Atsuyuki Suzuki

Toward a robust nuclear management system

This essay outlines a path toward a robust nuclear management system, a prerequisite if nuclear power is to play a significant role in creating a globally sustainable energy future. What do I mean by a robust nuclear management system? Looking back at the history of nuclear power development over the last 50 years, the nuclear industry was not able to obtain a wide range of public support, as originally expected; current achievements are not necessarily faring much better. The Three Mile Island accident in 1979 and the Chernobyl accident in 1986 had a severe impact on the level of public support for nuclear energy; both accidents were serious enough for people to feel extremely uneasy about the use of nuclear energy. The second issue that has contributed to global apprehension about nuclear power development is the fact that nuclear proliferation concerns have not diminished, but rather, have expanded as states continue to pursue nuclear weapons programs and as risks of non-state actors obtaining nuclear materials continue to increase. Managing the spent fuel from nuclear power production is closely related to safety and security issues because it contains plutonium as well as highly radioactive materials. Global concern over spent fuel management has been increasing as the amount of spent fuel has risen worldwide.

A robust nuclear management system must address at least these concerns – safety, security, and nonproliferation – in order to minimize anxieties among the public, nationally and internationally, regarding the widespread use of nuclear energy. A robust system is necessary for the global community to enjoy the dividends expected from using nuclear power for civilian purposes. The crucial question is how to create such a robust system. It is an enormous challenge; nonetheless, in light of current constraints on energy worldwide, my view is that it is necessary. Nuclear power has the potential to be a major energy source, meeting the base-load electricity demands anticipated in rapidly growing economies. Energy is, in many ways, an essential underpinning for future economic and social progress. At the same time, demands for energy need to be balanced with concerns about the environmental impacts of producing and using energy, particularly the emissions of pollutants into the atmosphere. Nuclear power provides an alternative source to meet energy demands in a substantially carbon-free manner.

This essay explores the ways in which comprehensive safety management with improved social communication and accountability for nuclear power development, complemented by transparency and international cooperation, can contribute to a robust system that addresses safety concerns, public anxieties, and nonproliferation issues. By sufficiently tackling these issues, the global community will be able to reap the benefits of nuclear power – namely, its contributions to mitigating carbon dioxide emissions and to fulfilling global energy demands.

To consider whether nuclear energy can play an important role in meeting the global demand for carbon-free energy, one must look at the long-term perspectives and imagine possible global nuclear energy scenarios for the year 2050. The 2003 MIT study, *The Future of Nuclear Power: An Interdisciplinary Study*,[1] attempts to imagine some of these scenarios. The study projects that 1,000 GWe of nuclear power capacity will be required in 2050, with regional estimates of 300, 210, 115, 50, 200, 75, and 50 GWe for, respectively, the United States; Europe and Canada; developed East Asia (Japan, Korea, and Taiwan); the former USSR; China, India, and Pakistan; Indonesia, Brazil, and Mexico; and others. Similarly, in 2008 the Organisation for Economic Co-operation and Development (OECD), via its Nuclear Energy Agency (NEA),[2] put forth a low and a high projection for 2050: 580 GWe and 1,400 GWe, respectively. This study emphasizes that current nuclear capacity would increase by more than 1,000 GWe for the high scenario and by more than 200 GWe for the low scenario. The OECD's International Energy Agency (IEA) projections from 2006 give the more moderate figure of about 900 GWe for the high scenario,[3] while the 2007 Intergovernmental Panel on Climate Change (IPCC) estimates the high scenario to be slightly lower than 1,400 GWe.[4]

The 2003 MIT projection of 1,000 GWe of nuclear power capacity for 2050 seems appropriate. However, given that more than 50 percent of the world's population lives in the Asian region, a slight modification is necessary. Looking at projections made by China and India alongside the actual national energy strategies pursued by these countries, the long-term energy demand in both China and India apparently requires much more nuclear energy than noted in the MIT projection. One of China's projections[5] predicts total electricity demand in 2050 to be about 1,600 GWe, approximately three times as much as in 2000, or roughly two-and-a-half times as much as the current level. Taking population growth into account, this projection appears quite reasonable. The configuration of the energy sources, however, is problematic. The projection requires 950 GWe of coal-fired generation in 2050, which is about two-and-a-half times the current level. The amount of nuclear energy for 2050 is projected to be 250 GWe, which is about 10 times the current level. If this becomes the case, carbon dioxide emissions will likely be more severe due to heavy reliance on coal power. Nuclear capacity of 250 GWe would be a minimum if the nuclear option is to play a significant role in Chinese contributions to solving global warming issues and reducing carbon dioxide emissions.

India's situation is similar. A 2004 Indian government study[6] states that the total electric energy demand in 2050 will be about 1,300 GWe, with roughly 600 GWe from coal and 250 GWe from nuclear. Considering the economic growth rate anticipated in India, this projection appears realistic, suggesting that a nuclear capacity of 250 GWe will be necessary to compensate (albeit slightly) for the increase in the quantity of carbon dioxide released from coal-fired electricity production in India. Thus the nuclear power needed in China and India in 2050 should be projected to be at least 500 GWe, rather than 400 GWe as estimated in the 2003 MIT study.

The MIT team recently updated the study,[7] saying, "With regard to nuclear power, while there has been some progress since 2003, increased deployment of nuclear power has been slow both in the United States and globally, in relation to the illustrative scenario examined in the 2003 report." Compared to 2003, they noted, "the motivation to make more use of nuclear power is greater, and more rapid progress is needed in enabling the option of nuclear power expansion to play a role in meeting the global warming challenge." The team concluded, "The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation."

I agree with this observation, and the 2003 MIT projections for developed nations such as the United States, Europe and Canada, and developed East Asia would be modified to be less. For example, in this case, nuclear power in the United States would not be 300 GWe, but 200 GWe. Thus, the global nuclear power scene in 2050 will be entirely different from the current scene. The amount of nuclear electricity in developing nations would be nearly the same as the amount in developed nations (say, 500 GWe for each), and in terms of capacity in individual nations, China and India would be the leading countries, possibly surpassing the United States or Europe and Canada unless more is done in those regions.

A world where China and India are the champions of nuclear power production would be a totally different playing field as far as the world nuclear regime and the world nuclear industry go. Thus, and returning to the original premise of this paper – how to develop a robust nuclear management system – the architecture of that system should be designed with the assumption that a number of new entrants will operate their own nuclear power plants and that China and India will have the greatest nuclear power production. In other words, a robust nuclear management system must recognize that the total amounts of nuclear electricity in developing nations will be greater than or at least comparable to the amounts in developed nations.

The evolution and improvement of safety management will be crucial to our nuclear future. How is safety best managed in a world where nuclear power expands remarkably in developing countries, and also spreads to a number of new entrants that construct and operate their own nuclear reactors? Nuclear energy can play an important role worldwide only when nuclear power development and reactor operation is safe, with no concerns about serious accidents. The challenge for us is to create a safer global nuclear option.

A robust nuclear management system, in which all countries are granted the right to use nuclear energy for civilian purposes, needs to emphasize the development of comprehensive safety management. To this end, safety standards, as a minimum requirement, must be implemented on an international basis. In particular, any nuclear country will have to follow safety obligations to ensure that no accidents with serious consequences take place. Every nuclear power nation is, to a large extent, hostage to the safety performance in other nuclear power nations by virtue of the adverse consequences that would arise from a serious nuclear accident. Therefore, only countries capable of meeting comprehensive, international safety management norms should be in a position to utilize nuclear power.

How should the world pursue comprehensive safety management? More particularly, how can nations currently utilizing nuclear energy maintain and advance safety management, and how should nations developing nuclear power programs build on and utilize the safety management practices currently in place in nations with developed nuclear power infrastructures? First, the defense-in-depth concept is employed within the nuclear safety area to lessen the frequency of trigger events; to prevent them from leading to more severe events; and to mitigate the consequences, if they occur. Except for the Chernobyl accident, this defense-in-depth concept has contributed significantly to the avoidance of serious consequences within the nuclear industry. The usefulness of this concept should not be understated, but it could benefit from further strengthening. The concept, together with multiple physical barriers, should be advanced with some additional requirements for accident-management tools, which have been increasingly demanded in the aftermath of the Three Mile Island and the Chernobyl accidents.

Looking at the experiences over the past few years, however, it is clear that defense-in-depth, even with accident management tools, has not been sufficient because defenses can deteriorate as time passes. This realization is one of the most instructive lessons learned from the history of nuclear safety: that technical/engineering systems are inclined to age, and thus face diminished effectiveness in safety performance. Furthermore, human factors have also contributed to lapses in safety.

To compensate for such deficiencies, quality management systems have been increasingly developed to ensure consistent safety performance and quality of human operations. As a result of increased focus on quality management and a defense-in-depth concept complemented by proper accident management tools, nuclear safety is now well managed. With an appropriate combination of the above-mentioned measures, nuclear safety as a whole has been maintained successfully to date, and many countries with nuclear power programs have shown excellent safety performance over the last couple of decades.

This record of excellence is due not only to the application of technical/engineering systems, but also largely to interaction with society. Regulatory systems have been improved over time, and these improvements have been based significantly on society's demands for elevated nuclear safety. This societal aspect of nuclear safety is sometimes perceived as a "stakeholder's involvement" issue. A more robust nuclear system would include a more structured relationship between nuclear safety and society, to maintain the safety scheme in a way that encourages timely detection of deterioration in technical/engineering measures.

The effectiveness of any such detection system will depend greatly on how much accountability the people request from operators and regulators.

The social system required for safety management is critical. There is a variety of stakeholders, and no one stakeholder should dominate. However, related stakeholders should work together to reach consensus through an interactive communication process. A safety management system must incorporate substantive and procedural aspects, and thereby would be perceived as a more democratic process. In the social sciences, this process is interpreted as a "communicative action" in the public sphere, advocated by German philosopher Jürgen Habermas,[8] a well-known scientist insisting on the emergent need to facilitate communication between specialists, professionals or technocrats, and the general public.

I believe that a part of sustainable nuclear development is ensuring that every nuclear country creates its own communication system that enables all related stakeholders or sectors to participate. Communicative actions are essential to maintain and enhance safety for two reasons. One is transparency, which is not merely openness or information disclosure, but more importantly, accountability to the public, complemented with feedback on safety measures. The second reason is flexibility, as social requirements for safety change with time, depending on an operator's past safety performance or how often troubles and incidents have occurred.

This type of communication system is employed not merely in the nuclear safety area but in many other fields as well. A well-known American social scientist, Nobel laureate Herbert Simon, argued in his seminal book *The Sciences of the Artificial*[9] that we need to pay greater attention to so-called procedural rationality, rather than substantive rationality. Simon writes:

> Economics illustrates well how outer and inner environment(s) interact and, in particular, how an intelligent system's adjustment to its outer environment (its substantive rationality) is limited by its ability, through knowledge and computation, to discover appropriate adaptive behavior (its procedural rationality).[10]

Simon's ideas apply to nuclear safety management. The inner system – that is, the defense-in-depth concept, with quality management – is owned by an individual operator or regulator and needs to adjust to its outer environment; the ability to do so, however, is unfortunately limited. Only through improved knowledge obtained from communication between nuclear energy's inner and outer environments can appropriate adaptive behavior be promoted.

Undoubtedly, there is no absolute safety. The defense-in-depth concept, with quality management, is designed to help make up for any safety deficiencies in individual parts of the system. Looking at nuclear history, it has worked well. With regard to the goal of sustainable nuclear development, however, more than traditional measures need to be employed. According to Simon's suggestion, to rest only on the rationality invented in the inner environment is inherently limited. What would be better is to communicate with the outer environment and thereby discover appropriate, adaptive behavior. In other words, nuclear operators and regulators should actively communicate with the broader society, particularly with the local communities and others affected by and interested in the development of nuclear power.

The most important factor in such communication is transparency because, on the one hand, it is tremendously helpful for confidence-building in society and, on the other hand, it gives good incentives for operators and regulators to improve safety performance. As an analogy with the Simon's theory, this type of interaction between the inner and outer environments brings about procedural rationality, which might significantly strengthen or complement substantive rationality (that is, resting on the defense-in-depth concept, with quality management).

Safety management based on procedural rationality together with substantive rationality has been developed in advanced nuclear power countries, and as a result, safety performance in those countries has been enhanced remarkably. The same type of management must be employed in countries new to nuclear power, if the nuclear option is to be robust in terms of safety.

Managing spent nuclear fuel is an additional critical issue for nuclear power development because of both public concerns about safety and concerns regarding nonproliferation and terrorism. The latter pertains to the risk that materials within spent fuel could be used for either nuclear weapons or radiological dispersal devices. The nuclear industry, governments, and the public in countries with nuclear power programs, as well as the international community at large, continue to struggle with how best to manage spent nuclear fuel. At the heart of the issue is the fact that spent fuel contains plutonium as well as other highly radioactive fission products.

The plutonium in spent fuel raises the long-standing question of whether or not to reprocess and recycle plutonium, together with uranium, for new fuel to be burned in nuclear power reactors. The question is connected to a variety of factors: economics, energy self-sufficiency, environmental burdens of waste management, resource conservation, and nonproliferation, as well as safety. Each country's policy decisions should take into account not only domestic situations but also relevant international situations.

France, Japan, Russia, China, and India are the countries presently conducting or pursuing recycling programs alongside reprocessing. The United States, Canada, Finland, Sweden, and South Korea do not use reprocessing and recycling programs; rather, they are seeking to implement programs for direct disposal of spent fuel at a geological repository.

Whether or not reprocessing is involved, a geological final repository is necessary to dispose of highly radioactive wastes. The programs for such final repositories are always very controversial because of the tremendously high potential hazards related to the extremely high radioactivity. The programs are also increasingly complicated politically, mainly owing to domestic factors. Currently, there are two extreme cases, both in non-reprocessing countries. One is the Yucca Mountain project in the United States, which the Obama administration stated is no longer an option for waste disposal, after the United States had spent billions of dollars on the project. The other extreme case is the Swedish program.[11] In Sweden, a site was eventually selected to be one of two candidate repository sites following a decades-long, patient discussion process. The site selection is a milestone for the program, and the Swedish case suggests the great success of the country's prudent approach. The lesson to be learned from Sweden's success is how useful social communication and acceptance by the local community can be.

Long-term safety assurances for high-level waste disposal is a central issue; intensive and extensive attention must be paid to safety based on procedural rationality that relies on social communications, as well as to safety based on substantive rationality (that is, the multiple-barrier confinement concept used in geological disposal design). Social communications are based on a step-by-step decision-making process and require non-confrontational dialogue with the public. This is exactly what Sweden has done, bringing about fruitful success in terms of selecting a site.

To obtain public understanding, one must demonstrate the safety concept based on the substantive rationality (geological disposal with multiple-barrier confinement). In Sweden, an underground research laboratory was constructed at a site where the geology is very similar to that of the real repository site. The research laboratory helped show the public the basic idea of geological disposal, and that was extremely helpful in gaining public understanding. One of the advantages in Sweden is that geology there is relatively uniform nationwide, making the technical identification of a geological environment for the actual repository relatively simple.

In Japan, the geology is extremely heterogeneous, and there is a variety of geological environments that could be candidates for a repository. Therefore, assuming that the Japanese repository site selection process will be particularly time-consuming because of both technical assessment and public involvement, Japan is pursuing a multiple-track approach, whereby the reprocessing and recycling program is under way, with interim storage as a means to manage the spent fuel. At the same time, geological disposal research has been implemented using underground research laboratories with different geological characteristics. This multiple-track approach is effective in providing flexibility for decision-making around repository site selection, but this approach also presents a disadvantage because, due to a short- and intermediate-term expedience associated with the approach, there is no sense of urgency for the government to make a decision. This lack of urgency lessens the political leadership, which is necessary for advancing the site selection process.

Japan's new Democratic Party administration, led by Prime Minister Hatoyama, issued an official statement that the nuclear policy in Japan will not change, although the new government was elected in a landslide, the result of the main campaign message, "Let us make a big change." As far as the global nuclear energy situation is concerned, however, significantly new political leadership is necessary. For instance, the new government declared that Japan aims to reduce CO_2 emissions until 2020 by 25 percent against the 1990 level, if other major countries also provide such a progressive commitment to resolve the global warming issue. If this is to be the case, Japan has to rely more on nuclear energy, which in turn requires greater public support for expanded use of nuclear energy. To obtain such public support, more visible progress is needed in the back-end of Japan's nuclear fuel cycle program – reprocessing and geological disposal – as well as better performance of reactor operations, which will not be possible without more efficient and effective regulations.

Selecting a site for a final repository will take time, and the only way to lead a successful decision-making process is to base it on social communication that isn't confrontational, but rather is an open dialogue with the public. There are two points to be stressed. First, for nations pursuing the reprocessing and recycling option, transparency is especially required to fulfill an international commitment to nonproliferation. Nonproliferation concerns are growing, and correspondingly, the need for international communication and cooperation is indispensable for improving the robustness of each nation's program.

Second, there is a great need to have international collaboration in the area of final repository. By and large, the construction cost of final repository depends heavily on its scale, that is, the amount of highly radioactive wastes that can actually be disposed at the facility. For the new entrants to nuclear power, for instance, it does not seem to make any economic sense for each one to have its own facility. If that were the case, the cost incurred might be too high for nuclear power to be an economically attractive option in that country. Thus, international cooperation is necessary to spread nuclear power use.

Given the difficulty in selecting repository sites, as indicated from past experiences in developed nations, a special arrangement may be necessary when considering international cooperation in this area. I think that the most practical way to implement international cooperation is to establish interim storage facilities of spent fuel, and not to make a rapid attempt to build an international repository. Again, the final decision-making process must be based on open dialogue internationally.

How should the global community pursue an appropriate course of nuclear power development, beyond considerations of safety, security, and stakeholder involvement/communication? Within industry, there are new trends and activities meant to take advantage of the growth in nuclear power around the world. In terms of reactor construction business, a merger and acquisition (M&A) trend has developed in global nuclear industrial sectors. Partnerships with the Multinational Design Evaluation Program (MDEP), originally proposed by the United States and France and now under multinational discussion at the OECD/NEA, for instance, would make remarkable sense for creating an economically healthier market for countries new to developing nuclear power.

In terms of business related to the nuclear fuel cycle, more robust global partnerships seem necessary for nuclear energy to expand steadily. As far as the front-end of the nuclear fuel cycle is concerned, a number of efforts have been undertaken to assure uranium resources and their enrichment. For example, the International Atomic Energy Agency (IAEA)[12] has proposed the idea of a nuclear fuel bank. Proposals for the back-end of the fuel cycle, however, are limited, regardless of the spent fuel management program used. The key is transparency of the program, which is a prerequisite for safe and secure use of nuclear energy.

It will be critical to have multiple dimensions in new global partnerships: developed and developing nations, large and small nations, recycling and non-recycling countries, and nuclear-weapons states (NWS) and non-nuclear-weapons states (NNWS), all working together toward common goals.

As for countries with developed nuclear power systems versus countries developing nuclear power, nuclear regulatory infrastructures in developing countries will have to be provided with appropriate aid from developed countries. In particular, comprehensive safety management needs to be established in countries developing nuclear power; the way to introduce it will depend on the social system in each country. The system should enable communication between society and the nuclear industry, and at a transitional phase, developed nations should help stimulate such communication through an international institution, like the IAEA or the OECD/NEA.

Cooperation between large and small countries is also important. The economy of each country's national fuel cycle program, for instance, depends on the total capacity of its nuclear power program. Countries with small nuclear programs may at times need special help. In particular, the technology for geological disposal of highly radioactive waste is extremely capital-intensive, and it does not make economic sense for every nation with a small nuclear program to have its own disposal program (though some propose that every nation should hold the responsibility to deal with its own nuclear waste).

A similar situation exists in the area of cooperation between countries recycling spent fuel versus non-recycling countries. Considering that reprocessing and recycling technologies are extremely capital-intensive, it makes little economic sense for every country to have its own complete recycling program, even though worldwide there is a social trend to recycle natural resources to the greatest extent possible. A particular arrangement may be required between recycling and non-recycling countries when some of the new entrants are interested in recycling.

Another dimension is the relationship between NWS and NNWS. Under the current world regime, a global architecture for peaceful use of nuclear energy could not be built without partnership between NWS and NNWS. A robust nuclear future is heavily dependent upon global public support for the peaceful use of nuclear energy. Unfortunately, concerns with nuclear power originate from the grave threats that arise from its military applications. In this respect, it is crucial for NWS to get rid of the nuclear legacy they still hold. Particularly, the highly radioactive wastes generated from defense programs should be disposed at the earliest possible time. To be specific, Russia, the United Kingdom, and the United States should take the initiative in demonstrating the technical feasibility of geological disposal, by making the disposal of their defense waste a high priority. If these countries took this step, the global opinion would be much more favorable regarding the peaceful use of nuclear power in NNWS as well as NWS.

One of the disadvantages of canceling the Yucca Mountain project is that the United States could lose the opportunity to take the initiative in demonstrating the safe implementation of a geological disposal program using its defense waste. Now it will have to postpone disposal of highly radioactive defense waste that was scheduled to be disposed of jointly with civil waste at the Yucca Mountain site. This delay could send a negative message to the world nuclear community with regard to the United States taking responsibility for its nuclear legacy and disposing of its defense waste. The Waste Isolation Pilot Plant (WIPP) in the United States, in New Mexico, specifically disposes of long-lived radioactive waste (as opposed to high-level) arising from the defense program, and is an example of a successful geological disposal program. It might make sense to explore the possibility of using the WIPP facility to demonstrate the safe implementation of disposal of defense high-level radioactive waste, since the geological environment at the WIPP site appears scientifically suitable for high-level radioactive waste as well as long-lived waste. Though the current agreement between New Mexico and the U.S. Department of Energy (DOE) precludes the DOE, the owner of the waste, from utilizing the facility for that purpose, it would be worthwhile for the United States to rethink the agreement and show that it is taking responsibility for its defense waste.

The magnitude of nuclear power programs in developing nations should be greater than the ones in developed nations, so that the nuclear option might make a material contribution to global energy and environmental issues – in particular, global warming. In order that this might come to pass, however, safety and nonproliferation issues will need to be managed properly, and new global partnerships will inevitably and increasingly be required.

In the reactor safety area, both the defense-in-depth concept (with quality management) and improved safety communication with the public will need to be employed in every nuclear power country. While a safety system based on procedural rationality should be designed to meet the specific needs of each country, the knowledge developed thus far in developed nations should be transferred to developing countries, especially through international programs. International efforts to ensure safe nuclear operations, such as the World Association of Nuclear Operators (WANO), have been successful in improving the safety and reliability of nuclear power plant operations. WANO has played a remarkable role in providing useful information on reactor operations for member companies, and encourages new entrants in nuclear power development to become a member in order to participate in such exchanges. Japan, for its part, has been an active member in WANO and other international efforts. With its years of operations and construction experiences, Japan can provide technical and safety knowledge from both an operator's and a vendor's point of view.

Technologies connected with the back-end of the nuclear fuel cycle are tremendously capital-intensive, and it makes little economic sense for every small country to have its own program. Thus, international cooperation, entailing global partnerships, is particularly necessary. Otherwise, the steady and robust global use of nuclear power will not be possible.

Lastly, a few words on why great emphasis should be put on the need for social communication, particularly in terms of transparency. What has been proven from the past 50 years of peaceful use of nuclear energy is that transparency is prerequisite for building confidence nationally and internationally. This is true for two reasons. First, as described above, transparency plays a significant role in maintaining and improving safety performance. Second, transparency is the most effective measure for nuclear nonproliferation as well, if it is used to ensure security. In a much broader sense, transparency is tremendously effective for maintaining a safety and security culture, and thereby contributes to acceptance of nuclear energy from the public at large. Japan, the only NNWS to employ reprocessing technology, has committed to safeguards and verification at all its facilities, to provide confidence to the IAEA and international community that no diversions of nuclear material occur. In 1999, Japan signed the Additional Protocol, providing the IAEA with a broader set of tools to search for undeclared materials and activities. Japan's collaboration with the IAEA and the international community not only has led to improvements in safeguards technology, but also illustrates how transparency of nuclear activities can enhance or improve safety and security, as well as public confidence.

Transparency is a cultural product of democracy, and conceivably, each country employing nuclear power in a safe and secure manner, through a mechanism that insists on transparency, would achieve the greatest outcome.

In a robust nuclear management system, where any country could afford to utilize nuclear power, each nation with a nuclear power program should create its own safety communication system with the highest possible level of transparency, so that it may enable all related sectors of society to participate. The current nuclear energy community should pursue this goal with highest priority.

ENDNOTES

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