The Changing Climate for Nuclear Power in the United States

Richard Meserve, Chair, US Nuclear Regulatory Commission

Introduction: ***Ernest Moniz,*** Professor of Physics, MIT

Ernest Moniz

It is a great pleasure to introduce Richard Meserve. Our relationship goes back thirty-five years, from our undergraduate years to our graduate education and then, finally, to a shared term in the Clinton administration.

Our earliest interactions occurred during the first of the summers we spent at AVCO Everett Research Laboratory, working on supersonic flowing gas lasers. Much of the job entailed setting off rather large bangs in our immediate vicinity. Only later did we realize that this was early training for our service in government.

We both went on to Stanford in physics. Much later, I went to the Department of Energy, where I had overall cognizance of nuclear issues—nuclear nonproliferation, nuclear power, nuclear weapons. Many of those issues brought me into contact with Mr. Meserve, as he became chair of the Nuclear Regulatory Commission (NRC), trying to work with the sometimes unruly Department of Energy and, of course, doing other tasks as well.

Earlier, Mr. Meserve was the counsel in the Office of Science and Technology Policy, under Science Advisor Frank Press. He was there during the acci-

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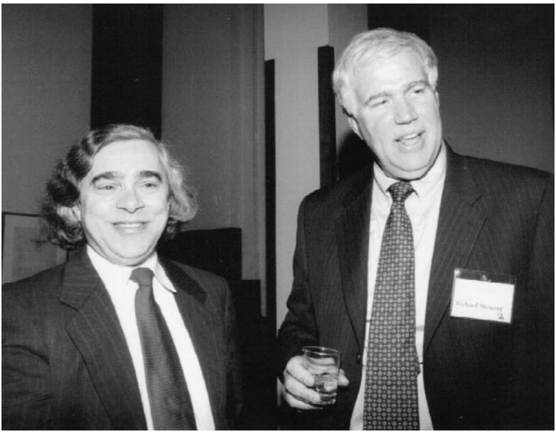

Ernest J. Moniz (MIT) and Richard Meserve (US Nuclear Regulatory Commission).

dent at Three Mile Island—one of those events that continues to cast a large shadow over the development of this field.

Mr. Meserve has been involved in many important activities relevant to a broader set of nuclear issues than we will hear about tonight. For example, in chairing and joining the various committees of the National Academies and in working with the Department of Energy, he led very important reviews of the weapons complex, with important consequences such as shutting down the very old Savannah River reactor that had produced plutonium.

He led a committee reviewing the issue of controlling nuclear weapons and materials in Russia—a major activity undertaken by our government over the past decade. Despite the considerable success of that effort, much work remains to be done, and Mr. Meserve's report helps keep our government's focus on this crucial security need. Mr. Meserve also headed a secretarial advisory committee at the Department of Energy that sought to define the parameters of openness: How does one go about declassifying materials? What are the right boundaries to draw? How do you eliminate nonsensical classification and put fences around things that need to be protected? When Mr. Meserve was nominated to chair the NRC, the Secretary of

Energy awarded him the gold medal for exceptional service to the department and to the nation over many years.

Tonight we will hear Mr. Meserve's reflections on what is a very interesting time in the nuclear business. On the one hand, despite the lack of commitment to building new power plants for many years, there are stirrings of a possible rejuvenation in that area, with environmental issues such as climate change serving as impetus. On the other hand, different environmental issues, including those related to nuclear waste, are still viewed as major impediments to going forward.

Let me touch briefly on the connection between nuclear power development and nonproliferation—not only in the traditional sense of people worrying about nuclear power issues spilling over into weapons, but also in the sense of nuclear power's role in helping to eliminate some cold war legacies—for example, the disposal of plutonium, which could lead the NRC to be faced with the issue of licensing plutonium fuels. The disposition of plutonium dioxide from nuclear power plants in the United States is an example of the kind of challenge that Mr. Meserve may face as issues regarding energy, environment, and security come together in the next few years. He is uncommonly qualified as a scientist, a lawyer, and a public servant to lead in the resolution of these pressing issues.

Richard Meserve

The United States is currently in a period of growing interest in nuclear power. The report of the Vice President's interagency task force on energy highlights the importance of nuclear energy as part of the country's electric power portfolio. Also, several bills pending in Congress deal with matters related to nuclear energy. My comments will focus on the current situation with regard to nuclear power in the United States and some of the issues bearing on it.

The Nuclear Regulatory Commission (NRC) does not have a role in the promotion of nuclear energy;

decisions about construction of power plants are made elsewhere in society. The NRC's role is to ensure that if a decision is made to proceed on a nuclear path, nuclear power plants and other related facilities are operated so as to provide adequate protection of public health and safety and adequate protection of the environment. Nonetheless, the agency does have an obligation to ensure that its regulatory requirements do not impose needless impediments. As a result, the NRC has sought to examine its regulatory activities to ensure that they enhance the agency's capability to protect public health and safety.

Nuclear Power in the United States and the World

Other countries rely on nuclear power to provide a large fraction of their electricity. For example, France and Lithuania obtain over 70 percent of their electric generation from nuclear power. By contrast, the United States relies on nuclear power for only about 20 percent of its electricity. In fact, when compared with other developed countries that employ nuclear power, ours is near the bottom in terms of the percentage of electricity generated by nuclear plants. The United States has alternative indigenous fuel supplies, principally an abundance of coal, which is not the case in many other countries. Natural gas is a fuel of increasing importance as well.

Although the contribution from nuclear plants in the United States as a percentage of electrical generation is relatively small compared with that in many other countries, the number of operating power plants is large. Currently, 103 nuclear power plants are licensed to operate in the United States, with a generating capacity in excess of 97,000 megawatts (MW). (This does not include Unit 1 of the Browns Ferry plant, which holds an operating license but was shut down in 1985 and cannot resume operations without the NRC's permission.) Ours is by far the largest commercial nuclear power program in the world; France, with the second-largest program, has 57 reactors, with a capacity of about 60,000 MW. Overall, there are about 440 commercial power plants around the world, with a total capacity of about 350,000 MW, so more than one-fourth of the world's nuclear electricity is generated by plants in the United States. The contrast between percentage and actual numbers reflects our huge reliance on electric power.

It is striking to note the growth in the amount of electric power that US plants generate. In 2000 the United States produced about 750 billion kilowatt-hours (kWh) of electricity from 103 nuclear plants. In 1990 the total generation was about 550 billion kWh from 111 nuclear plants. In other words, during a period in which there has been a decline in the number of nuclear plants, the total energy produced has increased substantially. The increment in power generation between 1990 and 2000 is the equivalent of about 23 additional standard (1,000-MW) plants. This increase in nuclear power production of nearly 40 percent over the last decade has come about as a result of significant improvements in plant operation.

One measure of this improvement is the capacity factor—the ratio of the actual power produced to the power that would be produced if the plant were operating 100 percent of the time. In 1990 the aggregate capacity factor for all US nuclear plants was about 60 percent, whereas in 2000 it increased to nearly 90 percent. Most plants in our country operate on a refueling cycle of 18 to 24 months and must shut down for several weeks to accomplish that task. As a result, a 90 percent capacity factor is only slightly less than the practical maximum. The vast improvement in performance by US nuclear plants has enabled the nuclear sector to maintain its share of the electrical market over a period in which the demand for electrical power has increased considerably. The nuclear industry has achieved this improved performance through better management, maintenance, training, and attention to detail.

Current Trends in the Nuclear Power Industry

The improved industry performance has been accompanied by a decline in the cost of nuclear-generated electricity. The average production cost of electricity from nuclear plants—which includes essentially all costs except for amortization of the plant—was about 1.71 cents per kWh in 1999. Although nuclear plants have high capital costs, many older plants have been fully amortized, so production cost is a relatively accurate measure of the power costs. Nuclear power's low production cost means that it is among the cheapest sources of electricity in the United States. Coal is slightly more expensive than nuclear energy, and while natural gas prices have fluctuated greatly over the past year, the fuel costs alone for US gas plants average several cents per kilowatt-hour.

The impressive economic performance of nuclear plants has proved very important as a result of retail price deregulation of electricity. Of course, in the traditional regulated market, the costs for the construction and operation of a power plant are part of a rate base; the utility company is allowed to recapture its costs plus a slight profit. Under deregulation, the competitive market determines the selling price of electricity—irrespective of the costs of generation—and the revenue of the generating company. Because nuclear plants are the low-cost producers, the business world now sees nuclear plants as very good investments.

Nuclear plants have other attractive features from the generators' perspective. Fuel costs are a comparatively small part of the overall cost of nuclear electricity, and they are generally predictable over the long term—quite unlike natural gas, for which the price has recently been highly volatile. Nuclear plants also are not affected by increasingly stringent emissions requirements, which have become important with regard to the use of coal. Moreover, the growing concern about greenhouse gas emissions is causing society to reassess the importance of nuclear power, which does not contribute to those emissions. The renewed interest in nuclear power was not anticipated as recently as a few years ago. Many pundits in the energy sector predicted that electric price deregulation would result in the premature retirement of nuclear plants because they could not compete economically, and that the US nuclear industry would decline. The actual situation is considerably different. There is now an aggressive market in "used" nuclear plants.

The restructuring of the market has yielded consolidation in the electric generation business, particularly with respect to nuclear power. The NRC currently has just over 30 different licensees for the 103 nuclear plants, a number that changes frequently as a result of plant sales, company mergers, establishment of joint operating companies, and other such industry activities. This is down from over 40 licensees just a few years ago. The expectation is that within five or ten years, there may be only about ten nuclear generating companies.

The NRC watches this process of consolidation with cautious optimism. The agency expects that licensees with a nuclear focus may be able to bring greater management expertise to the table, have greater capacity to identify and resolve problems, and be able to provide better employment opportunities for skilled individuals than licensees with more limited investment in nuclear assets.

Along with the positive aspects of consolidation comes one concern: that pressures on generators to reduce operating costs could affect plant safety. To date, however, the NRC has not seen indications of this sort of trend. The NRC tracks a number of indicators of plant performance and safety, such as automatic shutdowns (referred to as "scrams"), safety system actuations, plant events that are considered to be safety-significant, and collective occupational radiation exposure. Each of these indicators shows a trend toward safer operation over the past decade.

In short, the data show that nuclear electricity has become very competitive with alternative forms of electrical generation and that safety trends are improving in parallel with operating trends. The NRC believes that there is a logical reason for these parallel trends: A safe plant is a reliable plant for the simple reason that safety requires consistent, predictable performance. And for good economic performance, a plant must be on line, producing electricity. Thus, safety and good economic performance are inextricably linked through the common dependence on reliability.

While the nuclear power industry deserves much credit for improving both safety and economic performance, some of these trends can also be attributed to NRC initiatives. As nuclear plants were designed and built in the 1970s and 1980s, the NRC's focus was largely on design and construction issues. In the last decade or so, however, there has been a fundamental shift in emphasis toward operational issues. The NRC has identified issues requiring resolution by licensees, and the agency's increased attention in this area has also stimulated licensees to address operational concerns.

Recent Initiatives: License Renewal

Several major initiatives under way at the NRC bear on the overall issue of the contribution of nuclear power to the US electrical supply. The first of these is license renewal. The Atomic Energy Act limits the term of a license for a nuclear plant to 40 years. The choice of that duration was not a consequence of any technical judgments made by Congress; rather, it was driven by antitrust and financial concerns. There was optimism that nuclear power plants were going to produce large amounts of very inexpensive power, and Congress sought to limit the long-term dominance that a licensee might obtain. The statute did allow, however, for the NRC to consider license renewals in increments of 20 years.

The current fleet of nuclear plants began operations largely in the period from the mid-1970s to the mid-1980s. If plants were to shut down as they reached the end of their operating licenses, with no new construction and no license renewals, the United States would maintain its nuclear capacity near the present value of 97,000 MW until about 2010. Then, as plants were retired, a rather steep fall-off would occur until the last shutdown in about 2035. As a matter of national energy policy, this trend could be of concern, particularly if alternative sources of power are needed to deal with greenhouse gases and other fossil plant emissions.

The improved operational and economic performance of nuclear power plants has encouraged an enormous upsurge of interest in continuing to operate plants beyond the expiration of their initial 40-year licenses. Consistent with its statutory authorization to consider license renewal, the NRC has developed a process for the review of renewal applications. That process includes an extensive analysis that focuses primarily on aging issues, to ensure that the margin of safety of the plant will continue over the extended period of operation. To date, almost half of US nuclear plants have formally indicated their intent to pursue license renewal.

Review of applications for 20-year license renewals began in 1998, and three such applications, covering a total of six nuclear units, have been approved: Calvert Cliffs in Maryland, Oconee in South Carolina, and Arkansas Nuclear One. Seven applications are currently under review, and we know that many more will be submitted over the next four years. However, the NRC's license renewal rule generally does not allow an application for license renewal to be submitted unless the plant's remaining licensed operating period is less than 20 years; thus, plants licensed in the mid-1980s are not yet eligible. Based on statements of various industry leaders, the NRC expects that almost every operating nuclear plant in the United States will ultimately apply for license renewal.

Recent Initiatives: Advanced Reactor Designs

The industry's response to the possibility of license renewal has the potential to extend the period during which nuclear power can make a substantial contribution in the United States to around the middle of this century. However, if nuclear power is to retain a significant role in our nation's energy portfolio, new plants will eventually be needed. Consequently, another NRC initiative involves consideration of advanced reactor designs.

The agency has established a process for licensing new designs, called design certification. The traditional two-step licensing scheme used for all the plants now operating in the United States involved granting a construction permit and then, after the plant was built, issuing an operating license. Each step involved public hearings and potentially extensive litigation, which could put at risk the operation of a plant upon which billions of dollars had been spent. In contrast, the design certification process provides for early review of a standardized design in a publicly accessible process. If the design is approved, it can then be referenced in future license applications without the need to relitigate issues resolved during certification. The license that can be issued under this process is a combined construction permit and operating license. When it is completed, the plant may begin operation after the applicant demonstrates, through a structured regimen of inspections, tests, analyses, and acceptance criteria, that the plant, as constructed, conforms to the certified design.

Three designs have been certified: the General Electric (GE) Advanced Boiling Water Reactor (ABWR), the Combustion Engineering (CE) System 80+ (now owned by Westinghouse through the acquisition of both Westinghouse and CE by British Nuclear Fuels, Ltd.), and the Westinghouse AP600. All three designs are based on existing US water-cooled reactor technology. While the ABWR and System 80+ represent evolutionary improvements in conventional plants, the AP600 takes a "passive" approach to safety, in which the safety systems operate by natural means (gravity or pressure), without reliance on pumps or AC electrical power. However, there has been no move to construct one of these three designs in the United States, although ABWRs are operating in Japan and are under construction in Taiwan.

In recent months, interest in new plant designs has grown substantially. A task group sponsored by the Nuclear Energy Institute (NEI), an industry trade organization, is developing a business plan for new plant deployment. The president of NEI has announced an initiative called "Vision 2020," which involves deployment of 60,000 MW of new nuclear capacity in the next 20 years. About 83 percent of that total is to come from new plants, while the remainder comes from increasing the power output of existing plants. Concurrently, the NRC is in the early stages of review of four new reactor designs. One is Westinghouse's AP1000, similar in concept to the certified AP600 design but with an increased power output. The other three are small reactors, generically referred to as "modular," and represent a departure from conventional reactor technology.

Two of the modular reactors are cooled by helium rather than by water, and they depend on graphite to moderate (i.e., to slow down) neutrons in the reactor to keep the atomic chain reaction going. Both designs also use a gas turbine to produce electricity, rather than one that runs off of steam. One of the designs uses graphite-encapsulated fuel, in the form of spheres about the size of tennis balls. These spheres are called "pebbles," and the reactor is called a pebble-bed modular reactor (PBMR). The electrical output of this design is around 130 MW, or about one-tenth the amount of the most modern large water-cooled reactors. The basic design of the PBMR was developed in Germany more than 30 years ago, and an updated version of the design is being considered for deployment in the Republic of South Africa (RSA). Exelon, a US nuclear operating company, is a partner in the RSA project and has announced that if the RSA initiative is successful, it will apply to license the PBMR in the United States.

A second gas-cooled design, the gas turbine modular helium reactor (GT-MHR), is being developed by General Atomics, a US reactor vendor. This plant is somewhat similar to the PBMR, but its prismatic core is composed of stacks of hexagonal graphite blocks, which incorporate the graphite-coated fuel material. The electrical output of the GT-MHR design is about twice that of the PBMR.

The third advanced design being examined by the NRC is a water-cooled concept, but one that has a novel plant configuration. It is called the International Reactor Innovative and Secure (IRIS), developed by Westinghouse. The fuel and core design are similar to those of conventional reactors, but the IRIS design puts the steam generators—heat exchangers in which heat from the water that cools the nuclear fuel is used to boil nonradioactive water to run the turbine and produce electricity—inside the reactor pressure vessel, rather than having them as separate components. This makes the design much more compact than conventional plants and eliminates large-diameter pipes. The power output of the IRIS design has not been fixed but is expected to be in the same range as the PBMR and GT-MHR.

As noted previously, these designs are referred to as "modular." Existing nuclear plants are very large, with electrical outputs exceeding 1,000 MW, and require most of the construction to be performed at the construction site. Although economies of scale tend to favor large plants, modular plant designs may provide an opportunity for large portions of a plant to be factory-constructed, transported to the site, and installed, greatly reducing construction time and cost. Small plants may also have an advantage when the effects of price deregulation are considered. Deployment of a 1,000-MW plant could result in a supply of power that greatly exceeds demand, which would tend to depress the price. Deployment of a smaller unit allows a generating company to tailor the size of the unit to the demand. As demand grows, additional modules can be deployed with relatively short construction times, with revenue from the operating modules offsetting the cost of the new construction.

It must be emphasized that the NRC is in the very early stages of reviewing these plant designs. None has been formally submitted either for design certification or for a license, and the issues and economics associated with modular reactors are speculative. However, it is significant that serious discussions of these issues are occurring, particularly because the demise of the nuclear power industry was widely expected only a few years ago.

Recent Initiatives: Risk-Informed Regulation

For the last several years, the NRC has been working to modernize its approach to reactor regulation, using insights based on over 2,000 reactor-years of nuclear plant operation in the United States and improvements in methods of evaluating the risk of nuclear power plant operations. This is referred to as "risk-informed regulation" and represents one of the most far-reaching initiatives that the NRC has ever undertaken.

Most of the regulations that apply to nuclear power plants are relatively old and reflect the NRC's knowledge base at the time the rules were developed. The underlying philosophy was to ensure ample margins in engineering analyses; extensive quality assurance and control in design, component fabrication, and plant construction; and diversity and redundancy in plant systems, especially those believed to be important to safety. This overall approach, called "defense in depth," was designed to prevent the occurrence of an accident but also, if one occurred, to provide for mitigation of its effects.

While this regulatory system has worked well over the years, the accumulation of operating experience has shown that some design and operating margins are unnecessarily large. Moreover, great strides have been made in methods of quantifying the risk associated with reactor accidents. This technique, called probabilistic risk assessment (PRA), is a systematic evaluation of the plant to determine potential accident sequences and assess their frequencies by looking at the probabilities of failure of systems and components. The first significant application of this methodology to nuclear power plants was a project sponsored by the NRC and its predecessor, the Atomic Energy Commission (AEC), in the early 1970s. The study was led by Norman Rasmussen of MIT, and the publication of his report, the *Reactor Safety Study* (more commonly known by its report number, WASH-1400), was a watershed event in nuclear reactor safety analysis.

Since 1975, refinement of PRA techniques, augmented by an extensive database derived from plant operational experience, has turned PRA into a powerful tool for assessing nuclear plant safety. Risk-informed regulation involves using PRA as one of the bases, but not the only one, for improving the safety focus of the NRC's regulations. As risk-informed techniques are applied, regulations that are not safety-significant can be modified or eliminated, and excessive margins can be reduced. On the other hand, risk insights may also show that some regulatory requirements need to be enhanced.

The NRC's initial efforts in risk-informed regulation have yielded some early successes. The agency's reactor inspection program, carried out primarily by inspectors stationed at the plant (resident inspectors) and in the NRC's regional offices, has been completely revamped to provide a better focus on plant safety, and also to make the results of those inspections more easily understood by those outside the NRC, the agency's "stakeholders." The success of this program can be gauged by the fact that it has been endorsed by the NRC's licensees *and* by critics of the industry. However, it must be acknowledged that there are challenges as the NRC proceeds along this path. Risk-informing the existing regulatory structure has proven to be difficult because of the intricate—and sometimes subtle—relationships among various regulations. Changing one rule may impact others in unforeseen ways, and conflicts that arise in this manner must be resolved. While the NRC is committed to continue with its efforts to risk-inform its regulations, it recognizes that the process will sometimes be difficult.

Nuclear Waste

No discussion of nuclear power in the United States would be complete without mentioning the issue of nuclear waste. Many people are worried not only about the safety of the plants but also about the disposition of the spent fuel that results from nuclear plant operations. At present, spent fuel is held in pools at the reactors or in independent spent-fuel storage installations—giant casks, typically located at the plant site, that hold the fuel (loaded several years after removal from the reactor) and cool it by air convection.

Although the spent fuel at plant sites is safe, there is a limited amount of room for such storage, because these plants were constructed with the expectation that the federal government would establish a permanent, centralized repository for spent reactor fuel. The Department of Energy (DOE) operates a program to evaluate such a potential repository at Yucca Mountain, in Nevada. This project has been proceeding slowly for a number of years, with a very complex legal and technical system for site assessment and, ultimately, repository operation. Under current law, the DOE will be responsible for constructing and operating the repository. The Environmental Protection Agency is responsible for establishing standards that will govern the site. The NRC is the licensing entity for both construction and operation. There is a role for the President, in approving whether to go forward with the site once the DOE makes a formal recommendation to proceed, and a role for Congress as well. The current schedule calls for the Secretary of Energy to make a recommendation to the President by the end of 2001.

All the parties involved in the process must confront several challenges as it proceeds. There is no doubt that there will be stringent opposition, particularly by Nevada. The state has indicated that it intends to litigate at every available opportunity to prevent the repository from being sited at Yucca Mountain. Only time will tell if the United States is on a path for disposal of spent fuel.

Public Confidence in the NRC: An Essential Element

One of the biggest challenges that the nuclear power industry confronts is the concern of the public for the safety of its enterprise. The NRC tries to address the foundations for these concerns through its comprehensive regulatory program. The NRC believes that the industry is best served if the agency is—and is perceived to be—a tough regulator. Such a philosophy protects each licensee from the negative impact that would occur if another licensee were to fail to meet its obligations, resulting in a serious accident.

The NRC has an extensive program for public outreach and makes an effort to engage the public in all activities, in recognition of the fact that the public has a legitimate stake in the matters that come before the agency. We recognize that any decision that is made behind closed doors will be viewed as suspect. Ultimately, however, society must decide whether to encourage or discourage more extensive reliance on nuclear power. A quiet renaissance of interest in nuclear power is in progress in the business community. It remains to be seen how the climate for nuclear power in the United States may evolve in the future.
