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Global Perspectives on Nuclear Safety and Security After 3-11

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Summary

The earthquake and tsunami of March 11, 2011 did more than just devastate Japan and unleash a local nuclear disaster. They exposed a host of design flaws in current nuclear technology whose solutions are linked to dramatically unsettling security issues.

The nuclear power industry spent decades distancing itself in the public mind from the dangers of radiation released by nuclear weapons. Having largely overcome that psychological obstacle in many countries, it first had to overcome the immense challenges to sustaining public trust posed first by the Three Mile Island reactor meltdown in March 1979 and then the catastrophic failure of the Chernobyl reactor complex in April 1986.

In the last decade, with a self-proclaimed mandate to produce "low-carbon electricity" in the face of global warming, the industry looked set for a renaissance, especially in Asia - the only growth market for nuclear power plants in the last two decades.

Then came 3-11. On March 11, 2011, at 14 minutes before 3 o'clock in the afternoon the massive Tohoku earthquake unleashed a tsunami that killed some 20,000 people and swept over the Fukushima reactor complex, inundating buildings with water that rose up to 15 meters above sea level. In seconds, decades of public relations work was demolished. The global future for nuclear power is now dim although not yet pitch black.

Fukushima once again demonstrated the inherent risks associated with existing reactor technology. In the process it fused the issues of nuclear safety and nuclear security, which the industry and pro-nuclear governments had striven for decades to separate. As Indian physicist M.V. Ramana wrote after 3-11, "Catastrophic nuclear accidents are inevitable, because designers and risk modelers cannot envision all possible ways in which complex systems can fail"- and in the case of nuclear power plants, like some other potentially very high impact technological failures-the consequences of nuclear power plant failure can be truly catastrophic." [1]In this regard, a great many post-3-11 issues and options are being considered at the interface of nuclear safety and nuclear security. They include:

- Major technological redesign and retrofit of existing reactors and those under construction.
- The complete phasing out of nuclear power in a number of countries, possibly including Japan, in which case its plutonium must be disposed of in a secure and safe manner.
- The recognition that spent fuel is vulnerable if co-located with reactors that may fail, but that relocating it may make it vulnerable to attack by terrorist groups or by states, thus implying the need for more rapid, secure, and safe pathways to ultimate disposal of spent fuel.
- Regional and multilateral response mechanisms to large-scale, catastrophic nuclear accidents involving the possible evacuation of millions of people.
- The direct impact on inter-Korean nuclear insecurity due to the North Korean small light-water reactor.

The tragedy is that 3-11 did not have to happen. Scientists, military agencies and civil society organizations all anticipated and warned of the events that occurred at Fukushima. [2] Powerful institutions ignore such early warning signals at their peril. Ultimately, the people who lived in the vicinity of Fukushima paid dearly for the errors of the nuclear industry and its political allies.

Satellite imagee of thFukushima Daiichi plant after March 11, 2011.

Modes of Failure

The common-mode failures that occurred at Fukushima due to the earthquake and tsunami included the loss of offsite electrical power to the reactor complex, the loss of oil tanks and replacement fuel for diesel generators, the flooding of the electrical switchyard and perhaps damage to the inlets that brought in cooling water from the ocean. As a result, even though there were multiple ways of removing heat from the core, all of them failed.

The course of events at Fukushima is not yet documented fully; and the event itself is not over - the reactors are not yet completely shut-down although the molten fuel is now at a manageable temperature - so long as cooling is maintained.[3]Site stabilization and recovery including dismantling the broken spent fuel ponds and reactor cores will likely take 10-30 years.[4]Moreover, due to the underlying crustal stresses and reverse fault-lines in the Fukushima area, further earthquakes and tsunamis remain possible, even likely, so anything is possible.[5]

Within weeks of 3-11, nuclear engineers and power industry experts drew a number of specific lessons from the errors at Fukushima. These are widely applicable to existing reactors as well as future designs. These errors include:

- Locating spent fuel ponds and reactors at a coastal site subject to massive tsunamis without sufficient defenses to avoid the plant being overwhelmed and destroyed;
- Placing the spent fuel ponds at the top of reactor containment buildings to minimize the core-pond transfer distance and handling costs, thereby making access to the ponds very difficult in a crisis involving radiological release from the reactor cores;
- Using active, powered cooling systems in spent fuel ponds that have common failure modes with the reactors, thereby leading to loss-of-coolant-induced melting of spent fuel in the ponds and reactors and the generation of hydrogen and subsequent explosions that devastated the Fukushima containment buildings;
- Cooling ponds and reactors using fire trucks and seawater in an ad hoc manner that ultimately exacerbated the cooling problem via salt deposits on fuel rods and salt build-up in the ponds and reactor cores;
- Packing increasing amounts of fuel onto racks in spent fuel ponds due to the "constipation" (lack of immediate capacity caused by technical and political delays) in the off-site spent fuel processing and waste storage and disposal systems - the resulting crowding and heat generation from tightly packed ponds making it even harder to cool the spent fuel rods;
- Using insufficiently strong structures and support for the spent fuel ponds themselves. As a result of insufficiently robust design, the spent fuel pools may have cracked due to earthquake and tsunami-related stresses, leading to leakage of radioactive water into the containment building.

However, the problems have much deeper institutional and cultural roots that cannot be overcome by mere technological fixes. Not only were TEPCO's early "accidents" largely ignored in terms of its corporate safety culture and that of the regulators in Japan, but the utility industry presumed-apparently correctly in the case of Fukushima-that the costs of failure would be largely socialized in the case of a disaster.

In effect, 3-11 also announced that the "light water reactor" era is over, buried by the tsunami and its aftermath. As Richard Lester, chairman of MIT's Nuclear Engineering Department stated, a new generation of reactor designs, created by a new generation of nuclear engineers, is required. According to Lester, the changes needed are not incremental, but fundamental, and involve innovations such as integrated reactor-direct disposal systems, entirely new materials, and the use of massive computational capacity, so that "nuclear power plants of the year 2100 will have about as much resemblance to today's workhorse light-water reactors as a modern automobile has to a 1911 Model T."[6] For this reason, the required capacity will not be available until 2100 because the time it will take to train new engineers, design new reactors, fully test and review them for safety, and begin to deploy them on a large commercial scale based on market and social acceptability is roughly two generations!

Political Fallout

In Germany, Switzerland, and Italy, the fallout was immediate, with political authorities quickly announcing the phasing out of nuclear power, by 2022 in the German case. In China, after a review of safety issues associated with 26 reactors under construction or planned, the government announced that it planned to proceed as planned.[7]However, when the Wangjiang district government in Anhui province challenged the construction of a plant on safety grounds[8]itsignaled that the path forward even in China may be rocky, especially as local communities learn more about reactor operations and risk.

In India, a full-blown social movement led by farmers opposing existing and future reactors has emerged as a new national political force leading the national government to respond in a heavy-handed manner. [9] While marketing reactors in the United Arab Emirates, South Korea's president proclaimed that his country's reactors were safe, implicitly comparing them to inferior "Made in Japan" models. He conveniently failed to mention that Korea's reactors are in a war zone and are likely targeted by North Korea.

Other countries also reviewed their plans. In 2010, Vietnam, for example, had already discovered that the coast on which its first reactor is to be sited, like Fukushima, has already experienced a 20-meter tsunami, originating in the Manila trench.[10]This possibility, now underscored by 3-11, far exceeds the design basis of the reactor. The Indonesian reactor project has gone into hiding, waiting for local community opposition to subside to plans to build a reactor on the Muria Peninsula in Central Java. The Philippines' lone plant, at Bataan on the slopes of the potentially active Mt. Natib volcano was never switched on since it was completed three decades ago at a cost of $2.3 billion. Instead of rehabilitation it is to become a tourist attraction.[11]

Meanwhile, in Japan itself, the nuclear industry is circling the wagons in an effort to protect its role in the electric utility oligopoly that favors nuclear power. Industry insiders observe that the industry is prepared to accept many fewer light water reactors provided it can protect a reprocessing plant and breeder reactor that is based on plutonium fuel bred from otherwise inert uranium 238 - always the long run vision of the nuclear industry. However, Japan appears to have cancelled plans to restart the Monju breeder reactor.[12]The country's richest businessman, Softbank founder Son Masayoshi, is leading an insurgency involving both the market and many municipalities who are calling for networked renewable energy and a smart grid. [13] In Japan, therefore, the nuclear industry may have dug itself such a deep hole that it will be unable to climb out.

If this dismal end comes to pass, then the future of Japan's enormous stockpile of separated plutonium - now about 80 metric tons - will have to be addressed. If this plutonium is not used in breeder reactors - as seems highly probable - or in mixed oxide fuel for light water reactors - which seems only slightly less improbable - then plutonium's only residual value in Japan would be for nuclear weapons or for export, presumably to a nuclear weapons state. Both options would be hugely divisive in Japan and the region. Thus, the Fukushima meltdown will continue to echo back and forth between the safety and security realms for decades.

Post 3-11 Vulnerability to Attack

One of the most important discoveries at Fukushima is how brittle the spent fuel ponds were when they were deprived of coolant, especially as a result of co-location with reactors. The spent fuel ponds contain enormous amounts of radioactive material whose release could lead to wholesale evacuations of cities and towns. Thus, Fukushima was a "wet run" at what could happen not only after a technological failure, but as a result of an attack on a nuclear facility by a state or non-state actor, or as a result of terrorist diversion of spent fuel and its subsequent use to threaten or attack concentrated populations or military targets.[14]

In such an attack, one might also expect - as occurred at Fukushima - a set of unpredictable consequences and linked effects. Military analysts have long recognized that reactors posed such a risk, especially in the case of war or terror attack, but did not address the same risk in relation to spent fuel ponds.[15]

In the United States, independent researchers have analyzed the risks posed by poorly protected and badly designed spent fuel ponds in reactor containment buildings, putting pressure on the Nuclear Regulatory Commission to respond - to date with limited but not insignificant results.[16]Experts have also evaluated the risks of non-state actors attacking spent fuel ponds and casks at reactor sites, and have quantitatively and qualitatively estimated the immense, catastrophic releases that could result.[17]In some cases, simple repositioning of casks could reduce the risk substantially. Some redesign of storage casks could also greatly reduce the risk that a successful non-state actor could breach such spent fuel containers.

Importantly, the MIT *Future of the Nuclear Fuel Cycle* study, which was updated in March 2011, strongly recommended that spent fuel be stored in a central repository, noting that "requirements for on-site spent fuel management may increase and design basis threats may be elevated" as a result of the Fukushima disaster.[18]Due to the expanded risk of radiological contamination from attacks on dry casks or spent fuel ponds located outside the reactor building but co-located with reactors, it appears necessary to consider separating dry cask storage, at least surface storage, from reactor buildings in order to ensure that failure in either reactor or storage technology, due to accident, malfunction or malevolence, does not lead to disablement of contamination of the adjacent facility.

Such spatial rearrangement of on-site spent fuel storage at various types of power reactors, and from reactors to centralized sites, entails incurring costs. In addition, it also could increase vulnerability to possible attack on such storage sites once the spent fuel ponds or spent fuel in dry cask storage are moved outside the reactor containment building (as is the case already with pressurized water reactors). Ironically, so long as the spent fuel ponds are inside the reactor containment building, they are somewhat secured from armed attacks by the building itself and facility security systems, although variousmodes of attack such as crashing aircraft into reactor buildings on the 9-11 model still pose a conceivable threat to these enclosed pools.[19]

Once spent fuel is removed from the reactor building, as seems necessary after Fukushima, various cost and design choices will need to be made with regard to storage and disposition. Each of these choices entails different levels of risk. One such choice pertains to the cost and longevity of spent fuel storage technologies. Options include deciding between pools and dry casks, and between dry casks suitable for high level waste almost straight out of the reactor versus dry casks used only after five or ten years of decay and cooling off, which are less expensive, but also more vulnerable to attack. Other choices include:

- The use of ancillary barriers to reduce the possibility of successful attack and/or diversion of dry casks in storage on reactor sites;
- The use of surface versus underground storage facilities at reactor sites to reduce the possibility and consequences of land or aerial attack on dry casks;
- The use of various combinations of dry cask storage on reactor sites versus rapid removal of spent fuel to a centralized repository, located either on the

surface or underground, that uses either pools or dry cask storage; and

- The selection of choices outlined above in relation to retrievable forms of storage for eventual spent fuel reprocessing versus those designed for medium or longer term irretrievable disposal, such as deep borehole disposal.

Some of these steps could also move towards resolving the as-yet unsolved problem of what to do with nuclear wastes in the long-term (for example, deep borehole disposal would make these materials invulnerable to attack and isolate them forever from the biosphere). These and other design considerations affect the possibility that a devastating radiological attack by a state or a non-state actor could occur by exploiting the measures taken, post-3-11, to reduce the reciprocal risk of reactors and spent fuel storage systems, as well as the radiological outcome of a successful attack. The steps taken to reduce this reciprocal risk may also affect the probability of successful diversion of spent fuel for use in a dirty bomb or an actual nuclear weapon at another location. Evaluation of alternative disposition of spent fuel must also take the risk of diversion into account.

This post-3-11 safety-security linkage is a challenge for pro-nuclear states such as South Korea and China, whether or not they have nuclear weapons-the only difference in the case of nuclear weapons states being that they have more material to secure and to keep safe than those who only run a nuclear fuel cycle for nuclear power. They will have to address the issue of spent fuel disposition and disposal in a safe and secure manner while recognizing that the issue applies to existing reactors and will likely require retrofit to separate spent fuel ponds from reactor containment buildings.

Regional Safety-Security Linkages

The agenda for the Seoul Nuclear Security Summit of March 26-27, 2012 was set well before 3-11 occurred. Its focus on nuclear facilities and materials security derived from the first summit in Washington in 2010. However, as host, South Korea has pushed hard for the inclusion of the security-safety nexus at the summit. [20] At the very least, it is likely that a regional information sharing and early warning system will be established in East Asia involving China, South Korea, Japan and possibly Russia (the inclusion of Taiwan is unclear). This information strategy was proposed after Fukushima in part due to the failure of the Japanese government to share what it knewabout rapidly evolving events at the reactor site with neighboring states, leaving them to figure out for themselves the implications of radioactive plumes and possible exposure due to regional wind patterns, just as some Japanese fleeting from Fukushima's radiation moved into even more radioactive areas at the urging of the government and TEPCO. Whether regional coordination will go beyond annual meetings of senior officials and the signing of some agreements to address more profound issues of multilateral and regional response is unknown.

In this regard, one of 3-11's implications for regional insecurity includes large-scale humanitarian response and evacuation. Indeed, it emerged nearly a year after Fukushima that the Japanese government had been advised that it might have to evacuate the entire Tokyo urban region - some 35 million people.[21]A reactor accident in China or South Korea could have similar massive consequences, with enormous logistical demands involving millions of people. Even raising this scenario for discussion in China or South Korea seems politically impossible, in spite of the obvious lessons from Fukushima. Yet it seems inevitable based on actual operating experience. Based on the history of nuclear power, we find that for every 1,500 reactor-operating years, at least one such an accident will occur - and this figure could prove conservative as more countries with immature institutional and technological infrastructure promote massive and rapidly growing nuclear programs - that is, above all, China.[22]

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•Koide Hiroaki (interview), Japan's Nightmare Fight Against Radiation in the Wake of the 3.11 Meltdown

•Gayle Greene, Science with a Skew: The Nuclear Power Industry After Chernobyl and Fukushima

Notes

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[2] For scientists, see: K. Krolicki, S. DiSavino, T. Fuse, Special Report: Japan engineers knew tsunami could overrun plant, March 29, 2011, here.

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For civil society, see the "Jaws" scenario in Nautilus Institute, *Global Scenarios 2010 Will East Asia Mega-cities be Secure and Sustainable by 2050*? November 16, 2010, here.

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