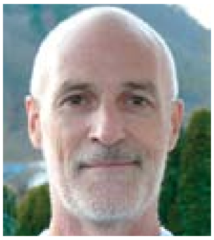
FUKUSHIMA DAIICHI: LESSONS LEARNED

NOTE FROM THE EDITORS: SIX PROMINENT SCHOLARS, POLITICIANS, AND POLICY MAKERS WERE ASKED THE QUESTION "WHAT HAS BEEN LEARNED FROM THE FUKISHIMA DAIICHI EVENT AND HOW WILL THIS IMPACT THE FUTURE OF NUCLEAR POWER?"

THE IMPORTANCE OF CLEAR COMMUNICATION

Ian G. McKinley[1]



The damage to the Fukushima reactors provided frightening images that shook confidence in nuclear power around the world. It is easy to forget that, as yet, there is no indication of radiological harm to the general public. Confusing and incorrect comparisons with the completely different situation in Chernobyl highlight a major lesson to be learned from this incident: the importance of clear communication.

Communication failed at every level. Known tsunami risks were not communicated to those charged with assessing natural hazards to nuclear facilities. The developing situation in the damaged units after the tsunami was poorly communicated to both the government and the general public, delaying decisions that could have limited the consequences and helped avoid unnecessary panic. Tools that could have been used to help plan the response to releases of radioactivity were introduced too late, and their output was presented in a way that only increased confusion and public concern. It should be emphasized that this was not simply a result of the chaos immediately after a major disaster nor was it limited to Japan—9 months after the Fukushima event, newspaper, TV, and Internet articles continued to sow confusion around the world.

At the Daiichi site, contamination levels are high and remediation will be a major challenge. Although hotspots and increased radiation levels exist off-site, health hazards from the radiocesium isotopes that now dominate activity levels are very small. Nevertheless, demonstration cleanup projects have been initiated and regional remediation will follow. A rich country like Japan can justify such actions, even if the health benefit is marginal compared to the effort invested. Such an objective perspective on the risks involved should, however, be clearly explained in order to reassure local residents and involve them in decisions about the actions that need to be taken.

Poor communication has also meant that, so far, potential options for optimizing the remediation work are being missed. Major efforts are being invested to manage lightly contaminated soil; however, this soil could be better utilized as ground cover on the more highly contaminated reactor site, providing radiation shielding and reducing doses to workers.

The communication problem extends to wider, international issues resulting from this incident. In several cases, knee-jerk reactions from poorly informed politicians have resulted in moves away from nuclear power, without any balanced consideration of the potentially larger environmental and public health hazards of the fossil fuel alternatives that would be introduced in its place. More seriously, the fact that two recent devastating tsunamis have resulted from megathrust earthquakes has focused risk assessment on this particular hazard combination—without considering that the historical record shows much larger tsunamis from other sources, such as volcanoes and landslides. Indeed, much of the infrastructure that supports our high population densities is located in areas where a natural catastrophe in coming decades is not just possible, it is inevitable. As was the case before Fukushima, the technology exists to assess such hazards and, to a certain degree, minimize consequences or prepare responses. Unless the existence and usefulness of such technology is effectively communicated to decision makers, however, these lessons will have to be relearned after the next natural catastrophe.

FURTHER BACKGROUND INFORMATION

The Fukushima Daiichi incident in context:

McKinley IG, Grogan HA, McKinley LE (2011) Fukushima: Overview of relevant international experience. Journal of Nuclear Fuel Cycle and Environment 18: 89-99

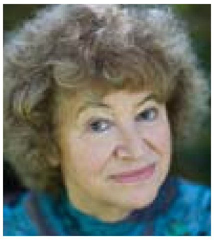
Tsunami risk overview:

McKinley IG, Alexander WR, Kawamura H (2011) Assessing and managing tsunami risks. Nuclear Engineering International 56 (687): 14-17

1 Ian G. McKinley (ian.mckinley@mcm-international.ch) is a technical consultant at MCM, Baden, Switzerland, and, since December 2011, a visiting professor at Okayama University, Japan. He was initially involved in the synthesis of relevant international experience to help plan on-site and off-site remediation. Currently he is supporting assessment of the first demonstration remediation projects and planning subsequent regional cleanup actions.

IMPROVING INTERNATIONAL COOPERATION

Catherine Cesarsky[2]



The Fukushima Daiichi accident undoubtedly has shaken the world of nuclear power in a very serious way and will leave indelible marks. Even after the release of the preliminary report by the Japanese investigation committee chaired by Yotaro Hatamura, not everything is known of the sequence of events and of their final consequence.

Main Lessons for Present Reactors

A first lesson from Fukushima is that very unlikely events may combine with each other in unanticipated ways, so the concept of "emergency preparedness" will have to be revisited. The main cause of the Fukushima accident was the tsunami, which resulted in the loss of the cooling capabilities and the internal electrical supply, including some of the emergency batteries. The design of the plant was highly resistant to earthquakes but had a limited protection against floods. Thus, in addition to a well-defined design basis, a nuclear plant must have some potential to resist external hazards that are "beyond design." Most operating light water reactors already have dedicated systems to cope with severe-accident conditions. For example, in France, passive hydrogen recombiners to protect against hydrogen accumulation were installed years ago. France will also be putting in place a rapid intervention force with off-site power supplies and cooling capabilities. Also, it has been proposed to identify an ultimate set of systems ("hard core") and to have them available in bunkers at the site in case of extreme conditions.

At Fukushima, for a few days after the tsunami and under very difficult conditions, the decay heat removal was maintained using on-site water reservoirs and pumping systems requiring no AC electrical supply. Thus a large early release of radioactive material was avoided,

2 Catherine Cesarsky is the High Commissioner for Atomic Energy in France and advisor to the French government on science and energy issues. She holds a physics degree from the University of Buenos Aires and a PhD in astronomy from Harvard University (1971). She is a member of the French Académie des Sciences and a foreign member of the National Academy of Sciences (USA), the Royal Society (UK), and the Swedish Academy of Sciences. She was visiting the Rokkasho nuclear reprocessing plant in Japan on March 11, when the earthquake and tsunami struck Japan.

and the Japanese government was able to evacuate people in time. The Hatamura committee argues that these systems could have been operated in a better way. The necessity for superior preparation and training of the plant staff is therefore another key lesson.

In terms of accident progression, a significant part of the radioactive inventory has been retained in the reactor containers, and it appears that the three coriums are trapped in the concrete basements of the reactors. For present reactors, in-depth studies of the physics and chemistry of severe accidents will have to be carried out. This knowledge is essential for defining management procedures and for developing severe-accident simulators devoted to operator training. Resistant instrumentation will also be required for ascertaining, as far as possible, the plant condition during an accident.

Future of Nuclear Power

For most countries involved, nuclear energy will likely remain an essential component of the low-carbon energy mix. The Fukushima accident has demonstrated the appropriateness of the safety objectives assigned to the new generation of reactors (generation III), which feature additional systems dedicated to severe-accident mitigation (e.g. corium retention, hydrogen explosions).

After more than thirty years of cooperation following the Three Mile Island (USA) accident, Fukushima also raises doubts about the efficiency of international cooperation. After Fukushima, improvements should be actively sought in:

- Speeding up current initiatives for harmonizing safety requirements, crucial to assessing the full compliance of commercial projects to internationally agreed-upon safety criteria for generation III reactors
- Progressing towards better harmonized safety regulations and sharing of best practices
- Developing international training
- Enhancing international cooperation in regulatory research, safety, and radiation protection
- Generalizing periodic nuclear power plant "stress tests" followed by peer reviews (as done in the European Union)
- Studying concrete measures to provide mutual assistance to operators in case of severe accidents, an issue especially important for small- and medium-sized electric utilities

After Fukushima, nuclear energy will have to regain public and political acceptance. A rational and consensual determination of all the consequences of the Fukushima accident and a "dynamic safety" approach with full use of lessons learned from the accident and stress tests will contribute to this challenging objective.

A JAPANESE PERSPECTIVE

Atsuyuki Suzuki[3]

The massive earthquake and immense tsunami on March 11, 2011, raise a fundamental question: Are human beings capable of managing unprecedented natural disasters? The question is also begged by the great 1755 Lisbon earthquake, which profoundly shocked Europeans. This event compelled a number of philosophers, including Immanuel Kant, to alter their thoughts drastically. As far as the Fukushima nuclear accident is concerned, my answer is "yes." My optimism is based on the performance of the nuclear power plants located in the coastal areas of northeastern Japan, where no serious consequences were experienced, even though these areas were subjected to a nearly equal-magnitude tsunami.

As an example, consider reactors #5 and #6 at Fukushima Daiichi. One of the three emergency diesel generators installed at Unit 6 remained available, and operators were able to successfully connect it to both units and provide sufficient power for accident management at these units. This surviving generator was air-cooled, not water-cooled, and it was installed at an elevation high enough to avoid the tsunami. This is an example of a defense-in-depth safety concept, where a diversity of designs offers the greatest resilience to an extraordinarily unlikely event.

In addition to diversity in design, we have learned the usefulness of prudent conservatism when considering natural phenomena that are conceivably always associated with the unknown. One of the issues that Japan's nuclear industry missed was to take into account the historical tsunami records in the analysis of reactor safety. The scientific knowledge obtained in recent years had indicated that a tsunami of a magnitude similar to that of the March 2011 event occurred in 869 AD in these areas; this fact was not known in the late 1960s and early 1970s, when the construction permits were granted. Unfortunately, no action was taken to reflect the new knowledge in order to enhance reactor safety. Thus, an overridingly important point raised by the accident is that new scientific findings should be adopted promptly and properly in order to improve nuclear safety. This is particularly true if the new information is related to extreme natural events that are difficult to predict.

After the accident, nuclear policy in Japan was placed under review. Priority was given to the environmental remediation of contaminated off-site areas and to implementing the dismantlement of the damaged reactors. These tasks will require patience, as well as substantial expenditures. The future of the nuclear power industry in Japan rests heavily on the successful achievement of off-site environmental remediation and the removal of nuclear material from the damaged reactors.

In the aftermath of the accident, however, there are countries that have not changed their policy, but continue to pursue their plans for reactor construction, and the Japanese government has expressed its readiness to be actively committed to the international nuclear business. Worldwide, energy security is critical. The political situation in the Middle East, for instance, underscores the inherently fragile nature of the international oil market, which can potentially affect the world economy. Naturally, the future of global nuclear power depends on such international energy circumstances, and my perception is that the global impacts of the accident will gradually disappear, as more realistic assessments are made.

3 Atsuyuki Suzuki is the president of the Japan Atomic Energy Agency (JAEA) and a professor emeritus of nuclear engineering at the University of Tokyo. Currently he leads the special task force at JAEA specifically dedicated to the partnership programs dealing with Fukushima matters, including environmental remediation of off-site areas as well as postaccident management of the nuclear power plants and environmental restoration of on-site areas.

ENVIRONMENTAL REMEDIATION, WASTE MANAGEMENT, AND THE BACK END OF THE NUCLEAR FUEL CYCLE

Joonhong Ahn[4]

The Japanese government has promised to make every effort to limit the dose rate in air in areas contaminated by the Fukushima accident to below 1 millisievert (mSv) per year (typical background exposures in Japan are 1 mSv per year). It has been estimated that decontaminating the highly contaminated areas (i.e. >1 megabecquerel/m^2 will generate an estimated 24 million m^3 of contaminated material. The estimated cost of disposal of the wastes from highly contaminated areas is a few trillion yen (one trillion yen ≈ 8 billion US dollars). If areas with lower contamination by radioactivity are also included in the cleanup, the total volume of waste material and the associated cost will be much greater; however, the health risks in areas of low contamination have been judged to be insignificant. Thus, considering the potential scale of the cleanup effort, the question "how clean is clean enough?" has emerged as a much-debated issue involving the convergence of technical, political, and societal concerns.

Over the past decade, the Nuclear Waste Management Organization (NUMO) of Japan has been responsible for the process of public participation in the siting of a geological repository for high-level and long-lived radioactive wastes. However, no municipality has yet to volunteer to host such a site on its territory. Now, a siting process that was deadlocked before the accident has become even more difficult. The realization of the amount of material that will result from decontamination related to the Fukushima accident and the necessity of moving forward with a solution have delayed the siting process for a repository for high-level radioactive waste. On the other hand, this delay may be a valuable opportunity for developing trust and new approaches for decision making that could lead to a break in the deadlock over selecting a site for a geologic repository.

Public discussion has also extended to a reconsideration of Japan's nuclear fuel cycle policy, particularly at the back end, that is, interim storage, reprocessing of spent nuclear fuel, and final geological disposal. Japan is the only non–nuclear weapons country with an industrial-scale capability for uranium enrichment and spent fuel reprocessing that has been approved by the international community. The motivation for developing a full-fledged, complete fuel cycle capability has been a national policy of energy security and independence. Plutonium generated in light water reactors and future fast breeder reactors has been considered to be a semi-indigenous resource. Because of the sodium leak in the Monju fast breeder reactor in 1995 and the technical difficulties with the vitrification process at the Rokkasho reprocessing plant, there was already growing public skepticism about the current nuclear fuel cycle strategy.

Due to the events at Fukushima, public agreement and perceptions concerning the development of nuclear power in Japan have changed significantly, and there is much discussion about whether the current nuclear fuel cycle policy should be revised. In any conceivable future scenario, including phasing-out nuclear power or abandoning the recycling of plutonium, the transition will require at least a generation. To successfully manage this transition period, interim storage of spent fuel will be essential. The protection of long-term storage facilities from natural disasters and terrorism will be a crucial technical and societal issue. The fate of accumulated plutonium should also be clearly accounted for, especially in the phase-out scenarios. New fuel cycle policies should be established from the viewpoint of making spent fuel more robust against accidents and disasters and reducing the risk of proliferating weapons-usable materials.

4 Joonhong Ahn is a professor in the Department of Nuclear Engineering at the University of California, Berkeley. He has led numerous joint research projects involving institutions in Japan, South Korea, and the United States, and the IAEA. He is currently conducting a joint research project with the Japan Atomic Energy Agency, in which criticality safety is being analyzed for geological disposal of molten nuclear fuel in the Fukushima reactors.

THE POST-FUKUSHIMA NUCLEAR INDUSTRY IN MONGOLIA

Undraa Agvaanluvsan[5]

The history of nuclear activities in Mongolia offers a good example of the development of nuclear capabilities in a developing country. Mongolia, once Communist, was closely linked to the former Soviet Union. The training of nuclear scientists began in the early 1960s, and most Mongolian scientists received their post-graduate degrees and research experience in nuclear physics at the Joint Institute of Nuclear Research in Dubna, Russia.

Though nuclear power was held in high esteem, there was also a strong fear of nuclear activities. This was due to the dual nature of nuclear technology. The two blocs in the Cold War, one led by the United States and Europe the other led by the Soviet Union, were in a nuclear arms race. As nuclear weapons were being tested, both sides claimed that the other was an "evil" force pursuing the development of an "evil" weapon. At the same time, both sides argued that they needed nuclear weapons for their defense. In order to sustain this policy, nuclear weapons were viewed as a necessary evil. The combined feeling of fear and allure was quite widespread among the Mongolian people, and this paradox was only enhanced by the fear engendered by the Chernobyl accident in 1986 and the hope created by the Democratic Revolution in 1990.

The Democratic Revolution brought Mongolia the freedom to adopt an independent nuclear policy. The anti–nuclear weapons sentiment is reflected by Mongolia's declaration that it would be a nuclear weapons–free country. Nuclear policy making remained mostly dormant until 2009, when Parliament approved the historic Nuclear Energy Law and Nuclear Energy Policy. With some of the world's largest and least explored uranium reserves, Mongolia knew that it needed a new policy in order to become a supplier of uranium for nuclear fuel. Thus, Mongolia joined the "nuclear renaissance," as did more than 30 other countries that were considering building nuclear power plants. During this time, support for the nuclear industry among the Mongolian public and political leaders was strong.

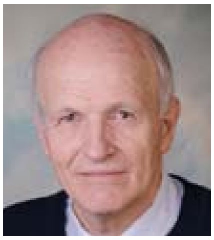
The situation changed after Fukushima. Rumors that the Mongolian government was considering building a nuclear-waste-disposal site caused much anxiety and opposition among the people. Although the government refuted the accusations, opposition groups formed against the government. The public, taking advantage of the new social media technologies, was not convinced by the government. This was mainly because the Mongolian government could not articulate its position and strategy for nuclear development. The rumors and discussion only ceased with a presidential decree in 2011, which stipulated that there would be no contract negotiations or cooperation in the nuclear arena without the approval of the National Security Council of Mongolia.

Mongolia does not yet have a nuclear power plant, nor is there a national consensus on how its extensive uranium reserves should be developed. Mongolia is an example of how difficult it is to develop a national nuclear policy in the post-Fukushima environment.

5 Undraa Agvaanluvsan, a nuclear physicist by training, is a former ambassador at the Ministry of Foreign Affairs and Trade of Mongolia, where she was in charge of nuclear energy and security issues at the time of the Fukushima event. Her expertise in nuclear science at Lawrence Livermore National Laboratory and in policy research at the Center for International Security and Cooperation, Stanford University, combined with her experience in nuclear-policy practice in the Mongolian foreign service, provides her with a unique and useful perspective on current concerns. *The views expressed here are the author's personal opinions and in no way express an official policy of the Mongolian government.*

MAKING NUCLEAR POWER SAFER AND LESS PROLIFERATIVE AFTER FUKUSHIMA

Frank N. von Hippel[6]



The Fukushima disaster made obvious some of the safety weaknesses of the General Electric boiling water reactors, including their small-volume containments. This was understood in 1972 within the U.S. Atomic Energy Commission (AEC), before Fukushima Daiichi Units 2 and 3 were licensed for operation and before the construction of Fukushima Unit 4 had even begun. A deputy director of the AEC's Directorate of Licensing warned, however, that questioning this design "could well be the end of nuclear power. It would throw into question the operation of licensed plants [and] would make unlicensable the…plants now under review." He was later appointed chairman of the U.S. Nuclear Regulatory Commission (NRC). Even today, the majority of the political leadership of the NRC is still reluctant to revisit past decisions.

A potentially more serious consequence of poor design is the way in which current nuclear fuel cycle arrangements, which legitimize national enrichment and reprocessing plants, spread the bomb while spreading nuclear power. As former International Atomic Energy Agency (IAEA) Secretary General Mohamed ElBaradei argued in 2003, we should move toward at least multinational control of such facilities.

If nuclear power is to have a future, it must be made safer and less proliferative. But even if this can be accomplished, the role of nuclear power will be limited during the next few crucial decades, as we try to cap and reduce carbon dioxide emissions, unless we get much more serious about energy efficiency. Global growth of electric-power demand is literally outrunning our ability to build non–fossil fuel capacity, even in China and India where the growth of both total electricity consumption and nuclear power are most dramatic.

In 2008, nuclear power accounted for 13.6 percent of global electric power, down from a peak of about 17 percent in 1999. The IAEA's projections of nuclear power have historically far exceeded reality, but in its 2011 projection, the IAEA predicts that nuclear power will account for only 6.2 to 13.5 percent of global electric power in 2050. Because of the rapid growth of demand, even this contribution will require global nuclear generating capacity to increase by 50–225 percent. The contribution of renewable energy— still mostly traditional hydropower—also declined between 1999 and 2008, by one percent to 19 percent, despite the rapid growth of wind and biomass energy.

The IAEA projections are based on its survey of national projections for the future of nuclear power, which, in aggregate, have declined by only about 5 percent since the Fukushima Daiichi accident. Many governments still believe in a future for nuclear energy, but it is no longer the dominant future many expected in the 1960s and 1970s.

If nuclear and other nonfossil sources of electric power are to play a more important role in limiting climate change, we must work on the demand as well as the supply side of the energy problem. Our new refrigerators and compact fluorescent bulbs consume one quarter as much power as the devices they replace, but much more is both possible and necessary.

6 Frank von Hippel is a nuclear physicist and a professor of public and international affairs at Princeton University, where he cofounded, in 1975, Princeton's Program on Science and Global Security; in 1989, the journal *Science & Global Security*; and, in 2006, the International Panel on Fissile Materials. In the decades before the Fukushima Daiichi accident, von Hippel and coauthors spotlighted and suggested remedies to the dangers of reactor containment overpressure during an accident and the practice of dense-packing spent fuel pools.