NUCLEAR POLICY

The Overlooked Back End of the Nuclear Fuel Cycle

The recent accident at the Fukushima nuclear power plant reinforces the need for renewed thinking about nuclear-waste storage and disposal.

Allison M. Macfarlane

On 11 March 2011, a magnitude 9.0 earthquake and associated tsunami knocked out all power systems at the Fukushima Dai'ichi nuclear power plant in Japan. Light-water reactors, the predominant type in Japan, the United States, France, and a number of other countries, use water to cool both the reactor core and the spent fuel pools; if active cooling is lost, the irradiated fuel heats the water beyond the boiling point. The Three Mile Island and Chernobyl accidents provided firsthand experience of what the loss of coolant can do to the core of a reactor. In addition to core damage, the Fukushima accident has brought into focus the dangers posed by spent fuel pools and has underscored the need to have a well-managed, working back end to the nuclear fuel cycle.

The spent fuel pool of reactor unit 4 of Tokyo Electric Power Co.'s (TEPCO's) Fukushima Dai'ichi nuclear power station in Fukushima prefecture is seen in this still image taken from video on 8 May 2011 and released 8 May 2011. The 11 March earthquake and tsunami damaged the nuclear plant in northern Japan, sparking the worst nuclear crisis since Chernobyl in 1986.

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The U.S. nuclear power industry suffers a number of the vulnerabilities exposed by the Japanese crisis. Spent fuel pools at power reactors are full and densely packed, and plans for the long-term management and disposal of such fuel are on hold. Planning for the management of spent nuclear fuel has, over time, consistently received less attention and fewer resources than it should have. Nuclear-waste disposal is controversial, both technically and politically; as a result, policies to resolve the debate suffer delays.

Although there are a number of lessons to be learned from the Fukushima accident, much still remains unknown. What is known is that the site hosted seven spent fuel pools, one at each reactor and a large central one in addition to a modest amount of dry cask storage. The pools of the GE Mark I reactors (units 1 to 5) are located five stories above ground (*1*). The pools all had high-density racks, open only at the top and bottom, but were not fully loaded like those at U.S. reactors. Water samples from spent fuel pools at units 2 and 3 suggest that the fuel in these pools was damaged, perhaps by falling debris in the case of unit 3 (*2*, *3*). The pool at unit 4 appears to be damaged by the earthquake (see the figure), and the reactor operators are planning to shore it up (*4*). In contrast, the dry casks apparently suffered little damage (*5*).

The first lesson of Fukushima is that interim storage of spent fuel, before reprocessing or disposal, needs to be rethought. First, the location of spent fuel pools at reactors requires examination: Locating pools above ground, just below the roof—when, in the case of an explosion, the pool can be exposed to the elements, be damaged from falling equipment, and lose cooling water from lack of structural integrity—should now be reconsidered, as should the existence of pools outside of hardened containment buildings. Pools at all U.S. reactors lie outside the hardened containment. The U.S. Nuclear Regulatory Commission maintains that pools located above ground level are safe (*1*).

Furthermore, densely packed spent fuel in pools poses a radiation-release risk. In the United States, spent fuel pool racks have been redesigned to hold up to four times the originally intended amount. Coolant loss, from natural causes or sabotage, could result in high releases of radionuclides (*6*, *7*). A 2003 report (*6*) suggested that a straightforward solution would be to move the older spent fuel into dry storage casks, which are passively safe, and revert to low-density, open-cage racks in the pools. The U.S. Nuclear Regulatory Commission disagreed and maintains that current safety systems are adequate (*1*).

Is it adequate policy to allow spent fuel pools to fill to maximum high-density capacity and then move older fuel into on-site dry storage, as is done in the United States? Would it be better to adopt Sweden's admittedly more costly approach of moving more recently discharged spent fuel to a centralized, underground spent fuel pool, instead, and thus avoid filling the reactor pools with hot spent fuel? Is off-site dry storage better? Fukushima has made it clear that interim storage is an integral part of nuclear-energy production and needs careful planning and well-executed policy.

The second lesson of Fukushima is that a long-term plan for the disposal of nuclear waste is required for any nuclear power program. Japan's long-term management strategy for spent fuel includes reprocessing it to extract plutonium (and maybe uranium) for reuse in new fuel and disposal of the subsequent high-level waste in a mined geologic repository in a yet-to-be-identified location (*8*). Reprocessing should, theoretically, allow spent fuel to be moved off reactor sites, but Japan's recently constructed reprocessing facility at Rokkasho, expected to start up in 2007, is not yet operating because of technical difficulties. Because

Department of Environmental Science and Policy, George Mason University, Fairfax, VA 22030, USA. E-mail: amacfarl@gmu.edu. The author is a member of the Blue Ribbon Commission for America's Nuclear Future, U.S. Department of Energy.

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Japan did not have an interim storage policy for spent fuel, responses to excess spent fuel at reactor sites have been ad hoc, and as a result, spent fuel has built up at reactors in Japan.

The spent fuel situation in the United States is similar, although U.S. policy has been to send spent fuel directly to a geologic repository and forgo reprocessing for economic and nonproliferation reasons. The United States had been working toward developing a geologic repository at Yucca Mountain, Nevada, but the Obama Administration pulled the license application in 2010, citing a lack of public acceptance and the political stalemate that surrounded the site (*9*). A Blue Ribbon Commission for America's Nuclear Future was established to rethink policy for the back end of the nuclear fuel cycle.

Although some may view the current "rethink" of nuclear-waste policy as a loss of momentum and a step away from a solution, the experience of other countries suggests the contrary. Sweden, probably the country with the most success, went through at least three iterations of nuclear-waste policy before finding a technically and politically acceptable site for their repository. The solution was to approach communities with reasonable geology that already hosted nuclear facilities (*10*). This third iteration produced two communities that actually competed for the repository.

SKB, the Swedish company managing the repository program, has submitted a license application to the Swedish Radiation Safety Authority and the Environmental Court in Stockholm. If the license is approved by the cabinet, the repository should open by 2023. Finland, France, Canada, Germany, Switzerland, and the United Kingdom have also gone through multiple iterations of developing high-level waste–siting policy.

The experience of all these countries has been to move away from a purely technical assessment of reasonable repository sites and toward one that balances technical assessments with public acceptance, by acknowledging the reality that, in a democracy, finding an acceptable site will only be successful with the consent of the affected public. Indeed, the United States has its own example of a successful geologic repository. The Waste Isolation Pilot Plant in Carlsbad, New Mexico, a repository for transuranic waste from the U.S. nuclear weapons complex, is supported by the local community and the state. It was not always this way; the state did oppose the plant for a number of years, but was given oversight of environmental impacts, which eased some of its concerns (*11*).

There is general international agreement that high-level nuclear waste, whether the remains of reprocessing or spent fuel itself, will require a geologic repository for final disposal. To establish that repository, a number of features are necessary (*12*). These include an institution to determine the location of a repository site and repository operations. This entity can be a private, industry-backed corporation; a governmental agency; or a hybrid. A secure and constant source of funding is required to implement the siting and eventual construction and operation of the facility. The siting process must be clearly established and should include consideration of how and when to involve the affected public and how to compensate them, as well as how and when to incorporate technical analysis and evaluation methodologies.

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Moreover, a successful siting strategy is an adaptive, staged process, in which most management decisions are not made at the outset but along the way (*13*). This process is being used in Canada to forge a consensus and began with a survey of the public's attitudes to repositories in general. Many aspects of Canada's siting process, such as the technical criteria to be used in siting decisions and the amount and form of compensation offered to communities, have yet to be determined.

The third lesson of Fukushima is that there are limits to the information that Earth scientists can provide to policy-makers, in terms of the magnitude of future events to be expected, associated damage (such as the liquefaction in the soil), and, especially, the timing of future quakes. Plate tectonics, the study of how the lithospheric plates of the Earth evolve, is a relatively young science. Although Earth scientists are well aware that Japan sits in a tectonically active region, they are far from understanding all the tectonic processes that occur over time, including those that generate large earthquakes and tsunamis (*14*). These uncertainties must be taken into account by decision-makers. There needs to be accurate and honest accounting of what is known and not known—whether related to the safety of a nuclear power plant or a given repository site.

The Fukushima accident has served to remind us that nuclear power cannot operate without a clear management and disposal strategy for back-end wastes. For too long, countries with nuclear power programs have left back-end decisions to the last minute. Countries that are considering acquiring nuclear power programs should take heed: Do not start to build a reactor without a clear plan for nuclear-waste management, including plans for a geologic repository; otherwise, there may be a high price to pay in the future.

References and Notes

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