewed-nrc-license-application-for-used-nuclear-fuel-consolidated-interim-storage-facility-in-west-texas.html.

[12] J. Winterie, et. al, Center for Nuclear Waste Regulatory Analyses, *Regulatory Perspectives on Deep Borehole Disposal Concepts* (May 2011), https://www.nrc.gov/docs/ML1114/ML111470719.pdf.

[13] World Nuclear News, *US company demonstrates innovative waste disposal concept* (Jan. 18, 2019), https://world-nuclear-news.org/Articles/US-company-demonstrates-innovative-waste-disposal.

[14] Science Magazine, *Protests spur rethink on deep borehole test for nuclear waste* (Sept. 27, 2016), https://www.sciencemag.org/news/2016/09/protests-spur-rethink-deep-borehole-test-nuclear-waste

[15] Forbes, *Deep Borehole Nuclear Waste Disposal Just Got A Whole Lot More Likely* (Jun. 24, 2019), https://www.forbes.com/sites/jamesconca/2019/06/24/deep-borehole-nuclear-waste-disposal-just-got-a-whole-lot-more-likely/#8d203b867c84.

requiring specialized disposal. These processes have been used globally and can be modified to meet a country's needs and particular waste storage requirements.[16]

(iii) Application of U.S. lessons in Taiwan

Taiwan has six nuclear reactors, and in 2019 it received around 15 percent of its energy supply from its four operable reactors—two housed at the Kuosheng plant and two at the Maanshan plant. The other two reactors are at the Chinshan power plant, but these were shut down in 2018 and 2019. The current government has pledged to shut down all of Taiwan's nuclear plants by the year 2025, as it plans to forgo license renewals and allow operation licenses to expire.[17] In July 2019, the Atomic Energy Council (AEC) officially approved decommissioning of the Chinshan units. As required by Taiwanese law, the decommissioning plan was filed in 2016, three years prior to the scheduled plant shutdown. Decommissioning will occur over a 25 year period and encompasses four stages: shutdown and defueling, dismantling, testing, and site restoration.[18]

Taiwan is well-prepared to address some of the challenges of decommissioning its nuclear fleet. However, as it starts this first-of-a-kind effort, it should look to lessons learned from projects abroad. Decommissioning project innovations in the U.S. can improve the efficacy of decommissioning efforts in Taiwan. Moreover, the country's existing options for waste storage and treatment may have been sufficient before the decommissioning mandate, but waste management needs are set to increase significantly as all six reactors go through the decommissioning process. Nuclear waste is largely stored at the Lanyu nuclear waste storage facility built in 1982 on Lanyu Island, also called Orchid Island. However, the storage capacity at Lanyu had been steadily declining long before the government decided to decommission its nuclear plants,[19] and protestors took to the streets in 2019 demanding that the 100,000+ barrels of waste be removed.[20]

Luckily, Taiwan has a regulatory infrastructure in place for waste disposal that could make integration of innovative waste management techniques possible. Similar to the U.S., Taiwan's waste management strategy for long-term management of high level radioactive waste is to store the waste in "deep geological disposal" after considering factors like environmental impacts and geological structures. Faced with an intractable problem, innovative approaches to consolidated storage or geologic disposal may be worth exporting. In particular, decommissioning necessitates a clearly formulated waste storage plan that encompasses waste processing, storage, and proper disposal. U.S. technical expertise in waste management is transferable to countries like Taiwan that have similar waste disposal needs, yet lack some of the technical necessities, such as storage space, and the experience necessary to properly implement a disposal plan. Applying U.S. lessons learned to Taiwan's decommissioning structure, particularly to the waste storage issue, can help the country avoid common pitfalls like inadequate storage facilities and improper waste treatment. Planning around these issues from the outset could help promote a safe and efficient decommissioning process.

Due to its notable experience in nuclear decommissioning, the U.S. can serve as a resource for Taiwan, particularly during these beginning stages of formulating decommissioning plans. Selecting the appropriate decommissioning model to incentivize innovation can shape how

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[16] Westinghouse Nuclear, *Waste Treatment Overview* (Feb. 2015), https://www.westinghousenuclear.com/Portals/0/D&D/Waste-Management/DDR-0109%20Waste%20Treatment%20Overview.pdf.

[17] World Nuclear News, *Taiwan government maintains nuclear phase-out* (Feb. 1, 2019), https://world-nuclear-news.org/Articles/Taiwan-government-maintains-nuclear-phase-out.

[18] World Nuclear Association, *Nuclear Power in Taiwan* (July 2019), https://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

[19] Enformable, *Taiwan looks globally for help managing spent nuclear fuel* (Mar. 6, 2015), http://enformable.com/2015/03/taiwan-looks-globally-for-help-managing-spent-nuclear-fuel/.

[20] The Diplomat, *Tao Indigenous Community Demands Removal of Nuclear Waste From Taiwan's Orchid Island* (Dec. 6, 2019), https://thediplomat.com/2019/12/tao-indigenous-community-demands-removal-of-nuclear-waste-from-taiwans-orchid-island/.

efficiently the project is completed. Keeping an open mind to new approaches to reduce and dispose of waste can help address pending radioactive waste management projects. While this process may seem daunting, a carefully constructed and executed plan that borrows from tried and tested experiences in the U.S. can help advance the process and place Taiwan as an international leader in the burgeoning field of nuclear decommissioning.

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