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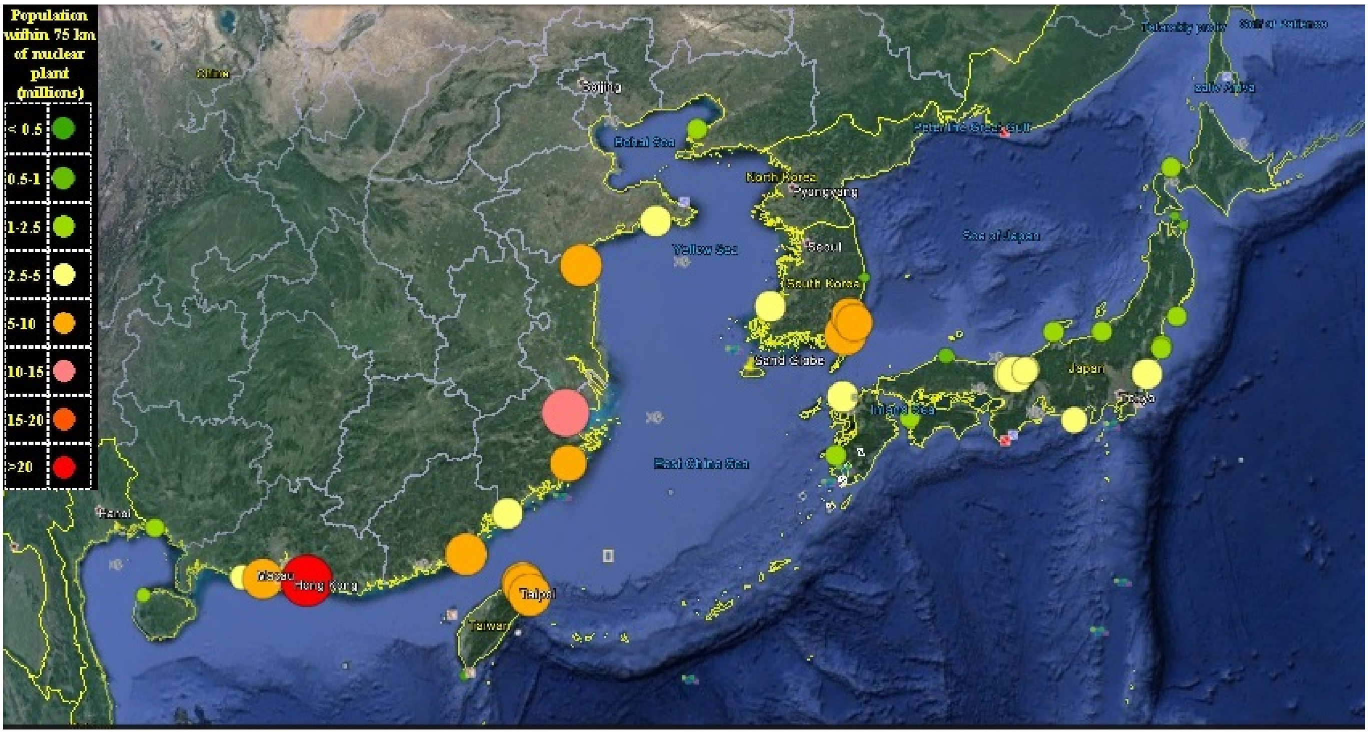
CHINA’S NUCLEAR SPENT FUEL MANAGEMENT AND NUCLEAR SECURITY ISSUES



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I. INTRODUCTION

In this essay, Hui Zhang reviews the status of spent fuel storage in China. He suggest that China should take steps to improve physical protection, reduce insider threats, promote a nuclear security culture, and improve nuclear cyber security. He also recommends China, South Korea, and Japans' nuclear security training centers should cooperate and exchange best practices on insider threat reduction, contingency plans for emergency response, and discuss regional cooperation for long-term spent fuel storage, including building a regional center of spent fuel storage.

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Banner image: population size living within 75 kilometres of each nuclear reactor in East Asia. Population increases with circle size and with colour, from green (< 0.5 million) to red (> 20 million), link to GoogleEarth downloadable file here.

II. NAPSNET SPECIAL REPORT BY HUI ZHANG

CHINA'S NUCLEAR SPENT FUEL MANAGEMENT AND NUCLEAR SECURITY ISSUES

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China has emerged as the central focus of the international nuclear industry due to its ambitious nuclear energy plans. The loss of water from a spent fuel pool could have catastrophic results. Spent fuel facilities could become a tempting target for terrorists. In this paper, I will briefly examine the vulnerabilities of spent fuel to terrorist attacks, in particular, for Chinese case. Finally, I will suggest measures how to reduce the risks.

China's nuclear power development and spent fuel management

As of March 2017, China has 36 power reactors (33 GWe) in operation with 21 units under construction (23 GWe). Developing nuclear power has become one key policy in reducing China's concerns about air pollution and climate change issues. To address these concerns, China has pledged to get around 15 percent of its primary energy from non-fossil sources by 2020, and 20 percent of its primary energy from non-fossil sources by 2030. To meet its ambitious goal, many Chinese officials and nuclear experts advocate that developing significant nuclear power is an imperative if the country is to increase the share of non-fossil fuel energy in its energy mix.

In its recently issued 13th Five-Year Plan (2016-2020), China reaffirms the target of 58 GWe in operation and 30 GWe under construction by 2020 as planned in 2012. Since May 2016, National Energy Administration (NEA) (under National Development and Reform Commission (NDRC) has been working on details on nuclear power development of 13th Five-year plan, and it is reported to plan a national goal of increasing total nuclear capacity to 120-150 GWe by 2030. Many more reactors are under consideration for construction in the coming decades. Within a few decades, China is expected to operate more nuclear power plants than any other country in the world.

Most of Chinese power reactors in operation and under construction are PWRs (except of two CANDU reactors). Those PWRs discharge approximately 600 tons of spent fuel in 2016. If China meets the target of 58 GWe of nuclear power by 2020, it will then be discharging approximately 1100 tons of spent fuel per year. Spent fuel discharges will increase significantly as China deploys more reactors.

At operational Chinese nuclear power plants built before 2005, the on-site spent fuel pools were designed to accommodate 10 years of spent fuel discharges and extended to 20 years storage capacity (except of two PWRs at Daya Bay NPP) with pool dense-racking. Newer plants are usually designed with 20 years storage capacity. Most of the spent fuel is stored in the reactor's spent fuel pools. Only the two PWRs at the Daya Bay plant, on line in 1993 and 1994, have reached their full storage capacity for spent fuel around 2003. Since then, Daya Bay has been shipping spent fuel to the wet storage pool at the pilot reprocessing plant. The 500-ton capacity of that pool was filled in 2014, a second 760-ton pool at the pilot reprocessing plant has been completed and is waiting for National Nuclear Safety Administration (NNSA) approval for operation. With the 760-ton pool at the pilot reprocessing plant, China would not need additional spent fuel storage until approximately 2027.[1]

Constrained by its national reprocessing policy, China's nuclear industry did not build larger AR pools or on-site dry storage for PWR's spent fuel during the past several decades. Since 2008, on-site dry cask storage has only been introduced at the Qinshan Phase III plant (two CANDU reactors) because China has no plans to reprocess any spent fuel from heavy water reactors. The two CANDU reactors, with lower burn-up, will discharge 176 tons of spent fuel annually. There are plans to construct 18 MACSTOR-400 concrete storage modules at a rate of 2 modules every 5 years, which could expand the on-site spent fuel storage capacity to 40 years.

At PWR sites, China does not use dry cask storage yet. However, recently the China National Nuclear Corporation (CNNC); and the China General Nuclear Power Corporation (CGN) has been considering to develop on-site, interim, dry-storage for its PWRs. In practice, dry cask storage would allow for decades of safe, secure, and cost-effective storage, while leaving both reprocessing and direct disposal options open for the future.[2]

Since 1983, China has maintained its spent fuel reprocessing policy. One major motivation for developing commercial-scale reprocessing is to reduce the burden of spent fuel storage at reactor sites. In July 1986, the State Council approved the construction of a pilot civilian reprocessing plant with annual reprocessing capability of 50 tons in the Jiuquan nuclear complex. In December 2010, it successfully conducted a hot test and CNNC pronounced it a fully operational pilot reprocessing plant. It took about 24 years from the project approval in July 1986 to the hot test in December 2010. However, reprocessing operations stopped after only ten days.[3] After reprocessing operations resumed in a short period in early 2016, it stopped again.

Meanwhile, CNNC began in 2015 to build domestically a medium-scale demonstration reprocessing plant (200 tHM/year) at Jinta, Gansu province. It aims to provide plutonium for initial demonstration fast-neutron reactors. Now it is at a stage of site preparation and planned to be operational by 2020. Moreover, since 2007 the CNNC has been negotiating with France's AREVA on the construction of a commercial reprocessing plant (800 tHM/year). Most recently, CNNC and Areva signed a memorandum of understanding (MoU) in June 2015 formally indicating the conclusion of technical discussions and the start of negotiations on business aspects. CNNC plans to build the plant in 2020. However, CNNC nuclear experts complain to AREVA's asking price as too high. It is not clear that this deal will be supported financially by the central government.[4]

The vulnerability of spent fuel pools to terrorist attacks

While Chinese nuclear experts widely believe the probability of terrorists or non-state actors acquiring nuclear weapons and fissile materials inside China is extremely low, the risk of sabotage at civilian nuclear facilities, in particular a nuclear power plant, is considered plausible. In a comprehensive assessment of the risk of sabotage of nuclear facilities, the China Academy of Engineering's 2005 book, "Management of Nuclear and Radiological Terrorism Incidents" concluded that, "one possible route nuclear terrorists would take is to sabotage [a] nuclear facility. Once [it] happen[s], it could seriously affect the environment and public. China has a number of nuclear facilities that have a variety of vulnerabilities if attacked."[5] As the number of nuclear power plants in China is rapidly increasing, such a risk poses a challenge to China's nuclear security.

One major concern is the vulnerability of a nuclear power plant's spent fuel pool to terrorist attacks. Most of Chinese spent fuel is stored at PWR's pools. It can be expected that PWRs will be the main-stream in China at least for the coming decade. Those PWR pools are usually outside the reactor containment building and partially or fully embedded in the ground. Also, constrained by its reprocessing policy, those pools are originally designed smaller and some are using dense packing approaches. Some studies show that if there were a loss of coolant at the dense-packing of pools, the spent fuel would heat up and catch fire and release huge quantities of cesium-137(Cs-137) into the atmosphere.[6] Even for the case of non-dense-packed pools, there could still be some sabotage scenarios that cause a significant amount of radioactive release.[7]

A 400 t PWR pool holds about 10 times more long-lived radioactivity than a reactor core. One major concern is the fission product Cs-137, which made a major contribution (about three quarters) to the long-term radiological impact of the 1986 Chernobyl accident. A spent fuel pool would contain tens of million curies of Cs-137. Cs-137 has a 30 year half-life; it is relatively volatile and a potent land contaminant. In comparison, the April 1986 Chernobyl accident released about 2 Mega Curies (MCi) Cs-137 into the atmosphere from the core of the 1,000 MWe unit 4. A recent Princeton study, based on reviewing the case of the spent fuel fire that almost happened at Fukushima in March 2011, shows that, in a worst case, had the windblown the released radioactivity toward Tokyo, 35 million people might have required relocation.[8]

A well-organized terrorist group with collusion between insiders and outsiders could compromise the cooling systems of a spent fuel pool in a number of ways,[9] such as causing the loss of cooling, thus boiling the water off through the failure of pumps or valves, through the destruction of heat exchangers, or through a loss of power for the cooling system. It is estimated that, in the case of a loss of cooling, the time it would take for a spent fuel pool to boil down to near the top of the spent fuel would be as short as several hours, depending on the cooling time of the discharge fuel; [10] ii) causing the drainage of coolant inventory by piping failures or siphoning, and by gate and seal failures. Furthermore, a heavy load including a fuel transport cask could be dropped in the pools thus causing a collapse of the pool floor and a water leak. As reported, "The analysis exclusively considered drops severe enough to catastrophically damage the SFP so that pool inventory would be lost rapidly and it would be impossible to refill the pool using onsite or offsite resources. There is no possibility of mitigating the damage, only preventing it." "The staff assumes a catastrophic heavy load drop (creating a large leakage path in the pool) would lead directly to a zirconium fire"; [11] iii) puncturing the pool and causing a drainage by suicide airplanes, or other explosives. For the case that spent fuel pools are located above ground level, a suicide airplane could breach the pool bottom or sidewalls and cause a complete or partial drainage. A US NRC study estimated that a large aircraft (one weighing more than 5.4 tonnes) would have a 45% probability of penetrating the five-foot thick concrete wall of a spent fuel pool.[12] Moreover, a terrorist attack could include some kinds of on-site explosions to damage the pools, such as if a large truck bomb were detonated near the pool; or if a terrorist carried a certain type of explosive to the pool and blew a sizeable hole in the pool.

Another risk is from the spent fuel pools at reprocessing plants. A reprocessing plant has even greater pool storage capacity than that of a reactor pool. The buildings that house the pools could be even weaker than those pools at reactor sites. In particular, the roof of the building could be more vulnerable. Most of the sabotage scenarios conceivable for reactor pools could be applied to these pools at reprocessing plants. However, unlike those freshly discharged spent fuels at reactor pools, the cooler spent fuel at reprocessing pools could be difficult to ignite automatically in the absence of cooling. There might still be some ways to cause a significant radioactive release by a successful terrorist attack, however. For example, a two- or multiple-stage attack by truck bombs, aircraft impacts or other kinds of on-site explosion could at least breach the zircaloy cladding or even partly melt the fuel cladding. Even though this would not ignite a spent fuel fire, a significant fraction of Cs-137 in the rods could be released into the atmosphere. Furthermore, terrorists could pour fuel in the pool and start a fire that would cause ignition of the zircaloy cladding and lead to a greater release of the Cs-137 inventory. Some Studies indicate that heating at 1,500 °C of high-burnup spent fuel for one hour caused the release of 26% of the Cs inventory[13].

Moreover, terrorists could sabotage against the storage facility for separated plutonium at reprocessing plant, which could result in a critical event. Also, a successful attack on high level waste tanks could lead to a radioactive release. [14]

Further, reprocessing activities would increase the risks of theft of plutonium by insiders or with insider cooperation. The operator of pilot reprocessing plant faces a challenge to establish an effective MC&A system in China. Although reprocessing operations stopped after only 10 days, beginning in December 2010, many problems, including a very high percentage of material unaccounted for (MUF), were identified.[15] It would be even more difficult to establish an effective MC&A system at the larger planned reprocessing facilities than at the much smaller pilot facility. Even with an advanced, modern MC&A system, measurement uncertainties at a reprocessing plant are typically in the range of 1 percent of plutonium throughput, amounting to 80 kg of plutonium per year at an 800 tHM/year facility. Given the inevitable uncertainties in accounting, it is likely that China will ultimately have to rely primarily on other measures to prevent insider theft.

The threat of nuclear terrorism in China

Outsiders with assistance from a small group of insiders could launch attacks against nuclear facilities including spend fuel pools. Such attacks could be conducted through cyber or physical means or a combination of both. Such a possibility cannot be ruled out in China.

China is facing a huge challenge of national widespread corruption, particularly in the nuclear sector. An anti-corruption campaign China initiated in 2012 has shown corruption is widespread among high-level officials and lower-level civil servants alike. In the nuclear sector, a number of former leaders have been accused of bribery and abuse of power.[16] These include a former director of the NEA, which is the principal authority over nuclear power plants and responsible for drafting plant safety and security regulations; a former director of the nuclear power bureau under the NEA; a former general manager of CNNC and a former vice-general manager of CGN. These charges raise the specter of a high potential for insider theft of nuclear materials, unauthorized access to restricted areas and conspiracy with other insiders or outsiders.

An insider might be motivated by a number of factors, including: desperation; greed and the temptation of bribery; political or religious ideology; social or cultural motivations; blackmail; and ego.[17] The risk of an insider threat is perhaps the most difficult to deal with, because insiders can access restricted areas. [18]They are knowledgeable about operations and rules. They have the opportunity to understand how to defeat, test, or circumvent safety and security systems and distract other insiders and guards. One or more of these individuals could take advantage of access to perform acts of theft or sabotage, and potentially aid terrorists.

China's nuclear facilities may also face an increasing risk of outsider terrorist attacks.[19] Extremists in the predominantly Muslim Uighur community want to form a separate state called East Turkestan in the Chinese autonomous region of Xinjiang. Their East Turkestan Islamic Movement (ETIM) claimed responsibility for more than 200 acts of terrorism between 1990 and 2001, and since 2013, ETIM has carried out more than 40 attacks that resulted in several hundred deaths.

Most early acts were limited to the Xinjiang area, but recent attacks have spread to other large cities, including Beijing, Kunming and Guangzhou. Where most targets were government buildings and police stations in the past, civilian targets such as train stations and supermarkets have recently increased dramatically. Moreover, past attacks relied mainly on simple tools that included knives and axes. But these have given way recently to suicide vests, car bombings, grenades and other explosives.

It is clear that the Xinjiang terrorists have close relations with international groups. Beijing has confirmed that the ETIM has long received training, financial assistance and support from al Qaeda. Hundreds of Xinjiang's Uighur Muslims are reported to be fighting alongside ISIS, the Islamic State, in the Middle East. Some, after training and actual combat experience, are known to have returned to China, presumably to prepare for attacks.[20]

China's neighbors in Central Asia and Pakistan have served as safe havens for ETIM members while allegedly being centers of nuclear smuggling and proliferation activities. It is possible that East Turkestan extremists could acquire fissile material or nuclear weapons from their bases in these areas, from which they could plan and launch attacks.

In short, in the years to come, it is plausible that terrorist groups might be able to put together an attack on civilian nuclear facilities, in particular a nuclear power plant—especially as the number of such plants rapidly increases. The Fukushima accident may also increase terrorists' interest in targeting China's power reactors. Further, China's current nuclear security system at its nuclear facilities including spent fuel pools could not be strong enough to protect from terrorist attacks.

Major challenges to China's nuclear security

In recent years, China has made important progress on nuclear security, including national laws and regulations, protection and control measures, nuclear security culture, international assurance, and international cooperation.[21] But, significant challenges still remain. Those weaknesses in China's nuclear security system may be exploited by terrorists.

All related regulations and rules on the security of nuclear materials and facilities— with the exception of physical protection guidelines issued in 2008 were issued before the 9/11 attacks. And the 2008 guidelines on physical protection contain no national-level DBT that operators must protect against, and no clearly defined standards for how each nuclear facility should design a DBT for its local conditions. Operators typically design their site-specific DBTs on a case-by-case basis, taking into account a number of factors, including the socioeconomic situation in the area surrounding the facility. As a former NNSA director noted, the existing DBT for nuclear power plants could have produced designs that are unable to resist attacks from large-scale and well-organized terrorist groups with powerful weapons.[22] It is not clear if the on-going Nuclear Security Regulations will address it in some way. Moreover, no Chinese regulations require to do realistic force-on-force exercises, as INFCIRC/225/Revision 5 recommends. However, such tests are vital for identifying the strengths and weaknesses of security procedures.

Moreover, Chinese nuclear facilities may be vulnerable to outsider and insider cyber-attacks. Although China is accelerating the development of national legislation focusing on cyber security, China has not yet written specific regulations and guidelines with provisions at nuclear facilities. Currently the licensing process for nuclear facilities in China does not cover cyber security for systems relevant to safety and security, though nuclear regulators are beginning to pay attention to these issues. It is not clear how nuclear cyber security will be addressed in new regulations.

Further, China still faces substantial challenges in its efforts to build a robust nuclear security culture.[23] Many Chinese experts continue to doubt that there is a credible threat to Chinese nuclear materials and facilities. China also faces the challenge of complacency among a significant number of senior officials within its nuclear industry. They believe that China already has strict nuclear security systems that have worked well and have been "accident free" over the past 50 years. Some managers doubt whether it is worth the money and time to establish and maintain a stronger security system. In some cases, the guards turned off detectors at portals for enrichment facilities to reduce their usage to avoid the need for frequent replacement.[24] In some cases, operators or relevant personnel who want to maintain a good record and avoid punishment downplay or conceal some faults.[25] Moreover, in large state owned enterprises in China, in particular in the nuclear industry which is developed from defense sector, it is traditionally not uncommon for decisions to be dominated by personal edict, rather than according to rules and regulations. Thus, everyone obeys the leader's orders and follows the leader's will (right or wrong).[26]This is a huge challenge to building a healthy security culture, which requires people not only to abide by the rules scrupulously, but also to have a skeptical and questioning attitude.

Reducing the risks

At the 2016 nuclear security summit, President Xi emphasized that, "the conclusion of the Nuclear Security Summit will not be the end of our endeavor, rather it will be the beginning of a new journey."[27] China should take further steps to strengthen its existing security systems for nuclear installations including spent fuel facilities.

Improving physical protection. China needs to review and update its basis used for designing physical protection for its spent fuel facilities to ensure that it reflects the evolving threats. China should use realistic "force-on-force" exercises to test its nuclear security systems' ability to detect and defeat intelligent adversaries trying to find ways to defeat the systems. Specifically, some measures should be taken, which would include hardening the pool floor and walls to prevent the breach by on-site explosion, weapon attacks or heavy load drop, and providing for emergency ventilation of spent fuel buildings or installing emergency water sprinkler systems to reduce the likelihood of fire in case of a loss of coolant. In addition, as much spent fuel as possible, especially spent fuel at dense packing pool, should be moved into the less vulnerable dry storage type of cask as soon as possible. Finally, it needs to deny access to these pools either by land or air to protect against sabotage, including re-examining the size of exclusion zones and adding effective physical barriers and delay mechanisms around nuclear facilities to prevent against truck bombs or suicide aircraft. All these facilities should be protected by well-trained, armed guard forces.

Reducing insider threat. China should take steps to decrease the vulnerability to well-trained insiders. In particular, in cooperation with relevant government departments, every operator must have an effective program for personnel reliability screening to strengthen access control. For example, security and other personnel with access to vital areas must be subject to periodic drug testing, background checks, and psychological or mental fitness tests, and they should be vetted at both specified and random intervals. The license conditions for facility operators should specify that personnel must report suspicious behavior to a clearly designated authority. Also, it should address that even trustworthy insiders could be blackmailed or coerced. Moreover, regulations should require constant surveillance of inner areas when they are occupied using either a two-person surveillance system or a technological surveillance system.

Promoting nuclear security culture. China needs to take further steps to combat complacency, including regularly reviewing nuclear security practice and systems; conducting self-assessments and drawing lessons from real incidents and security exercises. To build a robust nuclear security culture, each staff member should not only scrupulously abide by the existing nuclear security regime, but also maintain a questioning attitude and insist upon personal accountability. All staff should understand how their particular roles and equipment contribute to maintaining security. Moreover, the operator should conduct regular security exercises at its nuclear facilities, not only to improve the guards' and security personnel's professional skills, but also to inform them about the threats of nuclear and radiological terrorism, the reality that all security systems have vulnerabilities, and the importance and seriousness of nuclear security.

Improving nuclear cyber security. China should take further steps to address the growing threat of cyberattacks against nuclear facilities. For example, the requirements of cyber security protections should be incorporated in its new nuclear regulations and guidelines, and the nuclear licensing process. To ensure effective cyber protections, the regulators should also establish programs to test the system's performance, and enforce cyber security plans via regular inspections of cyber security programs.

Strengthening regional cooperation. China needs to continue and expand its international and regional cooperation on nuclear security. In particular, China, Japan, and South Korea should use their three nuclear security centers of excellence (CoEs) as a forum for best-practice exchanges, technical cooperation, research and development projects, and regional and global personnel training.

In October 2012, China, Japan, and South Korea agreed to set up a subgroup for their CoE coordination. Since then, cooperation has be underway, including training and information sharing about work plans , good practices exchanges, and expert exchanges. However, the three CoEs coordination and cooperation still needs to be strengthened. For example, greater coordination among three COEs for improving effectiveness includes optimizing each center's limited resources in a focused and targeted way, avoiding duplication and engaging in cooperative projects, and specializing areas on their respective strengths. Also, the three CEOs need better coordination and cooperation in human capacity-building assistance for other countries in the region.

The three CoEs should expand cooperation on information sharing without compromising sensitive information, including, training, development of standardized courses, exchanges of lectures and experts. Moreover, they can conduct jointly a range of research and development activities.

Also, the three CoEs should continue and expand best practice exchanges on a variety of front, including, how to decrease vulnerability to an insider threat, in particular at spent fuel facilities, and how to establish a robust DBT for spent fuel facilities, how to promote regional nuclear security culture, and how to enhance nuclear cyber security at nuclear facilities.

Moreover, China, South Korea, and Japan need to strengthen coordination and cooperation on emergency response and response preparedness in the event of an incident, theft, or sabotage. The contingency plans should also address a nuclear accident or incident in North Korea.

Finally, plutonium recycle is much more costly, much less safe and secure than LWR once-through cycle. There has no convincing rationale for commercial reprocessing activities or plutonium breeder reactors in the next couple of decades, the three states should rein in plans for commercial reprocessing. Dry cask storage offers a flexible, safe, and low-cost option that can postpone the need for either reprocessing or direct disposal for decades. It will offer important flexibility for any fuel cycle option chose. Also, China, South Korea, and Japan should discuss cooperation on long-term spent fuel storage issues, including building a regional center of spent fuel storage.

III. ENDNOTES

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IV. NAUTILUS INVITES YOUR RESPONSE

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