Will changing times require a Second Look at Nuclear Power?

by Alan S. Brown

NUCLEAR POWER PLANTS are suddenly back on the table as a potential major source of electrical energy. Long-time supporters of nuclear power now have new allies. Some believe it is the only way to meet future global energy demands without poisoning our planet. Others are looking for ways to reduce America's dependency on foreign suppliers.

Figure 1 (above right) Artist's conception of a Westinghouse Generation III+ nuclear power plant, incorporating new passive systems.
Figure 2 (above left) The 520-foot-high cooling tower marks the Grand Gulf Nuclear Station along the Mississippi River. Operated by Entergy Nuclear, it opened in 1985, 11 years after construction began.

Behind these calculations lies an undeniable fact: global demand for electricity is growing. The U.S. Energy Information Administration (EIA) expects electrical demand to rise more than 80 percent between 2002 and 2025. Nearly 60 percent of the increase will come from developing nations, which will consume more electricity than the mature market economies within 20 years.

Wind, solar, and other forms of renewable energy are unlikely to provide more than a fraction of future requirements. Instead, says EIA, the world must build hundreds of new power plants.

WARMING SIGNS

Most of these new units are likely to burn coal or natural gas. Their carbon dioxide emissions raise a red flag for environmentalists concerned about global warming. Some see nuclear energy, which eliminate 2.5 billion tons/year of coal-based power plant carbon emissions, as a way to save the planet. This has led to an about-face on nuclear power by several well-known environmentalists–or *greens*–who believe global warming is a more severe threat than nuclear contamination. Among the most prominent are Gaia theorist James Lovelock, Greenpeace cofounder Patrick Moore, and former Friends of the Earth chairman Hugh Montefiore, who was forced to resign as a director after he declared in favor of nuclear power.

Not every proponent of nuclear power is a green. Others argue that natural gas, America's

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preferred power plant fuel because of its low cost and clean burning characteristics, may not remain a bargain. From the mid-1980s through most of the 1990s, prices hovered below $2/MM Btu. They rose to the $3-6/MM Btu range in the 2000s. After Hurricanes Katrina and Rita battered the natural-gas distribution system, prices more than doubled to $15/million British thermal units (MM Btu) before settling back to $7/MM Btu.

Experts expect prices to remain high for several years as U.S. producers struggle to find new gas. EIA expects North American gas demand to rise 1.5 percent annually through 2025 while production increases only 0.5 percent. Imports of liquefied natural gas (LNG) are likely to fill the gap, and nearly 60 new LNG regasification terminals are now on the drawing boards.

The United States already imports two-thirds of its oil. Critics argue that importing even relatively small amounts of LNG leaves the nation dangerously dependent on foreign energy. They underscore their argument by noting that roughly three-quarters of all natural gas reserves are in Middle East and former Eastern Bloc nations.

INCENTIVES

The U.S. government is already making a concerted effort to jumpstart the moribund nuclear power industry. The last utility received a construction license for twin nuclear power plants, Watts Bar I and II, in 1970. Anti-nuclear activists delayed the opening of Watts Bar I until 1996 and stopped Watts Bar II in its tracks. In 1989, they finally forced Long Island Lighting Co. to close its Shoreham reactor before it generated a single watt of electricity.

The Nuclear Regulatory Commission hopes to end such billion-dollar fiascoes by issuing combined construction and operating licenses (COLs) that ensure a utility can operate a plant once completed. The federal government is also promising to insure utilities against regulatory delays (often generated by lawsuits) for up to $500 million for the first new nuclear plant and $250 million for the second.

Finally, the government is promising to defray the "first-mover" costs of building plants based on new technologies. It promises to underwrite the cost of the first 6,000 megawatts (MW) of new nuclear capacity with a production tax credit of $1,800/MW. It is also funding research into advanced nuclear power plants, spent fuel recycling, and pushing to open the Yucca Mountain spent-fuel storage facility.

Yet fundamental issues remain: Will new reactors prove safe? Can they compete economically? Can we safely manage nuclear wastes? What about proliferation? The answers are not always clear.

REACTOR SAFETY

The Three Mile Island partial core meltdown of 1979 and the Chernobyl reactor explosion in 1986 make safety the primary issue in the nuclear debate. The newest reactors, referred to as Generation III+, speak to many of these concerns.

To understand why, look at nuclear operations. As uranium fuel decays, it emits neutrons that split other uranium atoms that emit still more neutrons. This creates a chain reaction of splitting neutrons that release enormous amounts of heat. This heats the cooling water, whose steam powers the electrical generators. Stop the flow of water, and the reactor will overheat and begin to melt.

Existing Generation II plants use redundant pumps, chillers, generators, and pipes to ensure continuous water flow. Utilities added many of these safety systems over time. They work, but the design is neither simple nor elegant.

In the 1970s, nuclear power plant designers such as General Electric Power and Westinghouse began designing a new generation of reactors. "After 30 years of experience, we started with a clean piece of paper," explains Howard Bruschi, the former Westinghouse chief technology officer who oversaw the development of the company's Generation III and III+ units. "We invited plant operators into the design process and used their recommendations to simplify piping, controls, constructability, and operability."

The result, he says, was a simpler, more economical plant. Yet only a handful have been built. One reason is that Three Mile Island forced designers to reconsider nuclear safety. The result is Generation III+, a radical departure in which safety measures require no human intervention.

"Generation III delivers water by rotating machinery like pumps and back-up generators," explains Bruschi. "Generation III+ uses passive safety systems that depend on natural forces such as gravity, natural circulation, condensation, and evaporation. There are no pumps, fans, chillers, or diesel generators and fewer associated mechanical and electrical devices. Everything is much simpler and much less expensive."

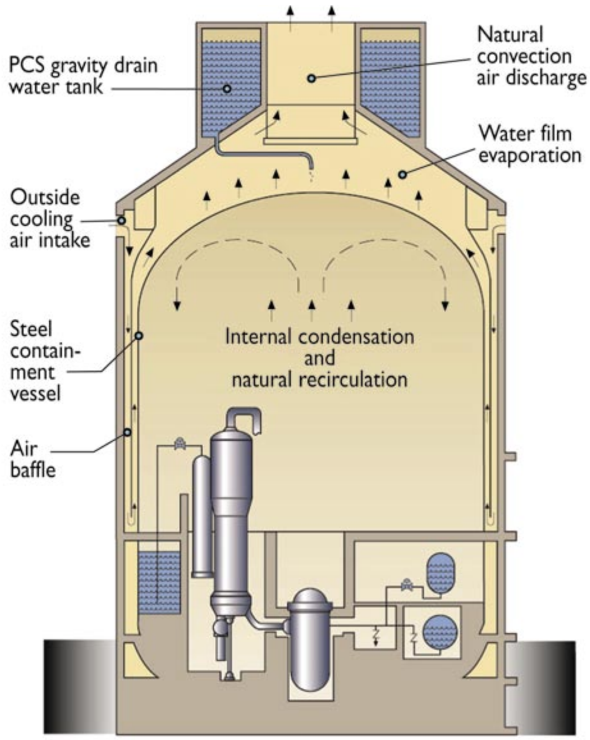


Figure 3 New "passive safety" reactor designs use such natural forces as gravity, circulation, condensation, and evaporation to react automatically to accidents without operator intervention.

Both the new Westinghouse AP1000 advanced pressurized reactor, which received Nuclear Regulatory Commission design approval in December 2005, and GE Energy's economic simplified boiling-water reactor (ESBWR), which submitted its design application in August 2005, use passive safety systems.

The AP1000 reactor, says Bruschi, sits inside a large containment vessel with no communication from outside the building [Fig. 3]. The containment vessel also houses a spherical tank of pressurized water plus two additional pools of water. If an accident occurs, the water-pressure drop automatically releases water from the pressurized tank. The two gravity tanks follow; the second with 500,000 gallons, enough to submerge the reactor.

Meanwhile, the mechanical system that holds the control rods above the reactor releases, and they automatically drop into place. Over the course of several days, they will absorb enough neutrons to stop the reactor's chain reaction. Yet the reactor will remain hot enough to boil the water covering it. The steam will rise to the roof of the containment vessel, where air outside the vessel will cool it. It will then condense and return to the bottom of the vessel.

The engineering is elegant, and the Nuclear Regulatory Commission has assessed the designs far more closely than ever before. Generation III+ reactors are clearly safer than their predecessors, though their ultimate test will come over decades of operation.

ECONOMICS

Passive design simplifies plant construction. The AP1000, for example, requires 50 percent fewer valves, 83 percent less piping, 87 percent less control cable, 35 percent fewer pumps, and 50 percent less seismic building volume than its predecessors. That makes a big bottom line difference. Generation III plants also produce about 25 percent more power than Generation II units.

More power for less money sounds like icing on the cake. After all, Entergy Corp., a major utility and the nation's second largest nuclear plant operator, earned 31 percent of its total profits from just five deregulated nuclear power plants; its five regulated nuclear plants and 75 fossil fuel units accounted for the rest. Dan Keuter, Entergy's vice president of nuclear business development, expects those five plants to provide half of the company's profits in 2006.

This is a startling turnaround for an industry that always struggled with profitability. One of the key factors behind the reversal is industry's rise in capacity factor, the amount of power a facility generates divided by its potential output. The more fully it uses its assets, the less it costs to generate electricity.

For most of the 1980s, America's nuclear plants operated at less than 60 percent of capacity. By 2005, utilities had pushed that figure to 88.8 percent, the highest of any U.S. power source.

Figure 4 (above) Refueling the reactor at Arkansas Nuclear One in Russellville, AR.

Figure 5 (below) Nuclear fuel comes in rod stacks. After use, those stacks are cooled in water for 10 years or more.

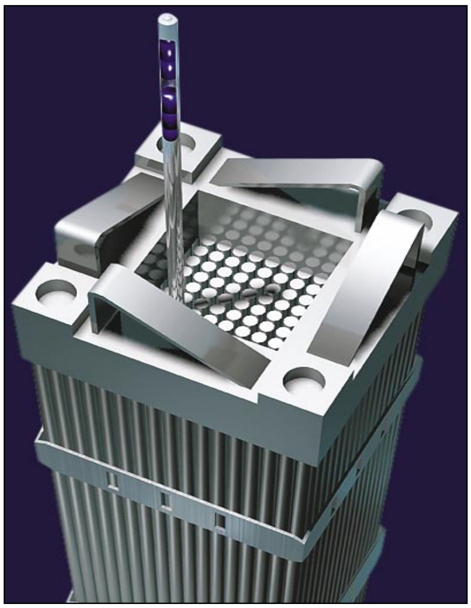
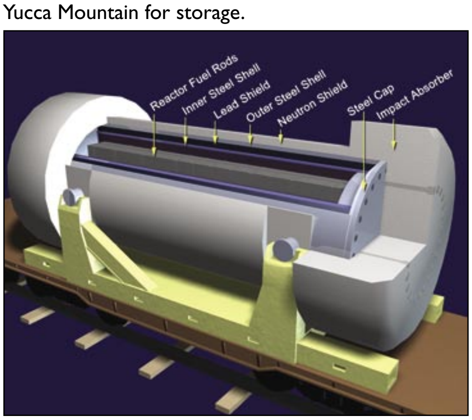


Figure 6 (below) Once cooled, the rod stacks would be housed in 125-ton steel canisters for transport to Yucca Mountain for storage.



Several factors lie behind the increase. The industry has upgraded to digital-control systems and resolved the start-up problems of any new technology. It also slashed refueling time [Fig. 4] from three months or longer in the early 1990s to under 39 days during the 2000s. Entergy's River Bend Station in St. Francisville, LA, even managed a 17-day turnaround in 2001. "We've become a mature industry," Keuter says.

High natural-gas costs have also helped. Fuel costs account for roughly 60 percent of the cost of gas-generated electricity. Gas-based electricity soared after Katrina and Rita. Uranium prices remained stable. Entergy's five deregulated plants simply raised electricity prices to the level of their gas-based competitors and earned the difference as profit.

In fact, Keuter claims, nuclear plants are the nation's least expensive energy option. He points to a presentation that shows the cost of power in 2003. Nuclear-based electricity cost 1.72 c/kW-hr, compared with 1.80 c/kW-hr for coal and 5.77 c/kW-hr for gas (based on gas at $4.88/MM Btu).

Unfortunately, Keuter's slide does not include the cost of capital or the time needed to build a new nuclear power plant. Capital, higher interest rates based on risk—remember, the last nuclear plant took 26 years to build, and long construction times account for about 60 percent of the cost of each nuclear kilowatt-hour. They comprise much smaller proportions of gas or coal power.

STUDIES

In 2003, a landmark study by a team led by MIT professors Dr. John M. Deutch *[MA B'61]* and Ernest Moniz attempted to model nuclear-power costs. Their base case assumed that utilities would spend $2,000/kW and take five years to build a new nuclear plant. The team compared this with $1,300/kW and four years for a coal unit and $500/kW and two years for a gas plant.

Assuming all three types of plants ran at 85 percent of capacity, electricity would cost 6.7 c/kW-hr for nuclear, 4.2 c/kW-hr for coal, and between

3.8-5.6 c/kW-hr for gas (assuming gas at $3.77-6.72/MM Btu). Nuclear could compete if it slashed construction costs 25 percent (bringing costs to 5.5 c/kW-hr); reduced construction time to four years (5.3 c/kW-hr); and cut operating costs 13 percent (5.1 c/kW-hr). Reducing construction costs to coal plant levels, $1,300/kW, would yield nuclear power at 4.2 c/kW-hr.

A study done one year later by economists at University of Chicago and RCF Economic and Financial Consulting, Inc., appeared more optimistic. RFC took a broader sample of nuclear-plant construction data, says its vice president Donald Jones. This led it to lower capital-cost estimates to $1,200/MW to $1,800/MW. Jones assumed 35 percent higher capital costs for first-of-a-kind engineering, three percent higher-than-average interest rates for risk, and seven years for construction. Even then, he believed new nuclear would generate electricity for 4.7-7.1 c/kW-hr.

Experience is likely to drive down costs and eliminate risk. This could lower the cost of nuclear power to 3.1-4.6 c/kW-hr. This makes it fully competitive with coal at 3.3-4.1 c/kW-hr and gas at 3.5-4.5 c/kW-hr. "If gas were to stay above $9/MM Btu, it would be priced out of the market," Jones adds.

Keuter is even more optimistic. He says Entergy has already received bids of $1,500/MW from vendors and already runs its reactors above the 85 percent capacity factor assumed in both studies. He believes today's modular plants will take less time to build. Nuclear's advantage would be greater still if the government ever imposes a carbon-emissions tax.

The industry can also count on longer lifespans. Designers estimated a 40-year service life when they built existing nuclear plants. Yet reactor internals exposed to decades of neutron bombardment have not degraded as fast as expected, says Stan Rosinski, who manages the technology innovation program at the Electric Power Research Institute (EPRI).

As a result, he says, 39 of America's 103 operating reactors have already received 20-year license renewals. Moreover, the lessons learned from the first generation of plants has led to changes in materials and welding and construction techniques that will enable new plants to run longer still.

WASTE STORAGE

A 1,000 MW nuclear power plant will generate roughly 20 tons of nuclear waste annually, including spent fuel and 10-to-15-foot-long rod stacks that contain it. In addition to uranium, spent fuel also includes radioactive isotopes formed during fission. Most disappear after a few hundred years. Others remain radioactive for hundreds of thousands or even millions of years.

In 1987, Congress chose Yucca Mountain [Fig. 7] to store nuclear waste. Located 100 miles north of Las Vegas, NV, it sits one mountain range over from the range where the nation tested nuclear weapons for 40 years. Yucca receives only 7.5 inches of rain annually. The facility will store 11,000 containers holding 70,000 metric tons of uranium in tunnels hundreds of feet below Yucca's volcanic rock and 1,000 feet above the water table.

"The civil engineering construction is not so difficult. Just make lots of tunnels, railways, highways, and some storage pads on the surface," says Joonhong Ahn, an associate professor of nuclear engineering at the University of California, Berkeley, who studies radioactive waste management.

Yet environmental lawsuits have transformed this relatively simple engineering project into an undertaking that will likely cost $60 billion—about half as much as the entire interstate highway system—when complete.

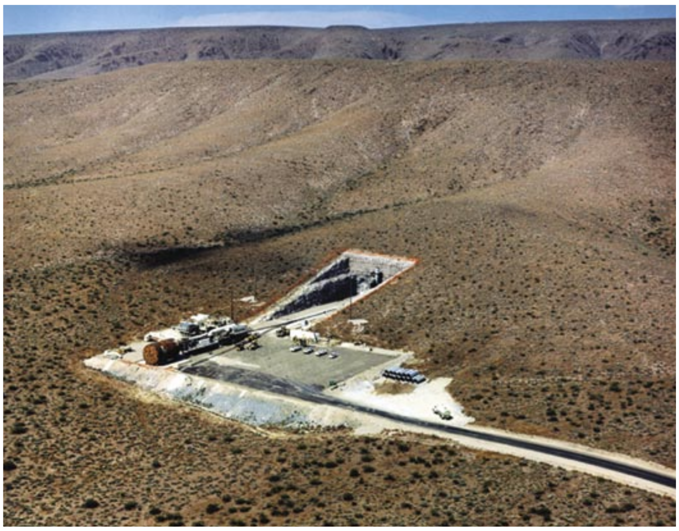


Figure 7 View of the south portal of the Yucca Mountain exploratory studies facility, showing the 25-foot-diameter tunnel boring machine.

Environmentalists argue that the site is not safe. As Ahn explains, Yucca Mountain is about 10 percent porous, and about 80 percent of those pores are filled with water. Assuming some nuclear canisters fail, radionuclides will eventually percolate through the aqueous pores and down to the water table. "The problem starts to become more serious after 10,000 years," he says.

The Environmental Protection Agency (EPA) says the facility must limit exposure of nearby residents to escaping radiation to 15 millirem (the amount of radiation absorbed by a person) per year for the first 10,000 years and 350 millirem for another one-million years. "The difference in background radiation within Nevada is about 400 millirem," scoffs John Kessler, who runs EPRI's high-level waste and spent-fuel management program.

RISKS

Environmentalists also worry that nuclear shipments could derail or fail in a traffic accident, spewing waste into the environment. Kessler is sanguine. "Both France and the United Kingdom shipped spent fuel every day. There have been a few accidents, but there has never been a release during shipment," he says.

In fact, shipping canisters [Fig. 6] are designed to resist failure. Their inner containers consist of huge metal casks about 6-7 feet in diameter and 15 feet long. They fit into steel overpack containers shaped like enormous dumbbells that come in two sizes: 125 tons for railroads and 40 tons for

Figure 8 (left) Indian Point, located 35 miles north of New York City, has two operating reactors—far left and right in photograph—and a mothballed unit (center). Activists have argued for its shutdown for more than 30 years.

trucks. Both designs were tested to survive a 30-foot drop onto an unyielding surface and 30 minutes at 800 °C in a fully engulfing fire.

Could a terrorist capture a shipment? Between 1993 and 2004, the International Atomic Energy Agency (IAEA) reported 18 incidents of trafficking in weapons-grade highly enriched uranium or plutonium; 220 incidents involving such low-grade nuclear materials as reactor fuel pellets and depleted uranium; and 424 incidents involving low-grade radioactive materials for radiography, measurement, and other legitimate uses.

According to IAEA, the incidents underscore terrorist interest in acquiring radioactive materials. While only high-level nuclear waste can be used to make atomic bombs, low-level waste is ideal for dirty bombs. While a dirty bomb is unlikely to kill anyone more than a few yards from the blast, the cost of cleaning up the radioactive material it broadcasts could cost billions.

Hijacking such large canisters would not be easy. Multiple layers of security ranging from biometric sensors and global positioning systems to armed guards surround them. Because they are so large, they would be difficult to remove from the crime scene.

Despite concerns, a closed, guarded, underground storage facility appears safer than current practice. Today, says Steven Kraft, senior director of used fuel management at the Nuclear Energy Institute, an industry trade group, we store nuclear wastes at more than 30 different power plants around the country.

Spent fuel removed from a reactor is far too hot to put in any container. Instead, plants store fuel rods [Fig. 5] in 40-foot-deep pools filled with water. Some pools are located in the ground, others in the containment buildings. All are seismic designs made from reinforced concrete.

It takes at least 10 years for fuel rods to cool. Many are then stored in vertical steel and concrete containers on outdoor pads. According to an EPRI study done shortly after 9/11, the outdoor casks could survive a direct crash from a Boeing 767 jetliner. "The casks would maybe fall over and bounce around a bit, but they would not break open," says Kraft. He also says classified studies show that spent fuel in pools would remain cool even if terrorists took over a reactor.

It is one more risk in a chain of risks. There are risks storing spent waste near reactors and risks moving them to Yucca Mountain. There will always be risks—perhaps ones we cannot yet envision—in operating even next-generation passive reactors. We may minimize those risks, but any failure could cause catastrophic harm.

The nuclear industry has taken real strides in responding to its critics. After Three Mile Island, it retrofitted plants to make them safer and more manageable. Their improved control shows clearly in their high and rising capacity factor. Moreover, new designs are undoubtedly safer than existing reactors, and Yucca Mountain is secure enough to push any real threat of contamination millennia into the future.

Risk remains part of the nuclear equation. Yet every equation has two sides. We must also face risks associated with rising hydrocarbon dependency and global warming (not to mention ongoing problems with coal-mining safety).

The former is a strategic issue. Many nations could resolve it by switching to coal, using more renewable power, and emphasizing conservation. Yet renewable power alone is unlikely to provide a large share of future power needs. Conservation helps developed economies to limit future power demands, but does little for developing nations that do not yet have enough energy to conserve.

Coal plants can provide the power growing economies need, but they shovel carbon into the atmosphere. This is causing a planetary challenge and potential consequences that we only dimly understand. Already, arctic ice masses are melting. Some suggest that ocean levels will rise and cause widespread flooding. Others foresee climatic changes that would wreak havoc with the planetary agriculture.

Figure 9 Entergy's Yankee nuclear plant generates about one-third of Vermont's electricity. The unit has proven very profitable since the runup in natural gas costs.

Compared to such sweeping global changes, the hazards posed by nuclear generation appear localized and not as threatening. Moreover, they are risks that engineers can mitigate if not entirely remove.

Clearly, nuclear power involves risk. Yet the status quo—building more hydrocarbon-powered power plants—involves potentially greater risks to the entire planet. Until we find a way to manage those risks, interest in nuclear power will continue to grow.

Alan S. Brown is an associate editor of *Mechanical Engineering* and a freelance writer for more than 25 years. He has written for a broad range of professional and engineering publications on topics ranging from aerospace, semiconductor, and control technology to outsourcing and homeland security. He lives in Dayton, NJ, *(insight@comcast.net)* and is a member of the National Association of Science Writers and co-chair of Science Writers in New York.