Seven Principles of Highly Effective Nuclear Energy Programs

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NATO conference, Yerevan, Armenia
May 26-29, 2009

Abstract

This paper presents seven principles that demand consideration for any country using a nuclear power program or wanting to acquire such a program. These principles are assessing the overall energy system, determining effective use of financial resources for energy development, ensuring high safety standards, implementing best security practices, preventing the spread of nuclear weapons, managing radioactive waste in a safe and secure manner, and enacting a legal framework that encompasses the other principle areas. The paper applies management methods that underscore development of strong independent national capabilities integrated within an interdependent international system. The paper discusses the individual responsibilities of states in all seven principles and offers recommendations for how states can benefit from greater international cooperation in nuclear energy development.

1. Independence, interdependence, and dependence

In recent years dozens of countries have expressed interest in potentially acquiring their first nuclear power plants. They need guidance on how to decide whether such plants are the right choice for them, and if that decision is made, how to manage effectively the complex nuclear power plant acquisition process, and how to ensure that these plants are operated safely and securely. Before examining the criteria or principles for making this decision and managing a nuclear power program, it is important to understand what is driving many states to consider this power source. While overt and covert motivations for new nuclear power programs vary from keeping up with neighbors' programs to transitioning to a lower greenhouse gas emission energy system, a common overt motivator is to become more energy independent.

Energy independence, however, is a myth, especially in the nuclear sector. To see why, examine the experience of countries that presently use nuclear power to generate electricity. Practically all of them are not self-sufficient in providing for all the required components of a nuclear power program, including reactors, uranium, fuel manufacture, and training of personnel. Even France with a vertically integrated, largely government-owned nuclear industry that has extensive uranium enrichment capacity, power plant manufacturing, and thousands of indigenously trained workers still relies on external supplies of natural uranium as the feed stock for this industry. Moreover, the nuclear industry has developed into one of the most globalized industries. For example, no longer can the United States claim to have major nuclear companies that are solely U.S.-based. Since 2006, U.S.-based Westinghouse has merged with Japanese-based Toshiba, and similarly U.S.-based GE Nuclear has combined with Japanese-based Hitachi. Furthermore, the French nuclear industry giant Areva has formed alliances with several other nuclear companies and has major branches outside France. Thus, the reality is that the degree of interdependence and interconnectedness in the global nuclear industry and infrastructure continues to grow.

Energy interdependence should not be feared and can be a source of strength if managed properly. It is important to emphasize that interdependence does not necessarily equate to dependence. An interdependent national energy system can be a highly secure system as long as it is a well diversified one. While many politicians receive applause from constituents for pledging energy independence, they should realize that an energy mix that does not rely too heavily on one energy source often provides the best insurance against supply disruptions. Each energy source varies considerably in its requirements for ensuring safe and secure use and protecting the public and the environment. Here, the focus is on the special requirements for safe and secure use of nuclear energy.

1.1 Unique characteristics of nuclear energy

Nuclear energy is not just another way to boil water (or heat up another working fluid) to make steam to turn a turbine to generate electricity. (Here, nuclear fission is considered but not nuclear fusion.) Nuclear fission to produce nuclear energy has two unique hazards. First, nuclear fission creates radioactive fission products. These fission products can last from fractions of a second to billions of years. In general, the fission products of greatest concern are those with radioactive half-lives—the amount of time it takes for half of the substance to decay—on the order of the human lifespan because they release most of their radiation over that span. Two relatively abundant examples of these radioisotopes are cesium-137 with a half-life of 30 years and strontium-90 with a half-life of 29 years. After these radioisotopes have decayed to negligible amounts, longer lived radioisotopes with half-lives on the order of thousands to millions of years will dominate the radioactive composition of discharged material from a nuclear power plant. Consequently, the decision to develop a nuclear power program carries with it the responsibility to protect human health and the overall biota for more than thousands of years through safe and secure management of radioactive waste. In addition, states with nuclear power programs have the responsibility to protect against nuclear accidents that can disperse radioactive materials to the environment and to mitigate the consequences if that dispersal occurs.

The second unique hazard of nuclear energy involves the dual-use nature of the nuclear fuel making technologies of enriching uranium and reprocessing of spent fuel to extract plutonium. These technologies can help produce either fuel for commercial nuclear reactors or fissile material for nuclear weapons. In particular, an enrichment plant has done most of the work to produce highly enriched uranium suitable for weapons after enriching to low enriched uranium for fuel purposes. Presently, only a few countries use commercial reprocessing plants to separate weapons-usable plutonium from spent fuel. If a large expansion of nuclear power occurs, more countries may operate reprocessing plants. While it is possible and worthwhile to make enrichment and reprocessing more proliferation-resistant, there is no proliferation-proof system. Nuclear power producing states have the responsibility to ensure that their commercial nuclear programs remain peaceful and do not proliferate into weapons programs.

2. Seven Principles of Nuclear Energy Systems

A principled-based system is rooted in integrity, openness, transparency, and a win-win environment. Covey (2004) has developed a principled-based system for personal growth that can provide guidance for developing a principled-based nuclear energy system. Covey identifies seven habits of highly effective people: be proactive, begin with the end in mind, put first things first, think win-win, seek first to understand and then to be understood, synergize, and finally sharpen the saw. The first three habits involve creating a strong independent person. The next three habits help the independent person make the connection to healthy interdependence. The final habit calls on the person to continually renew the habits. While being careful to not stretch the analogy between personal development and energy system development to the breaking point, it is worth examining each principle of highly effective nuclear energy systems in light of Covey's paradigms of independence, interdependence, and continual renewal.

The seven principles examined here involve the issue areas of energy system analysis, economics, safety, security, nonproliferation, waste management, and legal framework. For each of these issues, the individual state is ultimately responsible to upholding the principle but is embedded in an interdependent international system. As such, states have a common interest in assisting other states in meeting their collective responsibilities. In particular, states with mature nuclear power programs can and should play an active role in helping states without these programs think through the decisions involved in acquiring and managing nuclear power programs. The International Atomic Energy (2006b) has recently published a guidance document on the potential for sharing among countries with nuclear power programs. This document underscores that the "burden of infrastructure can be reduced significantly if a country forms a sharing partnership with other countries." Such sharing can reduce costs and spread economic benefits over many countries. This sharing can be a win-win situation in which two or more countries gain and no country loses. Also of note, the International Atomic Energy Agency and has recently published two other guidance documents [IAEA, 2007a and 2007b] offering advice for countries considering their first nuclear power plants.

2.1 Energy system analysis

Nuclear energy makes a significant contribution to world electricity generation (about 16 percent). Because nuclear power plants do not emit greenhouse gases (and the total nuclear fuel cycle is very low in such emissions), nuclear energy also makes a substantive contribution in reducing greenhouse gas emissions especially in comparison to replacing the approximately currently operating 440 commercial reactors with coal-fired power plants. (It would be very challenging to replace the existing nuclear power plants with the equivalent of other very low greenhouse gas emission sources.) Moreover, for countries that depend heavily on foreign oil or natural gas for electricity generation, nuclear energy can help displace use of these fuels and thus provide some relief of dependency on these outside fuel sources. However, nuclear energy so far only is used to produce electricity and has yet to make a significant contribution to the transportation sector. If and when cars and trucks use electricity or hydrogen to power fuel cells on a massive scale, nuclear energy can play a much more significant role in weaning countries off dependency on fossil fuels in the transportation sector. These macro-level and geopolitical considerations shape the positive perception of nuclear energy in governments' decision making.

But the high construction costs for nuclear power plants, the long preparation and planning time, and the necessary investments in a nuclear infrastructure tend to work against governments' decisions to pursue nuclear power. Governments also have the responsibility to factor in the unique attributes of nuclear energy that require additional costs to ensure safe and secure handling of radioactive waste and to protect against misuse of peaceful technologies in weapons programs. While it is beyond the scope here to discuss in detail planning considerations for countries' energy systems, it is worthwhile emphasizing that the first prerequisite for any country considering nuclear power is to conduct a thorough energy system analysis. This is a proactive approach that will assess what resources (energy supplies, technological infrastructure, and human capacity) a country has available to it presently and what it needs to acquire to meet its energy needs. Borrowing from Covey's principle of "begin with the end in mind," a country needs to determine as a prerequisite to this prerequisite where it envisions itself going in its energy development. It should seek to ultimately develop and reach a sustainable energy system, but the specifics of such a system will vary by country depending on the resources available to it.

Both the International Energy Agency (IEA) and the International Atomic Energy Agency can provide such planning assistance. But the IEA is too limited in its scope of member countries, and the IAEA is primarily focused on nuclear energy. What the international community needs is a world energy agency that would be global in scope and provide detailed energy planning. Notably, IAEA Director-General Mohamed ElBaradei has suggested development of such an agency. [ElBaredei, 2008] This agency would have to be able to perform lifecycle comparisons of differing energy development scenarios for any country.

2.2 Economics

Starting a nuclear power program can take 15 or more years depending on the status of a country's technological development. In addition, it will require substantial financial investment to build up a nuclear infrastructure. In particular, the educational system must have the necessary resources to make sure that the pipeline of technically skilled people will be ready for starting the program and ensuring its sustainability over many decades. Fortunately, countries do not have to build up this infrastructure on their own but can and should seek outside advice and support from countries that already have such programs.

Aside from acquiring the technological infrastructure, the biggest consideration is how to finance the construction of nuclear power plants. Financing poses a major challenge even for many countries that already have nuclear power plants. In general, the capital needed to build a nuclear power plant is significantly greater than that required to build a coal-fired plant and most certainly greater than that needed for a natural gas plant. But once the nuclear plant is built, its fuel costs are typically cheaper than the fuel costs for a coal or natural gas plant. In particular, the updated MIT nuclear power study [Deutch et al., 2009] has estimated the overnight costs (assuming a plant can be built overnight and thus minimizing the financing costs) as $4,000/kW for nuclear, $2,300/kW for coal, and $850/kW for natural gas in the United States, the fuel costs as $0.67/mmBTU for nuclear, $2.60/mmBTU for coal, and $7.00/mmBTU for natural gas, and the resulting electricity base costs as $0.084/kWh for nuclear, $0.062/kWh for coal, and $0.065/kWh for natural gas. The MIT report estimates that a $25/ton of CO2 charge would make nuclear cost competitive with coal and also cost competitive with natural gas for consistently high gas prices. Thus, factoring in this external cost into the internal cost of fossil fuel electricity generation will level the playing field for no- and low-carbon emission sources, including nuclear energy.

Countries will also have to factor in decommissioning and spent fuel storage and handling costs when figuring out the lifecycle costs of nuclear power. These costs, to date, have been estimated as a relatively small fraction of the capital construction and fuel costs. Another decision is whether to pay the costs of a reprocessing or recycling program. While on purely economic considerations, reprocessing costs more than the once-through uranium fuel cycle, certain countries have made the decision to pay these extra costs because of the view that a reprocessing program could in the long term give them more energy independence, help save on waste disposal costs, and will be needed if uranium resources become scarce, which reprocessing proponents believe could happen by mid-century if nuclear power experiences a major global expansion.

2.3 Safety

An often said aphorism in the nuclear safety field is: "A nuclear accident anywhere is a nuclear accident everywhere." This lesson was learned after the Three Mile Island accident in 1979 in the United States and the Chernobyl accident in 1986 in Ukraine. Actually, many lessons were learned and considerable safety improvements have been made after those accidents. First, nuclear regulatory agencies in many countries became more effective as strong independent government agencies. Second, the nuclear industry formed peer-review organizations that sought to achieve excellence in nuclear plant operations and safety. Third, design changes and equipment in nuclear plants have improved. Fourth, training and management of plant operators significantly have improved.

Nuclear power plant safety, in general, involves engineering and institutional aspects. Prior to the TMI accident, the emphasis in nuclear safety was much more on defense-in-depth engineering. While this is still essential, the fundamental change after TMI was to build up institutional capacities. That is, the human element was the essential component in nuclear safety that did not receive adequate attention—especially in the United States—prior to that accident. As Rees (1994) points out, utility managers and their staff had "fossil fuel mentality" before TMI. They thought of nuclear plants as just big fossil fuel plants. While they were cognizant of nuclear hazards, they had not developed a nuclear safety culture and had not instilled nuclear professionalism in their workforce. Soon after the accident, the industry responded by forming the Institute for Nuclear Power Operations (INPO). Over the past thirty years, INPO has served as a self-policing and peer review institution that has used peer pressure, confidential safety assessments, safety inspections, and a principled-based and results-oriented management approach to help nuclear power plant owners and operators achieve a high standard of safety while maintaining reliable operations. Similarly, after the Chernobyl accident, industry formed the World Association of Nuclear Operations (WANO), which has performed hundreds of peer reviews in nuclear power operating countries.

While INPO and WANO do not obviate the need for strong independent regulatory agencies, they do illustrate the power of "communitarian regulators." [Rees, 1994] Notably, these organizations have not fallen into the trap of least common denominator standards, which can often happen in order to achieve consensus. They instead underscore the effectiveness of industry organizations that strive for excellence. Rees concludes that this approach has worked in INPO and WANO because much of the management was instilled with a commitment to excellence and high safety standards due to their leadership's training in organizations such as the nuclear navy where that culture is integrated into all work activities. Most importantly, nuclear power plant owners and operators realize that they are "hostages of each other" in the words of Rees and that one major accident at one plant can harm the prospects for all other plants. Concerning the economic costs of safety, utility executives appear to face the tension between keeping overall plant costs down and maintaining high safety. But this is largely a false dilemma because preventive maintenance and safety training pay off in the long term, not only for helping to keep an individual plant running longer but also to sustain the vitality of the overall industry.

For countries needing safety guidance for starting up nuclear power programs, they should use the IAEA Nuclear Safety Series [IAEA, 2006a]. They can and should also seek advice from mature regulatory agencies. In addition, they need to adhere to the nuclear safety conventions.

2.4 Security

In this section, the focus is on physical security, not energy security. While improvements in nuclear safety have built on more than fifty years of experience in the commercial nuclear industry, the standards of excellence emulated from other nuclear organizations, and the decades long experience of the IAEA in developing nuclear safety standards, nuclear security has not received as much attention and resources from the communitarian perspective. One major reason for this discrepancy is that safety has been subject and amendable to quantitative probabilistic risk assessments. In contrast, security threats are much more difficult to quantify because of intelligent adversaries and the paucity of data due to the few attacks or attempted attacks on nuclear facilities. Another major difference is that safety culture has evolved to become more open about admitting mistakes in a "no fault" environment that should work to correct mistakes without seeking retribution on workers who have made mistakes or whistleblowers. In contrast, the security field tends to be more secretive by design because of not wanting to leak potential security weaknesses to adversaries. Moreover, many in the security field have voiced concerns on a not-for-attribution basis that the level of professionalism and culture in their field has not reached the high level as obtained by the safety field.

While it took two major accidents to stimulate needed improvements in safety and more interdependent professional development, perhaps the attacks of 9/11, although not nuclear or radiological related, will have a similar effect on the security field. For example, many in the industry have recently begun working with the Nuclear Threat Initiative, the U.S. Department of Energy, and the International Atomic Energy Agency in the newly formed World Institute for Nuclear Security (WINS), which was inspired by WANO. [Curtis, 2005] Peer reviews would help spur improvements in security and share lessons learned in order to develop better practices throughout the industry. The IAEA has also been developing the Nuclear Security Series, which is a companion to the safety series. However, the IAEA's nuclear security program is relatively small compared to its safety program. The nuclear security program would benefit from sustainable and adequate funding. One possible way to do this would be to include the security program's budget in the regular IAEA budget rather than fund it mainly from voluntary contributions. Further, major governmental parties to the Convention on Physical Protection of Nuclear Material (CPPNM) have recently agreed on an amendment to require stronger physical protection during domestic use of nuclear material among other needed improvements. But it will likely take many years for the amendment to achieve the requisite number of ratifications to enter into force. In sum, more international work is needed to implement better nuclear security practices.

2.5 Nonproliferation

The nuclear nonproliferation regime is a leading example of the power of interdependent action to protect individual states from the spread of nuclear weapons. This regime consists of multiple components that reinforce each other, including the Non-Proliferation Treaty (NPT), safeguards agreements and inspections, regional arrangements such as nuclear weapon free zones and bilateral and multilateral inspection regimes, including Euratom and the ABACC agreement among Argentina, Brazil, and the IAEA, export control regimes, and security assurances.

Second only to the UN Charter in universal application, the NPT includes all but four states: India, Israel, North Korea, and Pakistan. It has three main purposes: prevent the further spread of nuclear weapons, ensure access to peaceful nuclear technologies, and pledge countries to pursue nuclear disarmament and a treaty on general and complete disarmament. A renewed point of contention is the issue of access to peaceful nuclear technologies and the potential for misuse of those technologies in weapons programs. While the NPT does not explicitly guarantee that countries will have access to enrichment and reprocessing technologies, it does not explicitly rule out such access, and certain countries have interpreted the NPT to allow acquisition of these technologies. Recently, there has been considerable discussion about reinterpreting the treaty to limit access. This discussion has elicited push back from several non-nuclear weapon states in the developing world. They perceive that such reinterpretation will deny them their rights and thus infringe on their sovereignty. It is worth emphasizing that this right to peaceful nuclear technologies already comes with the responsibility to not acquire nuclear explosives and to maintain adequate safeguards on nuclear power programs. The International Atomic Energy Agency has the mandate to form safeguards agreements and to investigate countries' nuclear programs. Safeguards seek to deter diversion of peaceful technologies into weapons programs and to detect in a timely manner—to give enough time to interdict—such diversion. Concerns have been raised that safeguards as typically applied cannot detect or interdict in a timely manner. Notably, it can take as little as a few days to make highly enriched uranium or plutonium metal into a nuclear explosive, but safeguards inspections have not been applied at a frequency that could interdict such activity.

The most recent improvement to safeguards is the Additional Protocol to comprehensive safeguards agreements. The Additional Protocol was developed in response to the discovery in 1991 after the Gulf War that Iraq had been building a weapons program side-by-side with a peaceful program. Iraq had exploited a loophole in its safeguards agreement that limited inspectors' access to only declared nuclear facilities while undeclared facilities were considered off limits. While the IAEA Board of Governors already had the authority in the IAEA Charter to order a special inspection of undeclared facilities, in practice the Board has been politically reluctant to call for such inspections. The Additional Protocol has provided the IAEA with the authority to transform its safeguards inspections from a focus on accountancy to an investigatory culture. That is, under the Additional Protocol, the inspectors are required to determine whether there are any undeclared facilities and nuclear materials. Although the Additional Protocol has been successfully applied to many countries, it is still far from being universally applied. The Board of Governors needs to make the Additional Protocol a requirement for all countries with significant use of nuclear power. Moreover, the Nuclear Suppliers Group should make the Additional Protocol a condition for export of nuclear technologies. In the spirit of continual renewal, countries should also work toward trying to improve safeguards beyond the Additional Protocol. It is also worth redoubling international efforts to strengthen the application of existing authorities, to develop additional authorities, and to improve enforcement mechanisms especially the UN Security Council. [Goldschmidt, 2007] Finally, industry can and should consider self-policing in the nonproliferation field similar to its successful efforts using peer review in the safety field. [Hund and Seward, 2008]

2.6 Waste management

Each nuclear power producing state has the responsibility to safely and securely manage radioactive waste it generates. While a few countries have taken significant steps to opening up a permanent repository for high level nuclear waste, no country has actually opened up such a facility. Countries with small nuclear power programs could greatly benefit from working cooperatively with similar countries to site and build regional repositories. From the technical standpoint, this is a sound idea that has received support from numerous technical experts. But from the political perspective, this approach has confronted significant opposition. Nonetheless, it is worth pursuing as long as an equitable agreement can be reached. Such an agreement would provide the needed confidence that the site is safe and that the country hosting the site will receive fair compensation. Countries can and should share research and development on methods to reduce waste generation and more effective use of nuclear fuels. This activity ranges from research into reprocessing, fast reactors, and higher burn up fuels.

2.7 Legal framework

Overarching safety, security, nonproliferation, and waste management is a legal framework on the national and international levels. Each country with a nuclear power program has the individual responsibility to enact the appropriate legislation for implementing safety regulations, providing for adequate liability coverage in the event of an accident, ensuring safe and secure handling and disposal of radioactive waste, and securing nuclear facilities and materials. National legislation needs to be in harmony with international law, safety conventions, and treaty obligations. It is worth emphasizing that passage of a law and publication of regulations must go hand-in-hand with continual development of safety and security cultures.

3. Conclusion

In sum, planning for a nuclear power program and ensuring safe and secure use of nuclear power are complex endeavors. States should base their decisions on whether to proceed with nuclear energy development on sound and thorough energy system analysis and smart assessment of the capability to finance nuclear power plants comparing to other energy choices. Wise management of energy systems, especially nuclear energy systems, should build on a principled-based method that strives for excellence and that has a foundation of independent responsibility integrated to an interdependent international system. States seeking nuclear power programs should avail themselves of guidance from states with mature nuclear power programs. While energy isolation is not possible or desirable, a robust, well-balanced interdependent energy system provides the energy security that countries need.

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