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Nuclear Energy

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All Developments »

Associated Press

A cooling tower of Three Mile Island's Unit 1 Nuclear Power Plant in Middletown, Pa.

Updated: July 1, 2010

Overview

Nuclear power plants use the forces within the nucleus of an atom to generate electricity.

The first nuclear reactor was built by Enrico Fermi below the stands of Stagg Field in Chicago in 1942. The first commercial reactor went into operation in Shippingport, Pa., in December, 1957.

In its early years, nuclear power seemed the wave of the future, a clean source of potentially limitless cheap electricity. But progress was slowed by the high, unpredictable cost of building plants, uneven growth in electric demand, the fluctuating cost of competing fuels like oil and safety concerns.

Accidents at the Three Mile Island plant in Pennsylvania in 1979 and at the Chernobyl reactor in the Soviet Union in 1986 cast a pall over the industry that was deepened by technical and economic problems. In the 1980s, utilities wasted tens of billions of dollars on reactors they couldn't finish. In the '90s, companies scrapped several reactors because their operating costs were so high that it was cheaper to buy power elsewhere.

But recently, in a historic shift, more than a dozen companies around the United States have suddenly become eager to build new nuclear reactors. Growing electric demand, higher prices for coal and gas, a generous Congress and a public support for radical cuts in carbon dioxide emissions have all combined to change the prospects for reactors, and many companies were ready to try again.

The old problems remain, however, like public fear of catastrophe, lack of a permanent waste solution and high construction costs. And some new problems have emerged: the credit crisis and the decline worldwide of factories that can make components. The competition in the electric market has also changed.

Nonetheless, industry executives and taxpayers are spending hundreds of millions of dollars to plan a new chapter for nuclear power in the United States and set the stage for worldwide revival.

How It Works

Nuclear power is essentially a very complicated way to boil water.

Nuclear fuel consists of an element – generally uranium – in which an atom has an usually large nucleus. The nucleus is made up of particles called protons and neutrons. The power produces by a nuclear plant unleashed when the nucleus of one of these atoms is hit by a neutron traveling at the right speed.

The most common reaction is that the nucleus splits – an event known as nuclear fission — and sets loose more neutrons. Those neutrons hit other nuclei and split them, too. At equilibrium – each nuclear fission producing one additional nuclear fission – the reactor undergoes a chain reaction that can last for months or even years.

When the split atom flings off neutrons, it also sends out fragments. Their energy is transferred to water that surrounds the nuclear core as heat. The fragments also give off sub-atomic particles or gamma rays that generate heat.

Depending on the plant's design, the water is either boiled in the reactor vessel, or transfers its heat to a separate circuit of water that boils. The steam spins a turbine that turns a generator and makes electricity.

Sometimes instead of splitting, the nucleus absorbs the neutron fired at it, a reaction that turns the uranium into a different element, plutonium 239 (Pu-239). This reaction happens some of the time in all reactors. But in what are known as breeder reactors, neutrons fired at a higher force are absorbed far more often. In this process, spent uranium fuel can be recycled into Pu-239, which can be used as new fuel. But problems with safety and waste disposal have limited their use – a fuel recycling plant that operated near Buffalo for six years created waste that cost taxpayers $1 billion to clean up.

Discovery and the Birth of an Industry

The possibility of nuclear fission – splitting atoms — was recognized in the late 1930s. The first controlled chain reaction came in 1942 as part of the Manhattan Project, the wartime American effort to build an atom bomb. That project entailed construction of several reactors, but for them, the energy was a waste product; the object was plutonium bomb fuel. On July 16, 1945, at the Trinity Site in New Mexico, the project's scientists demonstrated a chain reaction allowed to multiply exponentially – the first blast of an atomic bomb.

Even before the war ended, the military was looking at reactors for another use, submarine propulsion. Work on those reactors began in the early 1950s, and on some other uses of nuclear power that never came to fruition, like nuclear-powered airplanes.

By general consensus, the first commercial reactor was a heavily subsidized plant at Shippingport, Pa. That was essentially a scaled-up version of a submarine reactor. In the United States and abroad, as the cold war and a vast nuclear arms race took shape, the race was on to find a peaceful use for the atom.

In December, 1953, President Dwight D. Eisenhower delivered a speech at the United Nations called "Atoms for Peace," calling for a "world-wide investigation into the most effective peace time uses of fissionable material.''

Messianic language followed. Rear Admiral Lewis L. Strauss, chairman of the Atomic Energy Commission, told science writers in New York that “our children will enjoy in their homes electrical power too cheap to meter.’’

The “too cheap to meter” line has dogged the industry ever since. But after a slow start in the 1950s and early '60s, larger and larger plants were built and formed the basis for a great wave of optimism among the electric utilities, which eventually ordered 250 reactors.

As it turned out, many of those companies were poor at managing massive, multi-year construction projects. They poured concrete before designs were complete, and later had to rip and replace some work. New federal requirements slowed progress, and delays added to staggering interest charges.

Costs got way out of hand. Half the plants were abandoned before completion. Some utilities faced bankruptcy. In all, 100 reactors ordered after 1973 were abandoned. By the time of the Three Mile Island accident, ordering a new plant was unthinkable and the question was how many would be abandoned before completion.

Safety – Three Mile Island and Chernobyl

The core melt-down at Three Mile Island 2, near Harrisburg, Pa. in March 1979, and the explosion and fire at Chernobyl 3 in April 1986, near Kiev, in the Ukraine, are events the industry cannot afford to repeat.

Three Mile Island unit 2 was the youngest reactor in the United States. The plant, like all others on line in the United States, had been built with impressive back-up systems to guard against a big pipe break that could leave the nuclear core without its blanket of water. But here a relatively slow leak combined with misunderstandings by the plant operators about their complex controls, factors that had not been anticipated.

The operators knew that they had a routine malfunction had taken action to deal with it. But as problems mounted, in their windowless control room, filled with dials, warning lights and audible alarms that all clamored for attention faster than they could absorb it, they did not realize for hours that a valve they believed they had closed was actually stuck open. Rather than resolving the problem, they had allowed most of the cooling water to leak out.

Tens of thousands of worried residents evacuated the surrounding area. The reactor core was destroyed, but with little damage beyond it.

The reactor had shut itself down in the first few moments of the malfunction, when an automatic system triggered control rods to drop into the core, shutting off the flow of neutrons that sustained the chain reaction. And even if that had not happened, the reaction would have stopped as the cooling water boiled away, because the water acted as a moderator, slowing the neutrons down.

The plant leaked radioactive materials; post-accident estimates said the amount was very small. No one died, but in a matter of hours, a billion-dollar asset had become a billion-dollar liability.

In contrast, the reactor in the Ukraine, Chernobyl, was moderated by graphite, a material that does not boil away. And as graphite gets hotter, its performance as a moderator improves, meaning that the reaction speeds up. When a malfunction made the plan run hot, instead of shutting down, the reaction ran out of control and the reactor blew up.

Graphite has another unfavorable characteristic: it burns on contact with air. At Chernobyl, once the reactor exploded, hundreds of tons of graphite became the fuel for a fire that lasted at least three and a half hours, providing the energy to disburse the tons of radioactive material inside.

The government said 31 people died of radiation sickness in the following weeks. Estimates of the eventual number of dead are colored by politics, but a United National panel said in 2005 that the release of Iodine-131, a highly radioactive material that gets concentrated in the thyroid gland, would eventually cause 4,000 deaths. An “exclusion zone” 36 miles in diameter remains in place, and hundreds of thousands of people have been resettled.

Safety – nuclear waste

When the nucleus of a uranium atom is struck by a neutron, the atom breaks into fragments. Nearly all these fission products, few of which exist in nature, are unstable. They seek to return to stability by giving off an energy wave, called a gamma ray, or a particle, called alpha or beta radiation. Some transmute into a new, stable state in a matter of seconds; others remain radioactive for millennia.

Most fission products with very short half-lives – the length of time needed for half their atoms to be transmuted into something else are intensely radioactive, which makes them a concern in the event of a leak. Other fission products, most of which are contained in spent reactor fuel, will remain radioactive for millions of years.

The Federal government always promised it would accept the high-level nuclear wastes, and beginning in the early 1980s, it signed contracts with the utilities, saying storage would begin in 1998. It hasn’t happened yet, and won’t before 2020, if then.

In the 1980s, the idea was to have the Energy Department study the geology of several sites and pick the best, but that job went very slowly, and Congress decided to make the choice itself. It chose Yucca Mountain, about 100 miles from Las Vegas, in large part because the site is extremely dry. But intensive study showed that what water does fall on the mountain runs through it far faster than scientists initially estimated.

In 2004, a federal appeals court threw out a set of federal rules for the site because they would only offer protection for 10,000 years, while scientists say the fuel would be hazardous for close to a million years.

President Obama declared that Yucca would not be used, but in June a federal judge ordered the Energy Department not to withdraw its application for an operating license, an application opposed by the state of Nevada and a range of private groups, some of whom hope the lack of a storage site will force the entire industry to shut down. The judge said Congress had required the department to file an application when it settled on the Yucca site.

California, Connecticut and other states have moved to block construction of new reactors until a repository is opened, but other states seem likely to go ahead.

In the meantime, at many plants the spent fuel is stored in casks that look like small silos, with a steel liner and a concrete shell. The fuel is put inside and dried, and the cask is filled with an inert gas to prevent rust. Then it is parked on a high-quality concrete pad, surrounded by floodlights and concertina wire, resembling a basketball court at a maximum-security prison.

Safety — Military Waste

The nation's biggest plutonium problem is not from nuclear power but from nuclear weapons. The most troubling is Hanford, a 560-square-mile tract in south-central Washington that was taken over by the federal government as part of the Manhattan Project. (The bomb that destroyed Nagasaki in 1945 originated with plutonium made at Hanford.) By the time production stopped in the 1980s, Hanford had made most of the nation's plutonium. Cleanup to protect future generations will be far more challenging than planners had assumed, according to a new analysis by a former Energy Department official.

The plutonium does not pose a major radiation hazard now, largely because it is under "institutional controls" like guards, weapons and gates. But government scientists say that even in minute particles, plutonium can cause cancer, and because it takes 24,000 years to lose half its radioactivity, it is certain to last longer than the controls.

The fear is that in a few hundred years, the plutonium could reach an underground area called the saturated zone, where water flows, and from there enter the Columbia River. Because the area is now arid, contaminants move extremely slowly, but over the millennia the climate is expected to change, experts say.

The finding on the extent of plutonium waste signals that the cleanup, still in its early stages, will be more complex, perhaps requiring technologies that do not yet exist. But more than 20 years after the Energy Department vowed to embark on a cleanup, it still has not "characterized," or determined the exact nature of, the contaminated soil.

So far, the cleanup, which began in the 1990s, has involved moving some contaminated material near the banks of the Columbia to drier locations. (In fact, the Energy Department's cleanup office is called the Office of River Protection.) The office has begun building a factory that would take the most highly radioactive liquids and sludges from decaying storage tanks and solidify them in glass.

That would not make them any less radioactive, but it would increase the likelihood that they stay put for the next few thousand years.

The problem of plutonium waste is not confined to Hanford. Plutonium waste is much more prevalent around nuclear weapons sites nationwide than the Energy Department's official accounting indicates, said Robert Alvarez, who reanalyzed studies in 2010 conducted by the department in the last 15 years for Hanford; the Idaho National Engineering Laboratory; the Savannah River Site, near Aiken, S.C.; and elsewhere.

Recent Developments: Safety and Output

In 2009, reactors are producing more electricity than ever before, about 20 percent of the kilowatt-hours used in this country, by getting more power out of old plants.

Many reactors were designed to produce more power than had been applied for. In the 1990's, a number of companies asked the Nuclear Regulatory Commission for "uprates,'' which allowed them to make changes, often small, that increased their output.

Nuclear plants are also running longer, in part because deregulation of the industry has given companies an incentive to get as much as they can out of each plant. A capacity factor – the percentage of power a plant could produce if it ran continuously it is actually putting out — of 60 or 65 percent used to be common; now the norm is 90 percent. Such increases have been essential to the survival of plans like Indian Point 3 in New York, which has gone from 40 percent in the 1980s to around 90 percent now.

Safety issues have persisted, and one incident in an Ohio plant in 2002 in particular shook confidence in the safety of reactors and the quality of nuclear regulation. Regulators ordered plant operators around the country to inspect a spot in the lid of reactor vessels that was known to be prone to leaks. In the Ohio plant, the operators were shocked to find that the boric acid that is mixed into reactor water to stabilize the reaction had eaten away a chunk of carbon steel the size of a football, leaving the vessel vulnerable to a failure.

New Designs, New Issues

On the drawing boards at government labs are all kinds of exotic designs, using graphite and helium, or plutonium and molten sodium, and making hydrogen rather than electricity. But the experts generally agree that if a reactor is ordered soon, its design changes will be evolutionary, not revolutionary.

Many of the new designs have focused on the emergency core cooling systems, where the new goal is to minimize dependency on active systems, like pumps and valves, in favor of natural forces, like gravity and natural heat circulation and dissipation.

Westinghouse is one of the companies trying to market a reactor, the AP1000. with what is called a passive approach to safety. Compared to Westinghouse designs now in service, it requires only half as many safety-related valves, 83 percent less safety-related pipe and one-third fewer pumps.

A French company called Areva is building the EPR, for European Pressurized Water Reactor, which has four emergency core cooling systems, instead of the usual two. That not only makes it less likely that all systems would fail, but would allow the plant to keep running while one of the systems is down for maintenance.

The third entry is General Electric's Economic Simplified Boiling Water Reactor, derived from its boiling water reactor design. It is tweaked for better natural circulation in case of an accident, so there will be less reliance on pumps. But three of its four potential customers have backed away.

The Nuclear Regulatory Commission is also considering a proposal that it give approval to a handful of standardized, completed designs, rather than approving each plant’s design individually after construction had begun. The hope is to cut a 10-year construction process in half.

Nuclear Power and Climate Change

Nuclear power has gained new adherents in recent years, including some environmentalists who had previously opposed it. The reason is growing concern over climate change, and the role of energy production in the build-up of carbon dioxide in the atmosphere. Nuclear plants do not burn fuel and so produce no carbon dioxide. Proponents of nuclear power say it is the only available method of producing large amounts of energy quickly enough to make a difference in the fate of the atmosphere.

In the 2008 presidential campaign, Senator John McCain, the Republican candidate, made expansion of nuclear power a central point of his agenda both for energy and global warming.

But expanding nuclear power to replace coal and oil would be a massive job, on a scale that some consider unrealistic. A study by the the Princeton Carbon Management Initiative estimated that for nuclear to play a significant role in cutting emissions, the industry’s capacity would have to triple worldwide over the next 50 years — a rate of 20 new large reactors per year.

At the moment, though, industry leaders in this country wonder whether the worldwide supplier base could support construction of more than four or five reactors simultaneously. Some reactors under construction, like a prototype EPR in Finland, are over budget and years behind schedule. All new projects have to depend on a single supplier for the biggest metal parts, Japan Steel Works.

And at the moment, the price of nuclear power seems too high. In Florida, Progress Energy wants to build two reactors with a total cost, including transmission and interest during construction, that translates into about $8,000 per kilowatt of capacity — the amount of power needed to run a single window air conditioner. On a large scale, it may be cheaper to build better air conditioners, some energy experts suspect.

Recent Developments

The Obama administration favors another $37 billion in new loan guarantees, beyond the $18.5 billion provided in a 2005 energy law. It opposes opening a waste repository at Yucca Mountain, although that goal has long been sought by the industry. It has favored new reactors as part of the energy picture.

And the industry is getting ready to build again. Executives say that regulation of carbon dioxide is coming, which will handicap their competitors, and that many nuclear plants are getting old and will need to be replaced.

In fact one company, Southern, has broken ground on a pair of new reactors near Augusta, Ga., but overall the nuclear renaissance is off to a slow start.

Nuclear energy has also begun to be looked on more favorably in Europe, too. The Finnish Parliament in July 2010 approved the construction of two nuclear power plants; just two weeks before, the Swedish Parliament narrowly voted to allow the reactors at 10 nuclear power plants to be replaced when the old ones are shut down — a reversal from a 1980 referendum that called for them to be phased out entirely.

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