



Nuclear Safety and Security After 3-11

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By Peter Hayes

March 22, 2012

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I. Introduction

The earthquake and tsunami of March 11, 2011 did more than just devastate Japan and unleash a local nuclear disaster. Peter Hayes notes that the events at the Fukushima nuclear plant exposed a host of design flaws in current nuclear technology whose solutions are linked to dramatically unsettling security issues.

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II. Report by Peter Hayes

-“Nuclear Safety and Security After 3-11”

by Peter Hayes

The nuclear power industry spent decades separating itself in the public mind from the dangers of radiation released by nuclear war or weapons testing. Having achieved that goal in many countries, it then 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-declared 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 killed thousands of people, and unleashed a tsunami that swept over the Fukushima reactor complex a little over an hour later, 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.” [\[1\]](#) In this regard, there are a great many post-3-11 linkages between nuclear safety and nuclear security, which are not yet fully recognized. They include:

- Major technological redesign and retrofit of existing reactors and those under construction.
- The phasing out of nuclear power altogether 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 terrorists 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 prefigured the events that occurred at Fukushima. Powerful institutions ignore such early warning signals at their own risk. Ultimately, the people who lived in the vicinity of Fukushima paid dearly for the errors of the nuclear industry and its political allies. Safe nuclear

power is possible and desirable. It just isn't available yet at an affordable price. Millions of people have concluded that there must be easier, safer ways to make electric power as a result of 3-11. They may be right.

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. [2] Site stabilization and recovery including dismantling the broken spent fuel ponds and reactor cores will likely take 10-30 years. [3] 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. [4]

Within weeks of 3-11, nuclear engineers and power industry experts drew a number of specific lessons learned 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 cost, 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 in Japan - 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 more technological fixes. In effect, 3-11 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. But, says Lester, this capacity will not be available until 2100! [5]

Political Fallout

In Germany and Italy, the fallout was immediate, with political authorities quickly announcing the phasing out of nuclear power. In China, after a review of safety issues associated with the scores of reactors under construction or planned, the government announced that it planned to proceed. [6] However, when the Wangjiang district government in Anhui province challenged the construction of a plant on safety grounds [7] it signaled 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 opposed existing and future reactors and emerged as a new national political force. While marketing reactors in the United Arab Emirates, South Korea's president announced that his country's reactors were safe, implicitly comparing them to inferior Made in Japan models. He noted that Korea is not historically afflicted by tsunamis like Japan and 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. [8] This possibility, now underscored by 3-11, far exceeds the design basis of the reactor. The Indonesian reactor project went into hiding, waiting for local 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 never switched on since it was completed three decades ago at a cost of \$2.3 billion, is not to be rehabilitated. Instead it will become a tourist attraction. [9]

Meanwhile, in Japan itself, the nuclear industry is circling its wagons to protect its role in the electric utility oligopoly that favors nuclear power. Informed 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. [10] The country's richest businessman, Softbank founder Son Masayoshi, is leading an insurgency involving both the market and municipalities who are calling for networked renewable energy and a smart grid. In Japan, therefore, the nuclear industry may have dug itself such a deep hole that it can never 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 gigantic amounts of radioactive material, the release of which 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. [11]

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. [12]

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 significant success. [13] 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 truly immense, catastrophic possible releases that could result. [14] 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. [15] 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 now consider separating dry cask storage, at least surface storage, from reactor sites in order to ensure that failure in either reactor or storage technology, due to accident, malfunction or malevolence, does not lead to 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, but also could increase vulnerability to possible attack on such storage. 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 various modes of non-state attack such as crashing aircraft into reactor buildings on the 9-11 model still pose a conceivable threat to these enclosed pools. [16]

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.

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. 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 was set well before 3-11 occurred, with a 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. 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 knew about 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. Whether regional coordination will go beyond annual meetings of senior officials and the signing of some agreements to 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 had to evacuate the entire Tokyo urban region - some 35 million people. [17] A reactor accident in China or South Korea could have similar massive consequences, with enormous logistical demands. Even raising this scenario 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; for every 1,500 reactor operating years, at least one such an accident will occur - and possibly far more often in countries with immature institutional and technological infrastructure to support massive and rapidly growing nuclear programs - that is, in China. [18]

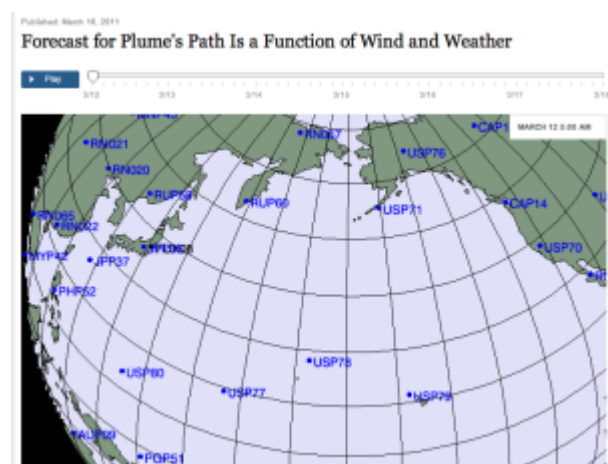


Image Source: Comprehensive Nuclear Test Ban Treaty

Organization, at:

<http://www.nytimes.com/interactive/2011/03/16/science/plume-graphic.html?ref=science>

Implications for Korea

3-11 also exposed the direct linkage between nuclear security and safety represented by North Korea's crash construction of a small light water reactor at Yongbyon. This reactor is intended to be about 10 percent of the size of one of the five reactors at Fukushima. The North Korean reactor will be directly upwind from Pyongyang and Seoul much of the year. It also presents a very real possibility of a loss-of-control and meltdown given its primitive technology and materials, not to mention an unreliable grid, which is one of the identified pathways to causing a crash shutdown of a light water reactor leading to the risk of a meltdown.

In light of 3-11, Seoul must make a fundamental choice in relation to North Korea's fuel cycle activities. It could engage the North to ensure that the small light water reactor project becomes an authentically inter-Korean project, and is implemented to international standards for design, engineering and construction - which is hard to visualize given the political and military standoff today. Obviously, this could not be done in isolation from resolving the nuclear weapons issue and a radical shift in both South Korean and American policy towards the North.

Alternately, it could treat the North's reactor as a rapidly emerging environmental-security threat to South Korea, and decide whether it will act militarily to halt the reactor's operation once it is turned on. (This could be as simple as cutting the power lines, provided this is done early enough to ensure that there is almost no radioactive waste fission products in the reactor core that could vent to the atmosphere in case of a catastrophic cooling failure and meltdown). Military intervention runs the risk of war, of course, and is as difficult to visualize as engaging North Korea.

A major reactor accident in the North would almost certainly exceed the North's capacity to respond to the physical and logistical demands of site stabilization and recovery operations, let alone the evacuation of large populations, possibly permanently. Paradoxically, such an accident might lead to a humanitarian operation involving external forces, possibly orchestrated by China or Russia, and even involving South Korean experts, equipment and material.

POSSIBLE SIDEBARS

Fukushima Premonitions

In 2007, the US Department of Defense in collaboration with the Korean Institute of Defense Analysis and Japan's National Institute of Defense Studies constructed a scenario called "Chains of Disasters." According to the IDA summary, this scenario aimed to develop responses to a "chain of regional crises for which they must analyze various possible measures to enhance tripartite collaboration in dealing with disaster, particularly centered on the military's role and capabilities in support of overall national objectives."

Here is the DOD scenario (no year is specified):

Chain of Disasters

January 24, 04:57 A major earthquake (8.7 on the Richter scale) strikes southwest of Hokkaido. Initial estimates report massive damages and numerous deaths. First reports state that the earthquake struck 3 km from the shoreline creating a tsunami of 2 to 8 meters causing further carnage along the entire southeast coastline and particularly in port cities. Communications and assistance to the affected areas are being hampered by the poor conditions of infrastructure resulting from the long cold spell. The picture at the moment is bleak, and information sparse.

METI's nuclear industrial safety agency sends a note to emergency coordinators that potential

damages to the Tomari I & II power reactors at the moment are uncertain. Communication difficulties at the site have temporarily interrupted efforts to gain a first-hand report. The 1993 7.8-scale earthquake created relatively few problems for the Tomari I & II plants 95 km from the epicenter. Preliminary indicators show the epicenter to be only 20 miles from these plants in this latest quake. There is some uncertainty over the potential impact of this much greater-scale earthquake, but follow-up studies indicate that there might be more difficulties.

Source: Scenario 140, in Open-Scenario-Repository-06-25-2010-4.xlsx downloadable at Institute for Defense Analyses, Open Scenarios Repository, at <http://openscenarios.ida.org/>

Note how this contrasts with a scenario constructed three years later in 2010 by the Nautilus Institute and civil society organizations at a workshop in Seoul. In this scenario, set in 2050, an earthquake-tsunami devastates Japan's coastal regions, induces meltdown and huge social and environmental catastrophe, but also elicits a massive regional response combined with a shift to non-nuclear power, especially renewables.

In the real world after 3-11, the Korean military was not called upon to respond alongside the US and Japanese military. In actuality, much of the humanitarian and physical cleanup has been left to civil society due to the inability of the Japanese government and the failure of the nuclear-corporate sector to respond.

The Nautilus scenario:

JAWS: a world which in 2050 is characterized by a struggling green economy and regional stability and cooperation.

- Between 2010 and 2030 nuclear energy grows at a rapid rate and by 2030 it supplies 65 percent of energy in the region in the name of green growth. Unfortunately, the decrease in climate disrupting emissions is too late to protect the region from 47cm of sea level rise.
- In 2020, the Olympics are held in North Korea and while reunification does not happen in this scenario, this international validation and recognition of North Korea fosters economic cooperation between the two Koreas and results in increasing stability for the entire region.
- In 2040, a massive earthquake triggers a tsunami which is exacerbated by the increased weight of the sea wreaking havoc upon disaster as the region's nuclear plants located on coastal shores are destroyed. These seemingly innocuous nuclear plants on the East Asia seaboard are the "Jaws," the invisible sharks beneath the surface which once awakened by the earthquake destroy that most basic infrastructure system, energy. In addition to the meltdown of the nuclear power plants, the mega-cities themselves suffer extreme damage: levees break, communities are under water: flooding, homelessness, disease and suffering abound.
- The region is saved from despair by the foundation of good-will built up over the preceding three decades which triggers international aid but it is clear that what is rebuilt will not look like what was destroyed. Individual communities feel that their governments failed them by relying so heavily on nuclear power and begin to shift focus towards more local governance and decentralized political systems. More threatening, however, is the shift away from nuclear and back to fossil fuel and climate changing energy technologies.

Source: Nautilus Institute, Global Scenarios 2010 Will East Asia Mega-cities be Secure and Sustainable by 2050? November 16, 2010.

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V. Nautilus invites your responses

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