DOES NUCLEAR POWER HAVE A FUTURE?

Michael E. Stern* & Margaret M. Stern**

I. INTRODUCTION

The simple answer to the question posited by the title of this Article is "Yes." The safety, environmental, economic, and legal reasons underpinning this affirmative response are reasonably straightforward. This Article will define and delineate the most compelling of those reasons.

When all costs and externalities are appropriately evaluated, the utilization of controlled nuclear fission as the basis for the commercial generation of electric power in the United States is cost-effective and safe. The public health and safety and environmental impacts of reasonably evaluated worst-case accident scenarios hypothesized for the new generation of domestic reactor designs are manageable, with the most significant consequences being economic. The regulatory requirements for new power reactors effectively preclude the release of significant quantities of radioactive materials from foreseeable events and postulated accidents.[1] Whereas current experience indicates that nuclear power is very safe relative to other methods of generating electricity, the consideration of safety and improvements of new designs combined with the assessment of relative risk associated with major energy sources, as discussed hereinafter, indicates that facilities under construction or undergoing regulatory approval are at least two, and in most cases four, orders of magnitude lower in risk to the health and safety of the public than currently operating electricity-generating facilities fueled by fossil fuels.

II. A LOOK BACK

A. The Legacy of Past Accidents

The recent history of the commercial nuclear industry worldwide includes three well-publicized accidents attributable primarily to failure to conform to design criteria, human operational error, and regulatory shortcomings. The most recent of these three events, the post-tsunami partial fuel melt and breaches of containment at the Fukushima Daiichi Nuclear Plant, is attributable to the occurrence of a natural event, the magnitude of which was initially believed to exceed the six-reactor facility's design basis.[2] International evaluations unambiguously conclude that the fuel and containment failures at the three

---

[1] 10 C.F.R. § 52.47(a)(2)(iv) n.3 (2012).

[2] *Fukushima Accident 2011*, WORLD NUCLEAR ASS'N, http://www.world-nuclear.org/info/fukushima_accident_inf129.html (last updated Aug. 30, 2012).

then-operating[3] Fukushima plants is more properly attributed to the improper establishment of design criteria for preventing potential flooding of the facility.[4] Those criteria did not fully account for the known tsunami risk and history of the site upon which the facility is located. Nevertheless, no deaths or serious physical injuries have been directly attributed to the event. The Fukushima response by the Japanese government has been to limit emergency response personnel and the general public to established radiation exposure limits and guidelines. Thus, future deaths projected by various authorities by application of the linear dose model are very unlikely to occur, because the consequence projections have not been demonstrated to be accurate for exposures maintained within established guidelines. Nevertheless, the Fukushima event resulted in a total loss by the facility owner of its capital investment in the facilities and more importantly, significant environmental damage to the local area.[5] In addition, remediation costs will be substantial, and future litigation will no doubt result in additional economic losses due to damages awards.

The massive economic loss and irrevocable disruptions of individual lives that resulted from the Fukushima event could and should have been avoided by appropriate comprehension and application of basic technical and legal requirements associated with the utilization of nuclear energy. There is no excuse for the fundamental failure of those parties with jurisdiction over and responsibility for nuclear safety at the Fukushima Daiichi Nuclear Plant to understand and implement such requirements.

During the 1979 accident at Three Mile Island Unit 2 (TMI 2), reactor operators terminated safety system operations based upon the facility license condition, which conflicted with other license requirements that were not necessary for the assurance of safety.[6] The operators improperly chose to observe the license condition specifying the maximum allowable pressurizer water level while shut down at an elevated temperature, rather than another license condition to which adherence was vital to prevent damage to the reactor fuel. In the United States, the development of facility license conditions are the result of extensive interactions between the licensee, the regulatory authority, the vendor responsible for the nuclear reactor design, and the architect or engineering firm responsible for the design of the facility.[7] Thus, the fundamental error made in the early hours of

---

[3] INT'L ATOMIC ENERGY AGENCY, IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI 12 (June 16, 2011), *available at* http://www-pub.iaea.org/mtcd/meetings/pdfplus/2011/cn200/documentation/cn200_final-fukushima-mission_report.pdf [hereinafter MISSION REPORT].

[4] *See id.* at 78–79.

[5] *See generally* WORLD NUCLEAR ASS'N, *supra* note 2.

[6] *See* 3 JOHN G. KEMENY ET AL., THE PRESIDENT'S COMMISSION ON THE ACCIDENT AT THREE MILE ISLAND, REPORTS OF THE TECHNICAL ASSESSMENT TASK FORCE, 75–77 (1979), *available at* http://threemileisland.org/downloads/197.pdf.

[7] *See* 10 C.F.R. § 50.36 (2012). Licensees are required to propose technical specifications necessary to assure safe operation of the facility. The NRC staff is

the TMI 2 event implicated the responsible federal regulatory authority, the reactor owner, and the design and engineering companies responsible for the construction and licensing of the TMI 2 plant.[8] The results of that error, which precipitated subsequent confusion by elected officials and others charged with the maintenance of public order, created a lasting public impression of the general inadequacy of U.S. nuclear facility designs, construction, licensing, and operations, as well as the incoherent federal regulation of the nuclear industry.[9] However, extensive investigation of the accident at TMI 2 resulted in the identification of no fundamental design errors as a cause of or as a contributing factor in the accident. The accident resulted from human error related to the comprehension and implementation of event mitigation steps specifically defined within the safety analysis of the facility that were in conflict with unwarranted concerns regarding reactor coolant system overpressure when the reactor coolant system was at elevated temperatures and the reactor shut down.[10]

The lessons learned from the TMI 2 accident led to improvements in communications by and between the nuclear facility; federal, state, and local authorities; and the public; as well as improvements in evacuation planning.[11] However, no fundamental changes have been made to the underlying General Design Criteria, 10 C.F.R. Part 50, Appendix A, regarding the basic three fission product barrier design requirements that are the legal backbone of commercial nuclear reactor regulation in the United States. The vast majority of the regulatory requirements flowing from the accident at TMI 2 are focused on enabling a more effective emergency response should a similar event occur at another facility in the future.[12]

---

responsible for the review and acceptance of those technical specifications that are included as conditions of the facility operating license. *Id.*

[8] *See* 1 MITCHELL ROGOVIN ET AL., THREE MILE ISLAND: A REPORT TO THE COMMISSIONERS AND TO THE PUBLIC 167–71 (1980), *available at* http://threemileisland.org/downloads/354.pdf.

[9] *Id.*

[10] *See* AMERICAN SOCIETY OF MECHANICAL ENGINEERS, BOILER AND PRESSURE CODE (2010). The Boiler and Pressure Vessel Code specifically requires that the reactor coolant safety valve be sized to provide protection from the combined effects of water injection with energy input from reactor decay heat, the reactor coolant pump energy input, and energy input from pressurizer heaters. Satisfaction of the requirements of the Boiler and Pressure Vessel Code is an integral part of the license conditions for all nuclear reactors. *Id.*

[11] *See* Emergency Planning, 45 Fed. Reg. 55,410 (Aug. 19, 1980) (to be codified at 10 C.F.R. pt. 50, app. E).

[12] *See also* U.S. NUCLEAR REGULATORY COMM'N, CLARIFICATION OF TMI ACTION PLAN REQUIREMENTS (1980), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0737/final/sr0737.pdf; *see generally* U.S. NUCLEAR REGULATORY COMM'N, CRITERIA FOR PREPARATION AND EVALUATION OF RADIOLOGICAL EMERGENCY RESPONSE PLANS AND PREPAREDNESS IN SUPPORT OF NUCLEAR POWER PLANTS (1980), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0654/r1/sr0654r1.pdf.

As to the Chernobyl accident, suffice it to say that the now-defunct Soviet Union's Cold War–era focus on military preparedness, coupled with its ideological fixation on the power of the state, and the consequent subordination of public health and safety to the overwhelming objectives of the militaristic system, precluded the development of a consistent set of safety-based reactor design criteria to which adherence was required.[13] Design flaws at the facility, described in multiple sources,[14] allowed the reactor to become uncontrollable because of the positive feedback to power increases—a condition prohibited in western designs. Additionally, the distribution of fissile material and moderating material following the ejection of the cooling water allowed the reactor to continue to operate subsequent to the catastrophic failure of fuel assemblies.[15] This continued operation, combined with the combustion of the graphite within the reactor, provided a very effective transport mechanism to distribute fission products to the environment, leading to the inevitable—radiation-induced illnesses, deaths, and environmental devastation. No non-totalitarian state has elected to utilize the RMBK technology employed at Chernobyl; the devastation wrought by its utilization serves as a monument to the folly of placing political ideology before public health and safety. The lessons learned from the Chernobyl disaster are primarily political and social, rather than technical, economic, or legal, and, thus, they have little relevance to the discussion of modern commercial nuclear technology.

B. The Legacy of Demand Reduction and Regulatory Changes

While the 1979 TMI 2 accident undoubtedly contributed to the outright cancellations of orders for new U.S. commercial nuclear plants, the TMI 2 accident had been preceded by other events, predominantly economic in nature, which had caused U.S. utilities to defer decisions regarding construction and licensing of new reactors prior to the accident.[16] Those economic considerations included acknowledgment of the reduction in the growth rate of electric energy demand that occurred in the late 1970s, and the economic impact of project modifications due to rapidly changing federal regulatory requirements. Those changes to federal regulatory requirements were in large part due to the establishment of the U.S.

---

[13] *See RBMK Reactors*, WORLD NUCLEAR ASS'N, http://www.world-nuclear.org/info/inf31.html (last updated June 2010).

[14] *See, e.g.*, INT'L NUCLEAR SAFETY ADVISORY GRP., THE CHERNOBYL ACCIDENT: UPDATING ON INSAG-1, 75-INSAG-7 (1992), *available at* www-pub.iaea.org/MTCD/publications/PDF/Pub913e_web.pdf; U.S. NUCLEAR REGULATORY COMM'N, REPORT ON THE ACCIDENT AT THE CHERNOBYL NUCLEAR POWER STATION (1987), *available at* http://pbadupws.nrc.gov/docs/ML0716/ML071690245.pdf.

[15] *See Why INSAG Has Still Got It Wrong*, NUCLEAR ENGINEERING INT'L (Apr. 9, 2006), www.neimagazine.com/story.asp?storyCode=2035398.

[16] *See No, the Three Mile Island Accident in 1979 Was Not a Major Cause of U.S. Nuclear Power's Woes*, THINK PROGRESS (June 25, 2011, 9:58 AM), http://thinkprogress.org/climate/2011/06/25/244122/three-mile-island-accident-nuclear-power/?mobile+nc&mobile=nc.

Nuclear Regulatory Commission (NRC), in 1974, as an independent regulatory agency with a statutory mandate to assure public health and safety.[17] Pursuant to the Energy Reorganization Act of 1974 the Atomic Energy Commission (AEC), which had jurisdiction over both safety regulation and development of new nuclear projects,[18] had its responsibility divided among two new agencies. The NRC was granted authority related to the protection of the public health and safety regarding matters associated with commercial use of nuclear energy and materials.[19] The Energy Research and Development Administration, the predecessor of the Department of Energy (DOE), assumed the remainder of AEC's responsibilities, including development of commercial nuclear technology and defense applications. The combination of decreasing demand for electricity, and the modifications and delays resulting from changes to regulatory approval requirements flowing from the NRC staff's development of new technical positions concerning the application of existing regulations that required revisions to designs of nuclear facilities under construction, eventually resulted in the cancellation of approximately 100 large nuclear facilities by electric utilities in all regions of the country. The regulatory changes that affected the subsequently completed reactors resulted in substantial cost overruns typically in the range of 100% of the original cost estimate for the facility.[20] The dominant reason for those cost overruns was project delay associated with design changes required necessary to address demands of a maturing technical staff of the new NRC, which was developing its technical review guidelines concurrently with its review of facilities then under construction.

The disruption to electric utility financing that flowed from the cancellation of a large number of nuclear facilities combined with the economic consequences of large cost overruns experienced by the facilities that were completed led to a thirty-year hiatus in commitment to new nuclear plant construction.[21] During that period, the development and refinement of nuclear facility design proceeded on a limited basis in response to the continuing international demand for nuclear power plants. At the same time, the U.S. utility industry displayed a complete aversion to the economic risk associated with the licensing process. Before expending resources on planning for the development of new nuclear facilities, the industry demanded modifications to that process to provide confidence that massive investments in new projects would not be repeatedly compromised by construction and licensing delays spawned by a continuous stream of new or revised NRC rules

---

[17] Energy Reorganization Act of 1974, Pub. L. No. 93-438, 88 Stat. 1233 (1974).

[18] Atomic Energy Act of 1954, Pub. L. No. 83-703, 68 Stat. 919 (1954).

[19] *Id.*

[20] BERNARD L. COHEN, THE NUCLEAR ENERGY OPTION ch. 9 (1990), *available at* http://www.phyast.pitt.edu/~blc/book/chapter9.html.

[21] *Id.* Many of the statements in this Article about the technical and pragmatic aspects of nuclear power, and the electricity industry more broadly, are based on the authors' first-hand knowledge as expert consultants in the industry over the past forty years.

and regulations and other regulatory guidance that is interpreted by the agency as having the force of law.[22]

III. REASONS FOR OPTIMISM: SAFETY, ENVIRONMENT, AND ECONOMY

A. *Nuclear Safety: A Modern Perspective*

As noted above, the results of detailed international evaluations of accidents at TMI 2 and at Fukushima have not yet identified any fundamental flaws in the design of the nuclear reactors and their associated safety systems. Since the accident at TMI 2, the NRC has authorized substantial increases in the rated power of licensed nuclear facilities without requiring any concurrent change to pump capacity or other safety features.[23] These power increase authorizations reflect the regulator's change in perspective to recognize and acknowledge the substantial safety margins available in the original designs of the reactors. The extent of those original margins have been ratified by engineering evaluations of extensive test programs that were initiated prior to the TMI 2 event and subsequently were completed, documented, and publicized.[24]

In the United States, commercial nuclear facility design, siting, licensing, construction, testing, operation, maintenance, and waste handling are activities conducted pursuant to the Atomic Energy Act and implemented pursuant to the NRC's regulations.[25] At the heart of this statutory and regulatory regime are the General Design Criteria for Nuclear Power Reactors (GDC) codified at 10 C.F.R. Part 50, Appendix A. It is noteworthy that since the initial promulgation of the General Design Criteria in 1971, no fundamental alterations have been made affecting the basic design requirement for the inclusion and maintenance of the integrity of three fundamental barriers to the dispersion of fission products to the environment. Given the evolution of the U.S. commercial nuclear industry to include, at present, 104 operating facilities, the fact that no changes have been found necessary in the fundamental three barrier design criteria is a significant indicator of the integrity of the original design basis for these facilities. It has been possible to design an emergency event classification and response system based upon maintenance of integrity, or the loss thereof, of the three barriers to fission-product release prescribed by the GDC: the fuel, the reactor coolant system, and the containment.[26]

---

[22] *See id*.

[23] *See, e.g.*, *Approved Applications for Power Uprates*, U.S. NUCLEAR REGULATORY COMM'N, (last updated July 20, 2012).

[24] *See* S. M. MODRO ET AL., U.S. NUCLEAR REGULATORY COMM'N, REVIEW OF LOFT LARGE BREAK EXPERIMENTS (1989), *available at* http://pbadupws.nrc.gov/docs/ML0625/ML062570206.pdf.

[25] 10 C.F.R. pts. 1–200 (2011).

[26] *See* Fission Product Barrier Emergency Event Classification and Response Sys., U.S. Patent No. 4,657,727 (filed Oct. 18, 1984) (issued Apr. 14, 1987).

It is instructive to consider how the operation of the GDC, if appropriately promulgated and implemented in Japan, could have precluded the consequences of the Fukushima event. The GDC require three barriers to preclude disruption by events such as the earthquake and resultant tsunami that destroyed the three Fukushima units. GDC criterion 2 requires that the facility be designed to address all potential site-specific environmental conditions.[27] In the United States, that requirement is met by demonstrating compliance with ground motion acceleration criteria determined by the NRC, in consultation with other federal agencies, including the United States Geological Service, and results in designation of a design-basis earthquake for the site, as well as potential flooding events, including a tsunami. At Fukushima, the failure to accurately designate the design-basis tsunami event for the site resulted in extensive flooding of the facility, which resulted in the total loss of all electric power to motors powering all rotating equipment (i.e., pumps, valves, and ventilation equipment) as well as to instrumentation providing information as to physical conditions within the plant needed by operators to evaluate and properly respond to those plant conditions.[28] In addition, GDC criterion 17 requires that emergency power be provided in order to ensure the operation of systems and components needed to provide emergency core-cooling water in the event of a loss of integrity of one fission product barrier or more.[29] At Fukushima, the tsunami wave disabled all electric power within the facilities.[30] This led to the loss of cooling of the reactor cores, which subsequently

---

[27] 10 C.F.R. pt. 50, app. A (2012) ("*Criterion 2—Design bases for protection against natural phenomena*. Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.").

[28] *See* INST. OF NUCLEAR POWER OPERATIONS, SPECIAL REPORT ON THE NUCLEAR ACCIDENT AT FUKUSHIMA DAIICHI POWER STATION 7-12, 45 (Nov. 2011) *available at* http://www.nei.org/filefolder/11_005_Special_Report_on_Fukushima_Daiichi_MASTER_11_08_11_1.pdf.

[29] *Id.* ("*Criterion 17—Electric power systems*. An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.").

[30] MISSION REPORT, *supra* note 3, at 39–40.

resulted in the loss of containment integrity due to venting necessary to prevent overpressure rupture.

The damaged Fukushima reactors are boiling water reactor units designed by the General Electric Co. (GE) in the 1960s and 1970s.[31] A characteristic of that vintage of the GE boiling water reactor (BWR) design is a relatively small containment volume, which includes a substantial amount of water in a suppression pool within the containment structure to provide reactor core cooling during the initial stages of any serious event. The small containment volume requires removal of heat following a disruptive event such as an earthquake or equipment failure subsequent to any reliance on the containment system. That heat removal is accomplished by heat transfer systems utilizing electrically powered pumps and valves.[32] Because all sources of electric power were interrupted due to the tsunami, the plant was unable to limit the pressure within the containment and required venting to the atmosphere. The plant was also unable to inject water into the reactor coolant system to replace the coolant that had been boiled off as steam, thereby cooling the reactor fuel. The inability to inject water into the reactor vessel led to insufficient cooling of the reactor fuel, resulting in overheating of the fuel cladding and a zirconium-water reaction, which totally destroyed the cladding utilized as a fission product barrier.[33] It also generated a large amount of hydrogen gas, which is very volatile and is explosive if mixed with oxygen. The loss of the cladding as a physical barrier resulted in the release of substantial amounts of volatile fission products from within the fuel assemblies to the reactor coolant system, which was directly vented to the containment.[34] The volatile fission products and the hydrogen generated by the zirconium-water reaction combined with the nitrogen and steam atmosphere in the containment.[35] At Fukushima, the lack of capability to remove heat from the containment resulted in the need for controlled venting to the environment to prevent total loss of containment integrity.[36] That venting resulted in the transport of the volatile fission products and hydrogen present in the containment atmosphere to the reactor building.[37] The

---

[31] Bill Dedman, *General Electric–Designed Reactors in Fukushima have 23 Sisters in U.S.*, OPEN CHANNEL ON NBC NEWS (Mar. 13, 2011, 1:38 AM), http://openchannel.nbcnews.com/_news/2011/03/13/6256121-general-electric-designed-reactors-in-fukushima-have-23-sisters-in-us?lite.

[32] Salomon Levy, *Fukushima Daiichi Crisis: How Would US Units Fare?*, NUCLEAR ENGINEERING INT'L (Dec. 7, 2011), http://www.neimagazine.com/story.asp?storyCode=2061344.

[33] MISSION REPORT, *supra* note 3, at 30–32.

[34] *Id.*

[35] *Id.* In BWRs, relatively small containment vessels are filled with nitrogen to establish an inert gas atmosphere within the containment during power operation, thereby precluding an oxygen-hydrogen explosion within containment subsequent to a loss of coolant event. 10 C.F.R. § 50.44(b)(2)(i)–(ii) (2003). An oxygen-hydrogen explosion would likely result in a loss of containment integrity due to overpressure rupture.

[36] MISSION REPORT, *supra* note 3, at 31–33.

[37] *Id.*

hydrogen mixed with oxygen in the reactor building, resulting in a combustible mixture, which was ignited by one of many potential sources of ignition. The resulting uncontrolled hydrogen-oxygen explosions destroyed each reactor building that was subject to such a venting operation. The mixture of volatile fission products was thus distributed to the environment in an unconstrained manner as a ground-level release resulting in local contamination with radioactive materials.

None of the existing fleet of older BWRs with relatively small containment structures is designed to avoid releases of substantial amounts of radioactive materials upon an extended total loss of electric power.[38] Domestic BWRs subject to NRC regulation have been required to upgrade the containment venting pathway to assure that any venting operation results in the discharge of the containment atmosphere—containing hydrogen and volatile fission products—at the top of a high stack to assure maximum dilution and avoidance of explosive mixtures within the plant structures.[39] Fukushima had not installed such upgraded containment venting systems.[40] When all electric power is lost for an extended period of time in a boiling water reactor facility with a Mark I or II containment and without the upgrades mandated by the NRC for U.S. facilities to address such events, a Fukushima-type outcome is inevitable.

B. *New Designs Preclude Recurrence of Adverse Environmental Consequences*

Current NRC regulations effectively require new facilities to incorporate enhanced safety features, including passive emergency cooling schemes designed to avoid operator action and possible error because of reliance on the combination of human response and active emergency systems that could fail.[41] The new reactor designs include provisions to preclude severe consequences from the loss of power to the facility for extended periods of time, thereby providing assurance that major releases of radioactive material to the environment will not occur. The new passive-safe nuclear steam supply system designs address the extended loss of power by utilizing features that result in a substantial reduction in the number of components.[42] In addition to enhancing reliability, such advances reduce the

---

[38] *See* Installation of a Hardened Wetwell Vent, Generic Letter 89-16, U.S. NUCLEAR REGULATORY COMM'N, http://www.nrc.gov/reading-rm/doc-collections/gen-comm/gen-letters/1989/gl89016.html (last updated Mar. 29, 2012).

[39] *See Resolution of Generic Safety Issue: Containment Performance*, U.S. NUCLEAR REGULATORY COMM'N, http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/157r1.html (last updated Mar. 29, 2012).

[40] MISSION REPORT, *supra* note 3, at 19; *see also* NUCLEAR ENERGY AGENCY, FUKUSHIMA-DAIICHI NUCLEAR POWER PLANT INFORMATION 5 (2011), *available at* www.oecd-nea.org/press/2011/BWR-basics_Fukushima.pdf.

[41] Levy, *supra* note 32.

[42] *See AP1000: Unequaled Safety*, WESTINGHOUSE, www.ap1000.westinghousenuclear.com/ap1000_safety.html (last visited Aug. 30, 2012).

capital cost of the new nuclear steam supply systems (as compared to older designs with a similar rating).[43]

New designs that incorporate passive-safe features represent a major reduction in risk. That risk reduction is recognized by multiple regulatory authorities to be at least one, and likely two, orders of magnitude—a factor of more than 100—lower than the currently operating facilities.[44]

The U.S. nuclear industry's response to the TMI 2 accident was to develop new designs that substantially reduce the need for operator action. They utilize heat-removal techniques that rely on natural forces and processes including gravity, natural circulation, and reflux cooling, rather than those that rely upon numerous electrically powered pumps and other complex systems to cool the reactor.[45] The approach is basically to increase the amount of cooling water inventory available, as well as improve the effectiveness of cooling by structural elements, by utilizing a large steel pressure vessel as the containment in pressurized water reactors (PWRs).[46] The free-standing steel pressure vessel containment can be cooled by convective air circulation or by water sprayed on the exterior of the containment structure from a tank positioned above the containment.[47] The free-standing steel containment structure provides superior heat transfer to the environment when compared to the containment design, featuring thick concrete structures with low heat transfer coefficients typical of currently operating facilities.[48] The features of the new designs would prevent an event such as that which occurred at Fukushima.

Commercial nuclear power has an exceptional safety record compared to other technologies. As in any complex enterprise involving the massive investment of capital, simply being better than the alternative is not the standard that should be applied to technologies involving inherently hazardous activities. Nevertheless, it is useful to consider how commercial nuclear safety compares with the safety record of alternative sources of energy. It is prudent to continue to develop enhanced safety features. When risk associated with utilization of nuclear technology is substantially lower than alternative energy sources, a decision to forgo utilization of nuclear technology due to risk is most imprudent.

The relative risks of various sources of electric power have been the subject of substantial scrutiny by the Paul Scherrer Institute.[49] The Scherrer Institute's detailed historical analyses of severe accidents (events with at least five immediate fatalities) within the energy supply industry worldwide between 1969 and 2008 indicate that, for Organization of Economic Cooperation and Development (OECD) countries, the number of fatalities by energy source is 2,239 deaths for

---

[43] *Id.*

[44] *Id.*

[45] *Id.*

[46] *Id.*

[47] *Id.*

[48] *Id.*

[49] *Risk Assessment: Comparative Risk Assessment and the ENSAD Database*, PAUL SCHERRER INST., http://gabe.web.psi.ch/research/ra/ (last visited Aug. 30, 2012).

coal, 3,383 deaths for oil, 1,257 deaths for natural gas, 1,880 for liquefied petroleum gas, and 14 deaths for hydroelectric power.[50] Nuclear, on the other hand, has no death attributed to any accident.[51] The composite data regarding severe events within all OECD countries between 1969 and 2008 was analyzed to generate a comparison by technology in the form of frequency (the number of accidents for each billion watt-years of electric energy produced) and consequence (the number of fatalities resulting from the accident) curves.[52] That analysis also included the frequency-consequence curve of an old Swiss BWR very similar to Fukushima Unit 1 based on its probabilistic safety analysis, which assumes that the linear dose model for radiation exposure was valid to project latent fatalities.[53] The results indicated that events at older nuclear facilities are orders of magnitude less likely to result in fatalities than events occurring at fossil-fuel generating facilities.[54] Additionally, the NRC has recently completed its assessment of severe accident consequences for currently operating reactors, and has concluded that the projected consequences for severe accidents are much less severe than previously asserted.[55] The NRC's conclusion was based on a detailed analysis of two older reactor facilities, Peach Bottom, utilizing a General Electric BWR design, and Surry, utilizing a Westinghouse PWR design.[56] The new passive-safe nuclear steam supply system designs represent an additional reduction of such severe events of more than one additional order of magnitude.[57] Thus, the likelihood of a severe accident at a nuclear power plant resulting in five or more deaths is approximately one millionth that of the safest of the hydrocarbon-based energy sources.

---

[50] SECURE, SECURITY OF ENERGY CONSIDERING ITS UNCERTAINTY, RISK AND ECONOMIC IMPLICATIONS: FINAL REPORT OF SEVERE ACCIDENT RISKS INCLUDING KEY INDICATORS 19 (2011), *available at* http://gabe.web.psi.ch/pdfs/secure/SECURE_Deliverable_D5_7_2_Severe_Accident_Risks.pdf.

[51] *Id.*

[52] *Id.*

[53] *Id.* No technical support for the linear dose model has been documented, as there are no discernable differences in cancer deaths corresponding to variations in natural background radiation exposure or occupational exposure within established guidelines.

[54] *See id.* at 29.

[55] *See generally SOARCA and the Decreasing Risk of Death*, NEI NUCLEAR NOTES (Feb. 3, 2012), http://neinuclearnotes.blogspot.com/2012/02/soarca-and-decreasing-risk-of-death.html; *Low Risk from Major Accident Consequences*, WORLD NUCLEAR NEWS (Feb. 2, 2012), http://www.world-nuclear-news.org/RS-Low_risk_from_major_accident_consequences-0202127.html.

[56] *Low Risk from Major Accident Consequences*, WORLD NUCLEAR NEWS (Feb. 2, 2012), http://www.world-nuclear-news.org/RS-Low_risk_from_major_accident_consequences-0202127.html.

[57] *See* WESTINGHOUSE, THE WESTINGHOUSE AP1000 ADVANCED NUCLEAR PLANT DESCRIPTION 16–18 (2003), *available at* www.ne.doe.gov/pdfFiles/AP1000_Plant_Description.pdf.

C. The Economics of New Nuclear Power

The overwhelming incentive propelling the trend to select nuclear power as the baseload choice for new construction in preference to conventional fossil and alternative energy sources is cost. A review of the costs of new nuclear installations reveals that when all externalities are captured and appropriately priced, nuclear power is very competitive and is likely to result in substantial savings regarding electric energy costs, while avoiding the environmental consequences of fossil fuel combustion.

1. Fuel Costs

There are three major elements that establish the cost of nuclear generating capacity. The first is the cost of the fuel—uranium oxide. The energy released from the fission of a single atom of nuclear fuel is approximately 100 million times the energy released from a typical chemical reaction.[58] Uranium has little practical economic value but for its energy content, and the world's known inventory of uranium is sufficient to meet hundreds of years of electric power generation requirements. The last fifteen years of electricity production costs, as reported by regulated utilities on the Federal Energy Regulatory Commission (FERC) Form 1 filings,[59] demonstrated that nuclear fuel costs are less than one-third the fuel cost for coal, approximately 10% of the cost of natural gas, and currently less than 5% of the cost of petroleum.[60] In the past, nuclear opponents have claimed that the total cost of nuclear power failed to include all externality costs. Today, cost estimates for new nuclear generation facilities incorporate all costs associated with mining, extraction, enrichment, fabrication, storage, and disposal.[61] In contrast, the current life-cycle cost estimates for hydrocarbon-based generation fail to incorporate the often speculative but nonetheless high economic costs of climate change caused by CO_2 emissions.

2. Operations and Maintenance Costs

The second cost component affecting the pricing of new nuclear generation is the cost of operations and maintenance (O&M). These expenses are a constant per interval of time, i.e., are effectively decoupled from the amount of power produced and the revenues resulting from the sale of that electric energy. The current typical O&M cost of nuclear facilities per unit of power produced is approximately three

---

[58] SAMUEL GLASSTONE & ALEXANDER SESONSKE, NUCLEAR REACTOR ENGINEERING ¶ 1.44 (1955).

[59] *Overview of FERC*, FEDERAL ENERGY REGULATORY COMM'N (Apr. 9 2012), www.ferc.gov/about/overview.asp.

[60] *See U.S. Electricity Production Costs and Components (1995–2010)*, NUCLEAR ENERGY INST., http://www.nei.org/filefolder/US_Electricity_Production_Costs_and_Components.xls [hereinafter NUCLEAR ENERGY INST.] (last visited Aug. 30, 2012).

[61] *See* Nuclear Waste Policy Act of 1982, 42 U.S.C. § 302(a)(2) (2006).

times higher than the O&M cost of combined-cycle gas facilities, and approximately double the O&M costs of large coal-burning facilities that have fully implemented emissions controls other than CO_2 capture and sequestration.[62] However, costs of compliance with Clean Air Act implementing regulations will drive up costs for all fossil-fired generating stations.[63] Although unlikely ever to be implemented, CO_2 capture and sequestration would likely substantially increase O&M expenses of both coal and natural gas fuel facilities.[64]

3. Capital Costs

The final cost component is capital cost. Like O&M costs, the financing costs for major electric generating facilities are effectively decoupled from the amount of power produced and the revenue resulting from the sale of that electric energy. Capital costs for nuclear power plants have historically been higher than capital costs for conventional fossil-fueled energy sources. The capital cost of nuclear facilities has been approximately 75% higher than pulverized coal without CO_2 capture provisions.[65] Currently, overnight capital costs for new large passive-safe nuclear generating facilities are estimated at $3900–4400/kw.[66] The overnight capital cost[67] of combined-cycle natural gas facilities has been approximately 25 to 30% of the capital cost of nuclear facilities.[68] A number of new nuclear power facilities have been authorized by state public service commissions that have jurisdiction over economic regulation of electric power facilities.[69] Nuclear power

---

[62] *Id.*

[63] Approximately one ton of CO_2 is produced per MWhr by a coal-fired generator. A carbon tax of $10.00 per ton of CO_2 corresponds to approximately $0.01 per kwhr as an additional cost of electricity produced by coal.

[64] Arnold W. Reitze Jr., *Electric Power in a Carbon Constrained World*, 34 WM. & MARY ENVTL. L. & POL'Y REV. 821, 855 (2010).

[65] MASS. INST. OF TECH., UPDATE OF THE MIT 2003 FUTURE OF NUCLEAR POWER 6 (2009), *available at* http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

[66] ELEC. POWER RESEARCH INST., TECHNICAL UPDATE 1022782, PROGRAM ON TECHNOLOGY INNOVATION: INTEGRATED GENERATION TECHNOLOGY OPTIONS 1–11 (2011).

[67] Overnight capital cost is the sum of costs of materials and labor which are paid each day during construction disregarding any cost of financing, i.e., the carrying cost of the facility which has been built for which the vendors or labor costs have been previously paid. Overnight capital costs have no cost of capital-interest-expense included.

[68] *Id.*

[69] Final Order, at 33, *In re* Florida Power & Light Nuclear Cost Recovery Amounts (Fla. Pub. Service Comm'n Nov. 19, 2009); Order Establishing Fee, *In re* Georgia Power Company Application for the Certification, No. 27800 (Ga. Pub. Service Comm'n Mar. 17, 2009), *available at* http://facts.psc.state.ga.us/Public/GetDocument.aspx?ID=114700; Order Approving Combined Application, at 120, *In re* Combined Application of South Carolina Electric & Gas Company, No. 2008-196-E (S.C. Pub. Service Comm'n Feb. 27, 2009), *available at* http://dms.psc.sc.gov/pdf/orders/c7b93e26-ca22-8dc1-7f2ededc1162f1eb.pdf.

facilities located in Georgia, namely Southern Nuclear Operating Co. Inc.'s Vogtle Electric Generating Plant Units 3 and 4, were issued their federal Combined Construction and Operating Licenses (COL) by the NRC on February 10, 2012.[70] These facilities utilize the Westinghouse AP1000 design, a passive-safe PWR, which was approved under the provisions of 10 C.F.R. 52 Subpart B on December 31, 2011.[71] In South Carolina, South Carolina Electric & Gas Co. (SCE&G) is currently conducting limited site preparation activities for additional nuclear units. V.C. Summer Nuclear Power Plants 2 and 3 are scheduled to complete the NRC review process resulting in the issuance of a combined license in 2012, thus permitting safety-related construction activities to begin.[72] Each of these facilities will be constructed on an existing nuclear power plant site. Site suitability issues at those sites were therefore largely resolved previously. Like the Vogtle facilities, Summer Units 2 and 3 are also utilizing the AP1000 design.

It should be noted that the February 10, 2012 NRC issuance of the COLs for Vogtle Units 3 and 4 represents the first NRC approval of applications for new nuclear power plants since the 1979 accident at Three Mile Island—a period of almost thirty-three years. The licensing of Vogtle Units 3 and 4 also represents the first utilization of passive-safe large power reactor designs in a new project; as noted above, the nuclear steam supply system (NSSS) design to be utilized at both Vogtle units is the Westinghouse passive-safe AP1000 design certified by the NRC in December 2011.[73]

Each of these projects has incurred substantial expense—exceeding one billion dollars—in the licensing process and in site preparation, which is allowed prior to completion of the NRC COL process.[74] In each case, the utilities are located in states that have retained the classic rate of return regulatory system governing utility operation and rates, and the respective state public service commissions concluded the selection of nuclear power as the source for future electric generation requirements was the low cost option with minimal economic risk.[75]

The decisions by the public service commissions in South Carolina and Florida focused on the uncertainty associated with the potential cost of CO_2

---

[70] U.S. NUCLEAR REGULATORY COMM'N, COMBINED LICENSE VOGTLE ELECTRIC GENERATING PLANT UNIT 3, DOCKET NO. 52-026, LICENSE NO. NPF-923 (Feb. 10, 2012), *available at* www.nrc.gov/reactors/new-reactors/col/vogtle/documents/col3/html [hereinafter COMBINED LICENSE VOGTLE ELECTRIC GENERATING PLANT].

[71] Design Certification Rule for the AP1000 Design, 10 C.F.R. pt. 52, app. D (2011).

[72] *See* 10 C.F.R. § 50.10 (2012).

[73] 10 C.F.R. pt. 52, app. D.

[74] Steven Mufson, *NFC Approves Construction of New Nuclear Power Reactors in Georgia*, THE WASHINGTON POST, Feb. 9, 2012, http://www.washingtonpost.com/business/economy/nrc-approves-construction-of-new-nuclear-power-reactors-in-georgia/2012/02/09/gIQA36wv1Q_story.html; Ray Henry, *AP IMPACT: Building Costs Rise at US Nuclear Sites*, THE GUARDIAN, July 10, 2012, http://www.guardian.co.uk/world/feedarticle/10330190.

[75] *See supra* note 69 and accompanying text.

regulation and on the uncertainty regarding the future cost of natural gas. Those decisions did not address CO_2 capture and sequestration, but considered the economic consequences of a carbon tax and different tax fees per ton of carbon emission.[76] In each case, the nuclear option resulted in the lowest projected cost for ratepayers.[77] In South Carolina, construction work in progress (CWIP) was authorized to be included in the current rate base for electric service.[78] That authorization was based on the very significant reduction in total cost to ratepayers over the life of the proposed plant due to the reduction in carrying costs during the extended construction period associated with nuclear power plants.[79] Such rate treatment also results in a lower perceived risk in the financing of the facility, thereby resulting in lower cost of such financing. Since the decision by the South Carolina Public Service Commission, SCE&G announced a $1.3 billion reduction in its cost estimate for the facility based on reduced price escalation estimates.[80] Additionally, SCANA, SCE&G's corporate parent, has just sold $250 million of medium term notes with a fixed rate of 4.125% at a 1.412% discount.[81] Within one week of the SCANA bond sale, SCE&G sold $250 million in 30-year first-mortgage bonds at 4.350% at a less than 1% discount.[82] Clearly, the capital markets are prepared to support development of new nuclear power plants in states where classic rate regulation remains effective and is structured to promote long-term stable costs for electric service.[83] It should be noted that in the states where new nuclear plants are being constructed, electric utility rates are among the lowest in the country.

---

[76] *Id.*

[77] *Id.*

[78] *SCE&G Files for Rate Adjustment Under Base Load Review Act*, SCANA (May 27, 2011), http://www.scana.com/en/news-room/current-news-releases/sceg-files-for-rate-adjustment-under-blra.htm.

[79] Order Approving Combined Application, at 120, *In re* Combined Application of South Carolina Electric & Gas Company, No. 2008-196-E (S.C. Pub. Service Comm'n Feb. 27, 2009), *available at* http://dms.psc.sc.gov/pdf/orders/c7b93e26-ca22-8dc1-7f2ededc1162f1eb.pdf.

[80] The South Carolina Public Service Commission had previously approved an 11% return on equity for SCE&G. *See* Press Release, SCANA, Retail Electric Rate Order of the Public Service Commission of South Carolina, docket 2007-229-E (Nov. 28, 2007), http://www.scana.com/NR/rdonlyres/3F4213F2-0CC3-4856-8D7B-1BEFB5A0C2C4/0/sceg_44_increase.pdf.

[81] Press Release, SCANA, SCE&G Announces Debt Offering (Jan. 18, 2012), http://www.scana.com/en/investor-relations/news-releases/2012-sceg-announces-debt-offering.htm.

[82] *Id.*

[83] Press Release, Business Wire, Fitch Rates SCANA's $250MM Senior Unsecured Notes 'BBB+' (Jan. 19, 2012), http://www.businesswire.com/news/home/20120119005912/en/Fitch-Rates-SCANAs-250MM-Senior-Unsecured-Notes [hereinafter Fitch Rates BBB+].

Capital cost represents the cost of the facility, including the cost of funds needed during construction, with the amount of funds required being related directly to the time required to construct the facility. Assuming that once approval to construct and operate a nuclear power plant is issued by the NRC (and possible appeals to the federal courts regarding the licensing decision are fully resolved), no additional changes are made to the facility, and that construction is completed in accordance with schedule, a nuclear power plant is likely the low-cost option for baseload electric energy production. Nevertheless, the time interval between the initial commitment of major resources to construct and the receipt of authorization to operate is the period of maximum economic risk associated with any major power plant. Historically, for nuclear power facilities, that risk has been massive, unpredictable (due to such disruptions as changes to NRC regulations made and implemented during the construction process), and often beyond the control of the owner of the facility. In the past, although the additional costs incurred due to changing requirements of the regulatory system (which were unforeseen at the time of approval to construct the facility by state utility rate commissions) were usually determined to be expenditures that satisfied the "just and reasonable" standard for recoverable costs, the large cost overruns due to changing requirements resulted in substantial disruptions in the social contract between the regulated utilities and their ratepayers.[84] The cost overruns experienced by the nuclear facilities were completed in the late 1970s through 1990s. The "rate shock" associated with those projects contributed to the development of a utility rate regulation environment that was open to deregulation and widespread abandonment of the utility regulatory system, which had developed in the early 1900s and served the country well for nearly one hundred years.[85] Proponents of the economic deregulation of the electric supply and distribution system claimed that a market system would yield lower costs.[86] Instead, the utility industry followed its trend of focusing on short term profits and avoiding economic risks associated with large capital investments.

In the case of nuclear power, the time between authorization to construct and readiness to operate has historically been years longer than for any alternative source of electric power (with the possible exception of major hydroelectric facilities). Under the licensing scheme in effect during the development of the current fleet of U.S. nuclear facilities, the NRC issued a construction permit that allowed construction of a nuclear power plant on the owner's site based upon a Preliminary Safety Analysis Report.[87] The reactor designer then commenced final detailed design efforts, which were documented in a Final Safety Analysis Report

---

[84] *See Introduction and History of the Shoreham Nuclear Power Plant*, LONG ISLAND POWER AUTHORITY, http://www.lipower.org/shoreham/history.html (last visited, Sept. 18, 2012).

[85] *See generally* Michael E. Stern & Margaret M. Stern, *A Critical Overview of the Economic and Environmental Consequences of the Deregulation of the U.S. Electric Power Industry*, 4 ENVTL. LAW. 79, 128 (1997).

[86] *Id.* at 105.

[87] *See* 10 C.F.R. §§ 50.34(a), 50.10, 50.23, 50.50, 50.55 (2012).

provided to the NRC for its review and approval prior to its issuance of the operating license.[88] The operating license was finally issued when the NRC regulatory staff was convinced that its concerns associated with the detailed review of the final design were adequately resolved and no new issues were introduced into the process. That regulatory review process became an economic disaster, because reviews were conducted by the NRC staff operating subject to few time constraints, and individual NRC managers had little control over the introduction of new issues into the review process. If new safety issues emerged, even when a plant's construction was nearly complete, all carrying costs continued during resolution of those issues, as well as costs now incurred as normal O&M expenses associated with having safety-related equipment operationally ready. Those costs were added to the capital cost of the facility until all new regulatory issues or requirements were resolved. Historically, delays exceeding one year after construction completion were common. Using current construction costs and rates, the cost for one year of delay to address a new safety concern could exceed 15% of capital cost for the facility.[89] Those capital investment carrying costs, combined with the O&M expenses associated with completed nuclear safety systems, typically exceeded the cost of actually resolving a regulatory concern by approximately two orders of magnitude.[90] A modification which involved the expenditure on the order of a few million dollars that resulted in a startup delay could increase the project's cost by approximately one hundred million dollars per month of delay. Absent assurance that exposure to modifications late in the construction process causing project delay would be precluded in future nuclear construction projects, nuclear power was not viewed as a reasonable option.

D. Combined Licensing: The New Protocol for the Legal Review Process

Beginning in the 1970s, utilities and the NRC initiated a standardization process for nuclear plant design and regulatory review in an attempt to reduce

---

[88] *See* 10 C.F.R. §§ 50.34(b), 50.10, 50.50, 50.55 (2012).

[89] *See* THOMAS D. MORGAN, ECONOMIC REGULATION OF BUSINESS 299–300 (2d ed. 1985). If a one-year delay occurs late in the construction of a nuclear facility when all operating and maintenance costs of normal operation are being realized because of NRC requirements then the normal nuclear O&M for that year delay add to capital cost combined with the cost of maintaining the construction personnel on site, as does the revenue requirements associated with the then-existing construction costs. Those costs as a percentage are ($0.015/kwhr × hours per year × capacity factor/total cost of the facility per kw) + cost of construction personnel + the annual revenue requirement percent. If the retained construction staff cost is 50% of O&M then the costs would be 1.5 x (0.15 × 8766 × 0.9/$4500.00) + revenue requirement for capital investment. In the case of SCE&G the cost would be 4% plus 11.4% for a total of 15.4% additional cost for a one-year delay, which does not include the cost of correcting the cause of the delay.

[90] A 15.4% increase in the capital cost of a $5 billion unit is approximately $800 million. Few modifications to nuclear systems and components to address regulatory concerns have exceeded $10 million per unit in overnight cost.

costs and to facilitate a more efficient regulatory approval process. Those efforts have evolved into the one-step licensing process established by Part 52 of C.F.R. Title 10, which today includes subparts addressing early site permits, standard design certifications, the COL process, standard design certifications, and manufacturing licenses. Each of these subparts defines processes that rely upon and reference specific requirements contained in other parts of the NRC regulations—predominantly 10 C.F.R. Part 50, which defines the majority of the requirements associated with assurance of safety of nuclear reactors. Part 52 restructures the NRC administrative process to provide a single occasion in which the applicant for an NRC license has the burden to demonstrate conformance to NRC rules and regulations and to demonstrate the existence of reasonable assurance of adequate protection of public health and safety regarding a particular proposed action such as a specific decision by the NRC. The prior process outlined in Part 50 required multiple steps in the process to obtain authorization to operate a nuclear facility. Each step was open to legal challenges and potential delays with the attendant economic risk leading to a high cost of capital for commercial nuclear projects. Even the opportunity for the NRC staff to impose additional requirements on designs that have been approved utilizing Part 52 has been limited by the Part 52 subpart B §52.63 to actions necessary to effect conformance to regulations in effect at the time of a design's certification, to satisfy the requirements of Atomic Energy Act as amended, to reduce unnecessary regulatory burdens, to correct material errors, to substantially increase safety at justifiable cost, or to contribute to increased standardization of certification information.[91] The objective of the nuclear industry in promoting the development of Part 52 of the NRC regulations was to preclude the opportunity for multiple legal actions regarding any technical issue or decision associated with a nuclear design or a particular facility while satisfying the requirements of the Atomic Energy Act.

The revised, comprehensive regulatory review and approval process has been implemented by the NRC pursuant to Title 10 of the Code of Federal Regulations, Part 52. Today, a condition precedent to any company's commitment to initiate construction of a new nuclear power plant is the assurance that the plant has obtained the necessary final regulatory approvals to begin operation upon construction completion. To obtain regulatory approval of a facility prior to its construction, the design of the major "building blocks" of the facility such as the site selected for construction, the NSSS, and the balance of plant (BOP), must be completely characterized in all major aspects.[92] With the site, the NSSS, and BOP fully accepted by the NRC, only the demonstration of conformance to design specifications and performance requirements (which demonstration is to be accomplished during pre-operational and start-up testing of a new nuclear unit)

---

[91] Finality of Standard Design Certifications, 10 C.F.R. § 52.63(a)(1) (2012).

[92] See U.S. Nuclear Regulatory Comm'n, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (May 4, 2012), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0800/.

would remain to be verified by the regulator such that the facility is allowed to proceed to full-power operation and ultimately to commercial operation.

Under the prior construction and operating licensing process, two separate licenses were granted by the NRC—the first prior to safety-related construction initiation and the second immediately prior to facility operation.[93] Since two administrative processes were required, substantial risks existed for delay, should an intervening party or the NRC staff raise any new issue during any phase of either review process. The potential for the delay of commercial operation following the substantial expenditures of funds to construct the facility and to prepare for operation includes additional costs, such as the cost of capital, operating staff carrying charges, and maintenance expenses during the delay. As noted above, such additional costs are likely to exceed 15% of anticipated capital cost per year of delay.[94]

Even pursuant to the COL process, with prior approval of all aspects of the site and facility design finalized and certified or approved, a new nuclear power plant currently under contract for construction will require five to six years to complete.[95] While the new passive-safe reactor designs represent a simplification of systems necessary to assure public health and safety, even those designs result in complex facilities which demand the highest quality of construction, detailed verification of satisfaction of legal and technical requirements, flawless documentation, and highly qualified management attuned to the combined technical, legal, institutional, political, and public relations considerations that accompany a massive engineering project that is viewed as ultra-hazardous.[96]

A multi-billion dollar private project with high economic value upon successful completion, and that would be subject to dire economic consequences due to any failure to perform above minimum regulatory standards that could result in extensive delays to project completion and commercial operation, presents a risk that demands a premium in the financial markets. To anticipate that the new large passive-safe designs will be constructed in less time than the construction intervals for the currently operating fleet of domestic nuclear power plants may be optimistic. The nuclear industry's knowledge base is in a rebuilding mode, and will be experiencing its own learning curve regarding execution of new nuclear plant construction. International experience in construction of new nuclear power plants is not encouraging. For example, Teollisuuden Voima and Areva-Siemens

---

[93] *See* U.S. NUCLEAR REGULATORY COMM'N, NUCLEAR POWER PLANT LICENSING PROCESS (July, 2012), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf.

[94] *See supra* note 90 and accompanying text.

[95] WESTINGHOUSE, AP1000 16 (2007), *available at* http://www.westinghousenuclear.com/docs/AP1000_brochure.pdf.

[96] Nuclear power is subject to strict liability in the event of any accident subject to Price Anderson Insurance provisions as specified in the Atomic Energy Act as amended. *See* 42 U.S.C. § 2210 (2006). Strict liability is a characteristic of ultra-hazardous activities.

are constructing a new passive-safe pressurized water reactor in Finland.[97] That plant has been in construction for six years and is now four years behind schedule, with extensive cost overruns.[98] In addition, Westinghouse is constructing the first of a number of new AP1000 units in China and has also experienced delays; however, Westinghouse claims to be on track to complete this facility on schedule.[99] These new facilities are large units that require the assembly of all major components on site due to the massive size of the respective components. While the number of individual components has been reduced from that of the currently operating large reactors, the projects are complex technologic facilities that require thousands of construction tradespeople five to six years to complete. The long duration of nuclear facility construction results in increased economic risk associated with the financing of all costs during the construction period when no cash flow associated with energy production exists. It is very unlikely that any new nuclear "merchant" plants will proceed prior to the demonstration by one or more regulated utilities successfully constructing a new passive-safe reactor within budget and on schedule. This situation is due primarily to the long-term economic risks incurred during the construction period.

IV. A NEW ALTERNATIVE: THE MODULAR APPROACH FOR NEW NUCLEAR PLANTS (AN ANALOGY TO THE NATURAL GAS COMBINED-CYCLE GENERATION MODEL)

The currently favored alternative to nuclear generation for provision of continuously available electric energy production utilizes hydrocarbon fuel. This generation system is the combined-cycle natural gas–fueled combustion turbine, with reclaim of the turbine exhaust thermal energy to produce steam to drive a turbine generator, thereby significantly increasing the power produced per unit of fuel—a combined-cycle facility. The cost of natural gas fuel is typically ten times the cost of nuclear fuel.[100] The overnight capital cost for natural gas–fueled facilities is typically 25% of the overnight capital cost for nuclear facilities.[101] The total capital cost for a combined-cycle natural gas facility, including carrying charges during construction, is on the order of one-fifth of that for a nuclear

---

[97] *Finland*, INT'L ATOMIC ENERGY AGENCY (2011), http://www-pub.iaea.org/MTCD/publications/PDF/CNPP2011_CD/countryprofiles/Finland/Finland2011.htm.

[98] *UPDATE 1-Finland's Olkiluoto 3 Reactor Delayed to Aug '14,* REUTERS (Dec. 21, 2011), http://www.reuters.com/article/2011/12/21/finland-olkiluoto-idUSL6E7NL2D120111221.

[99] *China AP1000 Nuclear Plant on Track After Delay-Xinhua*, REUTERS (Jan. 15, 2012), www.reuters.com/article/2012/01/15/china-nuclear-idUSL3E8CFOBF20120115.

[100] *U.S. Electricity Production Costs and Components (1995–2010)*, NUCLEAR ENERGY INST., http://www.nei.org/filefolder/US_Electricity_Production_Costs_and_Components.xls (last visited May 23, 2012).

[101] *See* MASS. INST. OF TECH, *supra* note 65.

facility.[102] The longer duration of construction associated with a nuclear project is very significant economically. Nevertheless, economic analysis indicates that in the case of baseload electric system requirements, nuclear power plants yield minimal environmental consequences and superior economic performance. When variable electric demand is considered, natural gas–fueled facilities have the economic advantage as compared to coal-fired and nuclear facilities because of their lower capital cost and shorter duration of facility construction.[103]

The major advantage associated with a natural gas facility is that such a facility typically requires two years to construct, as compared to the new passive-safe large nuclear units licensed under the COL process, which are estimated to require five to six years to construct.[104] As noted previously, the construction period for a new nuclear facility could be extended if the construction activity fails to conform to the detailed design and documentation requirements established by the NRC. Any significant error, omission, or management failure would result in a substantial project delay. The NRC staff is appropriately comprehensive in its oversight and responds to any issue perceived to compromise public health and safety or to question the adequacy of the NRC's oversight with a thorough technical and legal investigation, the results of which may lead to reconsideration of regulatory requirements and potential corrective actions resulting in project delay.[105] No similar scrutiny applies in the case of a gas turbine mounted on a slab of concrete. Additionally, the shorter construction period for natural gas facilities results in substantially less project risk associated with changing economic conditions, demand, prices of fuel and supplies, and regulatory requirements, all of which provide a significant advantage to natural gas facilities as a business investment.

Most of the major components of a natural gas combined-cycle facility are constructed in a factory and shipped to the site as a fully functional assembly to be combined with other major assemblies, to yield a complete facility. The combustion turbine-generator combination is delivered to the site as a completed assembly, or, at most, two components, namely the combustion turbine and electric generator with its auxiliary components. Supporting subsystems are also complete modular assemblies. These modules simply require interconnection to yield the functional system. Similarly, the exhaust heat steam generator is another subassembly, as is the steam turbine and the exhaust steam condenser. The combining of the key factory-built assemblies represents an efficient and simple construction process in which the number of interfaces and tasks are reduced and

---

[102] *New Plants: The Cost of New Generating Capacity in Perspective*, NUCLEAR ENERGY INST., http://www.nei.org/filefolder/WHITE_PAPER_-_Cost_of_New_Generating_Capacity_in_Perspective.pdf (last visited Aug. 30, 2012).

[103] Variable demand for electricity requires less generation, thus, the capacity factor of units shut down during low power demand is reduced. Since capital cost and O&M expense is time related, rather than output related, units with low capital costs and low O&M costs are more likely to be the lowest cost electric energy supply.

[104] Fitch Rates BBB+, *supra* note 83.

[105] 10 C.F.R. §100 (2012).

total site construction effort is substantially reduced in level of activity and duration.

The ability to coordinate the delivery of large complete assemblies with the scheduled completion of supporting structures and buildings and the delivery of other major components enables efficient project management, thereby greatly reducing total project duration and minimizing the carrying costs associated with major components. Supply contracts, which include significant penalties to major component vendors should they fail to deliver in accordance with contract commitments, also serve to significantly reduce project risk by transferring that risk to the limited number of major vendors.

The ability to construct factory-assembled modules for large nuclear power plants has not existed in the past. Major components of nuclear plants, including but not limited to, reactor vessels, reactor vessel internal units, coolant pumps, steam generators, large piping, additional subsystem pressure vessels, control valves, isolation valves, and support systems, were each fabricated by major commercial vendors worldwide, at separate locations remote from the reactor plant site. Large nuclear station components required assembly at the facility site. Each pressure vessel, pump, large valve, pipe section, and support was shipped to and assembled at the facility site to form the multiple complex systems that constitute a nuclear facility. The physical size of the assembled reactor coolant system of a 1000 MWe nuclear facility precluded factory assembly of the entire system. The construction of a 1000 MWe nuclear facility represented a major onsite construction effort effectively requiring the development of a special-purpose workforce composed of thousands of construction trades personnel; hundreds of engineers; hundreds of management, administrative, and service personnel; and extensive site security forces. Even on multi-unit sites, the construction schedules for adjacent nuclear units were not concurrent, and the completion of individual units could be separated by several years. These intervals corresponded to the annual growth rate of electric demand in the region and the rating of the facility. The multi-unit large nuclear facilities, such as the now-certified AP1000 and the GE Economic Simplified Boiling Water Reactor (ESBWR) (currently undergoing regulatory review), have estimated two to three year intervals for separate units to be constructed.

Nevertheless, the potential benefit for complete factory assembly of an integrated nuclear-powered steam supply system has not been overlooked by the U.S. nuclear industry. Due to national security and contracting requirements, the supply and fabrication chain for nuclear-powered propulsion systems for the U.S. Navy has remained totally domestic.[106] As a result of that national security requirement, the ability to construct all necessary equipment for smaller nuclear power plants that could be constructed at a factory and shipped to a site as a completed steam supply system exists within the current domestic industrial infrastructure. The capability to produce the large components of the

---

[106] *Powering the Nuclear Navy*, NATIONAL NUCLEAR SECURITY ADMIN., http://nnsa.energy.gov/aboutus/ourprograms/powernavy2 (last visited, Sept. 18, 2012).

1000-plus MWe nuclear power plants has been transferred from the United States to overseas suppliers who continued the development of nuclear facilities in the international market. However, when the U.S. industry stopped its expansion, the domestic capability for small nuclear power systems remained within the United States as a national industrial and security asset. Development of smaller nuclear power plants thus represents a potential base of domestic employment, which, when combined with the intellectual property rights associated with designs of new small reactors and the vast number of potential foreign customers for small passive-safe nuclear power plants, could represent an important source of international sales. As a result of these considerations, DOE has been providing incentives to domestic vendors to finalize development and licensing of new modular reactors which are factory-fabricated and assembled as a complete steam supply system, which can be delivered to a site on a single transporter using existing rail lines and large over-the-road transporters.[107] Several of these modular designs have been proposed. Some contain novel design features, such as the use of liquid metal coolants, gas cooling of the reactor, new encapsulation of the nuclear fuel, and other technology alternatives which have not been fully developed.[108] While numerous design concepts have been advanced as providing technical advantages and including claims of increased safety, the development of modular light water reactors, which rely on more than five decades of experience in both the existing commercial nuclear power industry as well as the naval nuclear program, when combined with passive-safe design approaches, represents the technology with the highest likelihood of short-term successful implementation.[109] The methodology for evaluation and demonstration of adequate protection of public health and safety associated with light water reactors is well understood by the NRC staff and by the commercial nuclear industry. The reconfiguration of the components of a pressurized water reactor coolant system as the basis for a new modular reactor design represents a refinement of the technology, which builds upon existing knowledge and experience, yielding high confidence in successful implementation at reasonable costs.

There are three modular reactor designs currently vying for DOE funding to support licensing activities: Babcock and Wilcox's mPower reactor,[110] the Westinghouse Small Modular Reactor,[111] and NuScale Power Inc.'s NuScale

---

[107] *See generally* DICK BLACK, OFFICE OF ADVANCED REACTOR CONCEPTS, U.S. DEPT. OF ENERGY, DOE SMALL MODULAR REACTORS (SMRS) PROGRAM (2010), http://www.nuclearinfrastructure.org/resources/DOE_Small_Modular_Reactors_Program_Dick_Black.pdf.

[108] *Small Nuclear Power Reactors*, WORLD NUCLEAR ASS'N, http://www.world-nuclear.org/info/inf33.html (last updated July 2012).

[109] BLACK, *supra* note 107, at 3.

[110] *Modular Nuclear Reactors*, BABCOCK & WILCOX CO., http://www.babcock.com/products/modular_nuclear (last visited Aug. 30, 2012).

[111] WESTINGHOUSE, THE WESTINGHOUSE SMALL MODULAR REACTOR (2011), *available at* http://www.westinghousenuclear.com/smr/fact_sheet.pdf.

modular reactor.[112] Each is a pressurized water reactor design that includes passive-safe features as a major design element.

A. The Babcock & Wilcox mPower Modular Reactor

The Babcock and Wilcox Company (B&W), the supplier of naval nuclear steam supply systems, is engaged in the final design and thermal hydraulic testing of its modular commercial reactor coolant system design.[113] The B&W design—the mPower reactor—is composed of a nuclear steam supply system wherein the entire reactor coolant system, including the reactor fuel, control system, circulating pumps, steam generators, and system pressure controlling volume, is contained within a single pressure vessel.[114] This design is advantageous in terms of safety and operations because it presents no opportunity for large reactor coolant piping system ruptures as there are no large reactor coolant pipes. All reactor coolant flow is maintained within the reactor vessel itself. Additionally, no penetrations exist in the lower head of the reactor vessel.[115] Emergency cooling schemes providing assurance of safety do not require external power; instead, they make use of passive systems, natural circulation, gravity, and fundamental thermodynamic principles to maintain adequate cooling of the reactor fuel for all postulated events, including loss of all electric power for extended periods of time.[116]

The B&W mPower design utilizes a relatively large containment vessel similar to the common practice of existing PWR facilities. The design pressure of the containment structure is relatively low as compared to that of the reactor coolant system, and the large surface area of the containment vessel walls provides a large heat transfer capability for cooling following a severe accident. The containment structure is protected by a reinforced concrete support structure. To address the potential risk of a terrorist attack utilizing large aircraft, the entire containment is located underground with due consideration for protection from flooding and for fire protection and prevention issues.[117]

The B&W mPower design produces superheated steam as a result of its once-through steam generator, wherein secondary system feedwater is injected at the

---

[112] *Overview of NuScale's Technology*, NUSCALE POWER, http://www.nuscalepower.com/ot-Scalable-Nuclear-Power-Technology.php (last visited Aug. 30, 2012) [hereinafter NUSCALE POWER].

[113] *Generation mPower Small Modular Reactor Testing Facility Opened*, NUCLEAR ST. (Oct. 3, 2011), http://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2011/10/03/generation-mpower-small-modular-reactor-testing-facility-opened-100301.aspx.

[114] *Id. See also* GENERATION MPOWER, THE BABCOCK & WILCOX CO. 3 (2012), *available at* http://www.babcock.com/library/pdf/E2011002.pdf [hereinafter GENERATION MPOWER].

[115] GENERATION MPOWER at 3–4. Lower head penetrations are recognized as a potential reactor vessel failure source in the event of a severe accident.

[116] *Id.*

[117] *Id.*

bottom of the steam generator tube bundle to be converted to steam and superheated as it passes up the interior of the tubes. Reactor coolant on the outside of the tubes passes downward, transferring energy to the steam and subsequently to the water steam mixture, and then to the feedwater at the bottom of the steam generator tube bundle.[118] The steam generator tubes are subject to compression because of the higher pressure of the reactor coolant system being on the outside of the tubes, with interior tube pressure being determined by secondary system steam conditions. Steam generator tube failure in compression is substantially less likely than failure caused by rupture associated with hoop stress exceeding tensile strength following tube wastage or corrosion. The generation of superheated steam also results in increased thermal efficiency and increased high-pressure turbine blade durability.[119] The increased thermal efficiency also enables economic utilization of air cooled condensers on nuclear power plants, which is particularly beneficial in the arid western United States where cooling water resources have substantial value for alternative uses such as domestic water needs.

The B&W mPower reactor coolant system is designed to be completely fabricated in a factory and shipped as a complete module to the site. The fuel elements are identical to those utilized in operating reactors but for the length of the fuel assemblies, which are shortened to approximately eight feet in active fuel length as compared to twelve or fourteen feet of the large PWRs.[120] The retention of the well-established reactor fuel design avoids numerous issues regarding safety evaluations and methodology of analysis regarding the NRC review and approval process.

B. The Westinghouse Small Modular Reactor

The Westinghouse PWR, with its U-tube steam generator, is the most common of all existing commercial reactor designs.[121] It has served as the base for the PWR development, which has been utilized domestically as well as in France, South Korea, Sweden, Spain, and Italy, among other countries. The Westinghouse Small Modular Reactor (WSMR) retains many of the design concepts implemented in its standard PWR designs, as well as in the new large AP1000 passive-safe design. The WSMR configures the reactor coolant system to be completely located within the reactor vessel.[122] Rather than a U-tube configuration for the steam generator, a once-through design is utilized. However, as in the case of the U-tube design, the reactor coolant flows through the steam generator tube, while the secondary coolant being converted to steam is on the exterior of the tubes, such that the higher-pressure fluid is on the inside of the steam generator tubes. Additionally, the Westinghouse steam generator as implemented in the WSMR is

---

[118] *Id.*

[119] BABCOCK & WILCOX CO., STEAM 12-2 (37th ed. 1963).

[120] *Id.*

[121] *Nuclear Power Plants*, WESTINGHOUSE, http://www.westinghousenuclear.com/ProductLines/Nuclear_Power_Plants/ (last visited Aug. 30, 2012).

[122] WESTINGHOUSE, *supra* note 111.

effectively a separation of the typical Westinghouse steam generator into two components with the tube bundle positioned within the reactor vessel, with the steam drum being located exterior to the reactor vessel and exterior to the containment. As with all other Westinghouse steam generators installed in commercial nuclear facilities, saturated steam is produced by the WSMR. It is interesting that Westinghouse has elected to retain its long-established approach to steam generator design in the WSMR, although the potential advantages of a once-through reactor coolant flow path provide the potential to lower the water inventory on the secondary side of the steam generator tubes and thereby increase thermal efficiency of the entire facility.

The containment design of the WSMR is a refinement of the approach utilized in the Westinghouse AP1000 passive-safe design which, as previously noted, has been certified by the NRC. The containment structure is a compact steel pressure vessel that is proportionately much smaller than the AP1000 design because of the ability to economically optimize compact size and higher design pressure in the size range of the WSMR containment. The WSMR containment is intended to operate as a vacuum to enable reduced insulation requirements while limiting heat loss from the reactor vessel and precluding the potential for hydrogen-oxygen reactions in the event of a severe accident that results in a hydrogen generation because of a zirconium water reaction. In the event of a severe accident, the lower portion of the reactor vessel will be submerged in water from the various water sources located within the containment.[123] All water ultimately drains to the bottom of the containment, thereby flooding the volume surrounding the lower portion of the reactor vessel. The prevention of containment overpressure due to overheating following an accident is accomplished when the exterior of the containment is surrounded by a flooded annular space, thereby cooling the containment walls and condensing the steam atmosphere within the containment to replenish the water inventory surrounding and cooling the reactor's fuel. While the available water inventory provides seven days of passive cooling, additional water can be added to extend passive cooling indefinitely.[124]

The WSMR, similar to the B&W mPower design, utilizes existing designs for the reactor fuel while reducing the active length of the fuel to eight feet. The WSMR effectively builds upon the substantial experience that has been developed with Westinghouse PWRs and relies on components that have proven to be reliable. Westinghouse has reconfigured its basic design approach and repackaged the various necessary elements to reduce the size of the overall plant, to simplify and reduce the number of systems and components needed to assure safety and reliable operation, and to enhance safety by incorporation of passive-safe design concepts. Because the WSMR relies on Westinghouse's experience for all major

---

[123] *See* WESTINGHOUSE, THE WESTINGHOUSE SMALL MODULAR REACTOR (2011), *available at* http://www.westinghousenuclear.com/smr/fact_sheet.pdf.

[124] *Id.*

elements of the design, it is viewed by the DOE as a design that can be implemented in the near term.[125]

C. The NuScale Modular Reactor

The NuScale modular reactor, designed by NuScale Power Inc., differs substantially from the B&W and Westinghouse modular designs. While the NuScale design relies on existing PWR fuel element design, other NuScale design features are unique. NuScale utilizes natural circulation of the reactor coolant, rather than forced flow by reactor coolant pumps, to transfer energy generated by fission in the reactor to steam generator tubes located within the reactor vessel.[126] The power density (MWth of heat generation/ft^{3}of fuel volume) of the NuScale design is very near the power density of the currently operating PWRs as well as of the Westinghouse and B&W modular designs. The operating pressure of the NuScale reactor coolant system is 1500 psig, while typical PWRs operated at 2200 psig. NuScale claims the reduced operating pressure combined with a reduced maximum temperature in the reactor coolant system will reduce stress corrosion cracking concerns.[127] These changes to the typical operating conditions of PWRs currently licensed by the NRC represent a non-trivial change from prior experience regarding operating conditions of the reactor and the demonstration of adequate safety. While neither Westinghouse nor B&W has elected to deviate from its experience base regarding operating conditions of the reactor fuel, NuScale is venturing into new operating space. The reception to be given to NuScale's design by the NRC remains to be seen.

Whereas B&W relies on a relatively large containment vessel, which is passively cooled in the event of an accident, the NuScale design employs a substantially smaller steel containment vessel with a high (450 psig) design pressure. The containment vessel is totally submerged in a pool of water. The NuScale containment atmosphere is a vacuum during normal operation to reduce thermal heat loss from the reactor coolant vessel without reliance upon insulation being installed on the reactor vessel.[128] The evacuated containment also eliminates oxygen as a post-accident concern and effectively eliminates corrosion within the containment structure. The containment's submersion in a pool of water assures that overheating of the containment will not occur as long as the water pool retains its integrity. The positioning of that water pool below ground level and construction of the pool as a very heavily reinforced concrete structure to withstand any postulated seismic event, reduces seismic risk as well as potential terrorist threats with aircraft. The submersion of the containment vessel also provides an additional medium—the pool water—to capture any radioactive

---

[125] BLACK, *supra* note 107, at 3.

[126] NUSCALE POWER, *supra* note 112.

[127] *Id.*

[128] *How NuScale Technology Works*, NUSCALE POWER, http://www.nuscale.com/ot-How-NuScale-Technology-Works.php (last visited Sept. 19, 2012).

material that could leak from the containment during or following any accident.[129] Additional structural elements of the facility contain or surround the water pool and provide additional opportunities to isolate or capture radioactive materials prior to release to the environment and subsequent exposure by members of the general public. The effectiveness of the additional means to mitigate the release of radioactive materials following an accident is yet to be assessed by the NRC. The various system interconnections, which should be isolated following any accident, may be the more significant potential pathway for postaccident release of radioactive materials.

The NuScale design anticipates that each reactor will provide steam to a turbine generator-condenser-feedwater composite system that is not safety-related. Multiple NuScale units are anticipated to be constructed at a particular site with a common water pool, in which all containment vessels with their respective reactor coolant systems will be inserted.

The NuScale design represents a more significant departure from existing PWR design concepts and experience than the modular designs of either Westinghouse or B&W. While the NuScale design incorporates numerous new design features or concepts that may be viewed to enhance safety, the practical utility of those features and concepts, as well as their impact upon the duration of the NRC review and approval process remains to be determined.

V. CONCLUSIONS AND PREDICTIONS

The production of large amounts of electric energy is a complex enterprise in which every alternative’s costs, consequences, and risks must be thoroughly and rationally evaluated.

The rate of occurrence of severe accidents with non-nuclear sources of energy are orders of magnitude higher than the projected rate of occurrence of events of similar severe consequence associated with currently operating nuclear power plants. The new passive-safe facilities being constructed in Georgia and South Carolina are orders of magnitude less likely to cause injury to public health and safety than the operating nuclear facilities that are much safer than any other major energy source.

Nuclear-fired generation is currently the low-cost alternative for baseload electric energy. The cost associated with operating and maintenance costs of nuclear power have been stable for fifteen years, as have nuclear fuel costs. During the last fifteen years, the cost of natural gas first increased by 150% and subsequently decreased by 40%.[130] The view of experts within the natural gas industry is that current low prices are unsustainable and the likely stable price is twice the current low market price.[131] If that projection is correct, the natural gas

---

[129] *Id.*

[130] NUCLEAR ENERGY INST., *supra* note 60.

[131] Richard J Pierce, Professor, George Washington Univ. Law Sch., Remarks at the Wallace Stegner Center, University of Utah S.J. Quinney College of Law Conference:

fuel cost will exceed the sum of all costs of power generated by new nuclear facilities. While the raw fuel cost of coal has remained stable for the last fifteen years, the potential consequences of either a CO_2 tax or a requirement to capture and sequester CO_2 would substantially increase the cost of electric energy produced by coal. Additionally, the cost of conformance to the Clean Air Act regarding particulates, heavy metals, and other criteria emissions, as well as restrictions on disposal of coal facility wastes have increased the cost of energy from coal facilities to equal the cost of energy from new nuclear facilities.

The uncertainty associated with the future costs of energy from both coal and natural gas has resulted in approval of new nuclear construction by the public service commissions of two southeastern states where deregulation has not been implemented. In regions of the country where the electric supply system is deregulated, new nuclear power facilities have not proceeded to date due to lingering perceptions of economic risks associated with prior nuclear project cost overruns linked to changing regulatory requirements during the extended construction periods historically required to complete construction of nuclear facilities. If the new nuclear facilities being constructed in Georgia and South Carolina are completed on schedule and within budget, concerns regarding project risk will be greatly mitigated.

Following the establishment of the NRC as an independent agency in 1974, the NRC developed its detailed guidance and technical positions based upon rules and regulations previously established by the Atomic Energy Commission. The accident at TMI 2 occurred subsequent to the commitment by U.S. utilities to construct all of the currently operating nuclear facilities. While the fundamental requirements of the General Design Criteria were not amended subsequent to the TMI 2 event, the NRC promulgated major modifications to emergency planning requirements. In addition, a comprehensive review of all requirements for operating license applications caused significant delays to those facilities that were undergoing construction and engaged in obtaining final approval to begin operation. The large cost overruns associated with the nuclear facilities completed since the late 1970s are a direct result of the maturation of the NRC as an independent regulatory agency responsible for assurance of public health and safety.

The maturation of the NRC as an independent agency has been completed with the establishment of the facility and design licensing and approval process presented in 10 C.F.R. Part 52. The key element of that process is the COL process, wherein an applicant can obtain NRC authorization to construct and operate a new nuclear facility based upon established acceptance criteria and detailed design specifications prior to engaging in the multi-year construction of safety-related structures, systems and components. The new approach to licensing provides assurance that all issues are resolved early in the process prior to the expenditure of the very large capital investment and time required to construct a

---

Electric Power in a Carbon Constrained World: Will It Be the Fuel of Choice for Electric Power Generation? (Feb. 9, 2012).

nuclear facility. The first units to utilize the new licensing process, Vogtle Units 3 and 4, have been licensed by NRC,[132] and more nuclear facilities are now in the licensing pipeline.[133]

The development of the revised licensing process, which includes the provision for manufacturing authorization wherein an entire nuclear steam supply system may be fabricated in a factory and subsequently shipped to an approved site for installation and operation, also has the potential to greatly reduce the time required to construct a nuclear facility. DOE's program supporting the licensing of small modular reactors is intended to reduce the economic risk associated with very long-duration construction process of large nuclear facilities, reducing it to the time interval experienced by combined-cycle natural gas power plants. Additionally, the smaller capacity of modular units provides the potential for utilization in geographical regions where electric demand does not warrant construction of a very large nuclear power station. Three passive-safe modular designs which adapt existing pressurized water reactor components and experience are proceeding through the NRC certification process. Babcock & Wilcox, Westinghouse, and NuScale are proceeding with licensing of their respective modular designs with the NRC utilizing the provisions of 10 C.F.R. Part 52. DOE appears to consider that modular reactors will be available for use in the near term.

One hundred and four operating nuclear power reactors licensed in the United States are providing approximately 20% of the nation's electric energy requirements with minimal environmental consequence, as compared to alternative sources of baseload electric energy.[134] The reliability of these facilities has been demonstrated by the industry-wide capacity factor exceeding 90% over the last ten years and the granting of twenty-year extensions of the operating licenses by the NRC to facilities approaching the end of their initial forty-year license terms. The regulatory structure and detailed requirements are well established with a mature independent oversight agency providing reasonable assurance of protection of public health and safety. It is undisputed that errors have occurred, resulting in severe economic consequences that should have been avoided, and that would have been avoided had the then-existing requirements been properly satisfied. Nevertheless, no fatalities have resulted from accidents associated with nuclear reactor designs utilized in the United States, and it is unlikely that any deaths will ever be proven to have resulted from those events.[135] The amount of energy produced by nuclear power over the last forty years is massive, the environmental consequences of that production have been extremely low, and no determinable public health consequences have been identified. However, the environmental and

---

[132] *See* COMBINED LICENSE VOGTLE ELECTRIC GENERATING PLANT *supra* note 70.

[133] *New Reactor Licensing Applications Schedules*, U.S. NUCLEAR REGULATORY COMM'N, http://www.nrc.gov/reactors/new-reactors/new-licensing-files/new-rx-licensing-app-legend.pdf (last visited Aug. 30, 2012).

[134] *U.S. Nuclear Power* Plants, Nuclear Energy Inst. http://www.nei.org/resourcesandstats/nuclear_statistics/usnuclearpowerplants/ (last visited Sept. 8, 2012).

[135] *See supra* Part II.

health consequences of alternative sources of major amounts of electric energy are manifest.[136]

A society presented with means to provide massive amounts of electric energy at competitive, if not the lowest, cost, with substantially less risk to public health and safety than that posed by alternative energy sources and the lowest environmental consequences, would, if rational decisions were the basis for action, proceed with full utilization of that energy source. All of those conditions currently exist regarding proceeding with new nuclear facilities in the United States.

The reasons for an optimistic view of the future of nuclear power in the United States are obvious.

---

[136] *See supra* Part II.