PART I

GENERAL CONCEPTS
NUCLEAR ENERGY: PAST, PRESENT, AND FUTURE

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Unlike some aspects of nuclear technology, the process of generating electricity in a nuclear power plant is not very complicated. U235, a naturally occurring element, is one of the few materials on Earth that can be forced to undergo fission—its atoms can be forced to split, releasing prodigious amounts of energy. In a nuclear power plant, uranium pellets arranged in rods are collected into bundles and submerged in water. Induced fission heats the water and turns it into steam, which drives a steam turbine, which spins a generator to produce power.

According to Marshall Brain, whose essay “How Nuclear Power Works” appears on the HowStuffWorks Web site (http://science.howstuffworks.com/nuclear-power.htm), "a pound of highly enriched uranium . . . is equal to something on the order of a million gallons of gasoline. When you consider that a pound of uranium is smaller than a baseball, and a million gallons of gasoline would fill a cube 50 feet per side (50 feet is as tall as a five-story building), you can get an idea of the amount of energy available in just a little bit of U235.” One metric ton of nuclear fuel produces the energy equivalent of two to three million tons of fossil fuel. Due to the abundance of radioactive minerals in the Earth’s crust, nuclear power offers what some believe to be a limitless supply of reasonably priced energy, as long as we safely contain the radioactive material.

1.1 HISTORY

The first experimental nuclear power apparatus was created in 1942 by Enrico Fermi and his graduate students at the University of Chicago. A product of naval propulsion research, nuclear power emerged in the United States as a commercial power option in the 1950s. A Pennsylvania utility, Duquesne Light, built the first commercial nuclear power reactor at Shippingport, Pennsylvania, in 1954. Nuclear power was commercially attractive because it offered the opportunity to generate power without the air pollution that accompanied the burning of fossil fuels. Waste volumes are comparably scaled: Fossil fuel systems generate hundreds of thousands of metric tons of gaseous, particulate, and solid wastes. By contrast, according to the Nuclear Energy Institute (NEI), boiling water nuclear power reactors produce between 50 and 150 metric tons of low-level waste per year, while pressurized water reactors produce between 20 and 75 metric tons. The volume and mass of the waste can be further reduced by 95% by reprocessing the spent rods.

At present, 33 countries around the world host 444 operating commercial nuclear energy-fueled electric generating facilities. Those facilities have cumulatively recorded over 10,000 years of operation. The United States remains the largest single producer of nuclear energy in the world, with 104 plants that supply over 800 billion kilowatt (kW) hours. In 1998, those plants supplied 674 billion kilowatt (kW) hours.

The gains came as a result of improving equipment, procedures, and general efficiency—not a single new
nuclear plant was built over that period. The increased efficiency and capacity of the nuclear fleet means the industry added the equivalent of 26 new 1,000 MW reactors to the grid. France has the second largest number of nuclear power plants with 59, and three are under construction. Japan now has 55 nuclear power plants, followed by 35 in the United Kingdom. Russia follows with 29, and then Germany with 20. China currently has seven operational plants and 132 more planned by 2020. Approximately 80% of France’s electricity demand is met by nuclear energy, while Britain uses nuclear energy to generate 23% of its electricity. Other countries with significant nuclear power include: Spain, 29%; Germany and Finland, 32%; Sweden, 44%; and Belgium, 58%.

1.1.1 Accidents
The first recorded commercial nuclear power plant accident occurred in the United Kingdom at the Windscale power plant on October 10, 1957 when fire destroyed the core of a plutonium producing reactor sending clouds of radioactivity into the atmosphere, while the chemical accident could have caused fatalities, none were ever reported. The 1979 event at Three Mile Island in the United States occurred because faulty instrumentation gave false readings for the reactor environment. That led to a series of equipment failures and human error. As a result, the reactor core was compromised and underwent a partial melt. Radioactive water was released from the core and safely confined within the containment building structure. Very little radiation was released into the environment, and no health impacts were recorded.

The Three Mile Island incident underscores the relative safety of nuclear power plants. The facility’s safety devices worked as designed, preventing injury to humans, animals, or the environment. The accident resulted in improved procedures, instrumentation, and safety systems, meaning nuclear reactor power plants in the United States today are substantially safer than they were in the past. Three Mile Island’s Unit One continues to operate with an impeccable record.

The worst nuclear power plant disaster in history occurred when the Chernobyl reactor in the Ukraine experienced a heat (not nuclear) explosion. If such an explosion were to have occurred in a Western nuclear power plant, the explosion would have been safely contained. All Western plants are required to have a containment building: a solid structure of steel-reinforced concrete that encapsulates the nuclear reactor vessel. The Chernobyl plant did not have this fundamental safety structure. The explosion blew the top off of the reactor building, spewing radiation and reactor core pieces into the air. The graphite reactor burned ferociously—which would not have happened if the facility had a containment building from which oxygen could be excluded. The design of the Chernobyl plant was inferior in other ways as well.

Unlike the Chernobyl reactor, Western power plant nuclear reactors are designed to have negative power coefficients of reactivity that make such runaway accidents impossible: When control of the reaction is lost, the reaction slows down rather than speeds up. The flawed Chernobyl nuclear power plant would never have been licensed to operate in the United States or any other Western country. The accident that occurred at Chernobyl could not occur elsewhere. The circumstances surrounding the Chernobyl accident were in many ways the worst possible, with an exposed reactor core and an open building. Thirty-one plant workers and firemen died directly from radiation exposure as a result of the Chernobyl accident.

1.2 Radiation
In September 2000, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published its Report to the General Assembly with Scientific Annexes, a document of some 1,220 pages in two volumes. According to the UNSCEAR report and subsequent discussions, roughly 1,800 thyroid cancer cases in children and some adults might reasonably be attributed to radiation exposure after the Chernobyl incident. More than 99% of those cancers were cured. Beyond the thyroid cancers, reported UNSCEAR, there is no evidence of any major public health impact attributable to radiation exposure after the Chernobyl accident.

In countries that do not reprocess their spent nuclear fuel, of which the United States is the primary one, the nuclear waste disposal is a political problem because of widespread fears disproportionate to the risk reality. Waste disposal is not an engineering problem because the United Kingdom and most other countries manage their small volume with relative ease. But in the United States, spent nuclear fuel and high-level radioactive waste have been accumulating for nearly 60 years, when nuclear materials were first used to produce electricity and to develop nuclear weapons.

Nuclear fuel has been used in 104 nuclear power plants in the United States and nearly 200 of that nation’s nuclear naval vessels. As in the United Kingdom, the fuel is solid, in the form of ceramic/uranium pellets the size of a pencil eraser. After a few years in a reactor, the uranium pellets in the fuel assembly are no longer efficient for producing electricity. At this point the used, or “spent,” fuel assembly is removed from the reactor and placed in a pool of water to cool.

1.3 Waste and Reprocessing
In most other countries where nuclear power is generated, these fuel rods are chemically reprocessed for additional
use. In the United States, however, President Jimmy Carter outlawed this procedure in 1977 as a result of his incorrect assessment that some weapons grade plutonium was created in the process. Although President Ronald Reagan rescinded Carter’s executive order, no power plants in the nation have initiated such a recycling program. Thus, without a central disposal site, 60 years of nuclear waste remains in on-site water pools or sealed above-ground in metal canisters within concrete bunkers. U.S. waste that was planned for disposal at the Yucca Mountain storage facility in Nevada resides instead in temporary storage at 121 sites in 39 states. After decades of scientific study, it is clear no legitimate safety issues preclude opening Yucca Mountain for the storage of spent nuclear fuel. Few scientists question the safety of the site, which has been studied for nearly two decades, while few who oppose nuclear power will ever accept any site. For the time being, U.S. President Barack Obama has announced that no work will go forward on the completion of Yucca Mountain as the nation’s nuclear waste repository during his term in office.

1.3.1 Recycling Opportunities

If U.S. nuclear power plants were to begin reprocessing spent nuclear fuel, as is done in the United Kingdom, France, and other nations, only 2 to 3% of the material now scheduled to be stored at the Yucca Mountain nuclear repository would have to be stored there, and the whole nuclear waste problem would disappear. After reprocessing, the total unusable portion of three full years of nuclear power production can be stored indefinitely in a dry cask about four times the size of a telephone booth.

The stated rationale, mentioned above, for not reprocessing spent nuclear fuel is the concern that reprocessing nuclear fuel produces weapons-grade plutonium that could, in theory, be smuggled to undesirable entities. What is not commonly recognized, however, is that the plutonium in spent fuel rods is not weapons-grade material. It consists of four different isotopes, which essentially pollute the plutonium necessary to make nuclear weapons.

After the collapse of the Soviet Union, Senators Pete Domenici (R-NM) and Sam Nunn (D-GA) negotiated a remarkable deal with the Russian government under which the U.S. purchases enriched uranium from its stockpile of disassembled weapons and recycles it through U.S. power plants as fuel. As a result, one of every 10 light bulbs in America is now lit by a former Soviet weapon, because 20% of U.S. electricity is produced by nuclear power, and half of the fuel is Russian. The important thing to remember is that the technology currently exists and is being utilized in other countries to virtually eliminate nuclear waste through the reprocessing of spent nuclear fuel. Reprocessing will become more efficient and economical as technology continues to advance. Thus, it is entirely possible, utilizing existing technology, to produce nuclear power without spreading any dangerous chemicals or materials into the environment. But even in the United States, all the high-level by-products from 50 years of nuclear fission could be assembled 10 feet high on a single football field. The French store all their high-grade waste from 30 years of providing nearly 80% of their nation’s electricity under a single room in Cap la Hague.

1.4 SAFETY RECORD

It is remarkable that the combination of human fallibility and mechanical failure over the last 40 years has resulted in a nuclear safety record unsurpassed by any other industrial activity. Commercial nuclear electricity has killed zero members of the public over that period. Conventional electric plants powered by coal, oil, and natural gas produce more than 200 accidental deaths per year.

Nuclear power plants also roam the world daily without any significant problems. Every week, one or two nuclear power plants dock at a major port in America or somewhere else in the world. And these power plants have been doing so for half a century now. No accidents of any kind have ever marred these dockings, no leaks have cleared blocks of cities; no emergencies have been declared. It is indeed amazing how thoroughly the United States has lost sight of the fabulous fleet of nuclear submarines that have operated below the radar these past 50 years, since the Nautilus, the first nuclear powered submarine, was launched in 1954. Since then, the U.S. Navy has launched more than 200 nuclear-powered ships, of which 82 are currently in operation. Nuclear ships from all countries are welcomed into 150 ports in 50 countries. They have traveled nearly 150 million miles without a serious incident. Navy reactors have twice the operational hours of our civilian systems. This is a long record of safety, an achievement the public needs to understand.

1.5 THE FUTURE OF NUCLEAR PLANTS

There is no denying that escalating costs of nuclear power plants will impede some growth in their industry. A 2008 study by Synapse Energy Economics, Inc., titled Nuclear Power Plant Construction Costs by David Schissel and Bruce Blewald, shows that costs have risen in the past decade from a range of $2 to $4 billion to a range today between $6 and $9 billion, well above coal and natural gas plants. A new generation of nuclear power plants may one day use an innovative technique called the pebble bed modular reactor. This reactor encases the nuclear source material in ceramic spheres about the size of tennis balls and transfers the heat into helium gas, which creates enough
pressure to turn a turbine. The heat generated rises to about 900 degrees centigrade (it would take nearly 3000 degrees to actually melt the ceramic and release any radioactivity). Concurrently, the medium of helium dramatically reduces any potential impact on the environment, were a release to occur. Their costs are expected to be considerably less as a result of the inherent safety features, which also may reduce remaining unwarranted fears held by the public.

On the other hand, if we compare nuclear costs to renewable power such as wind and solar, nuclear is far less expensive, partly because a 1000 megawatt (mW) plant can be built on 200 acres, while an equal amount of wind and solar energy require more than 100 square miles of land area. Barry Brooks, at Web site bravenewclimate.com/2009/12/06/tcase7, calculated the quantities of cement, steel, and land required for equivalent solar and nuclear power plants. He found that a solar plant requires 15 times more concrete, 75 times more steel, and 2,530 times more land.

Communications experts say that fear is the best way to get attention when you’re trying to win an argument. Groups who oppose nuclear power have certainly mastered that technique by playing to economic, environmental, and safety fears. Perhaps North America should fear that it is falling behind in advancing nuclear power. As a result, North America may be unable to compete with countries that have cheap, clean, reliable nuclear power while they are stuck with a bunch of windmills and solar farms producing expensive, unreliable energy or, more likely, not much energy at all. The prospect of North America ignoring this problem-solving technology that was invented there is unfortunate. In January 2006, U.S. Senator Lamar Alexander of Tennessee said the Chinese sent a delegation of nuclear scientists and administrators to the United States on a fact-finding mission. They toured the Idaho National Laboratory, the Argonne National Laboratory, and visited GE and Westinghouse trying to decide which technology to choose for their nuclear program. Perhaps, surprisingly, while the United States hasn’t issued a construction permit to build a new reactor in the past 30 years, most countries still look to it for leadership in this technology. The Chinese eventually chose Westinghouse technology for their first reactors. At the time, Westinghouse was an American company. In 2007, Toshiba bought Westinghouse, so it is now a Japanese company. By 2008, the Chinese had shovels in the ground. The first four Westinghouse reactors are scheduled for completion by 2011. They also bought a pair of Russian reactors, which should be finished around the same time. They started talking about building 60 reactors over the next 20 years and just recently raised it to 132. They’re in the nuclear business.

What the United States accomplished in the meantime? Senator Alexander says that people have been talking about a “nuclear renaissance.” Finally, in 2007, NRG, a New Jersey company, filed the first application to build a new reactor in 30 years. The licensing process at the U.S. Nuclear Regulatory Commission will take five years, after which opponents will file lawsuits and the whole thing will move to the courts. If they’re lucky, they might have a reactor up and running by 2020. Other companies have followed suit, and there are now 34 proposals before the NRC, but nobody has yet broken ground. So it isn’t likely the Chinese will be coming to us any time soon for more tips on how to build reactors.

Of the 34 proposals before the Nuclear Regulatory Commission, 20 are designed by Westinghouse, now a Japanese company, and nine are from Areva, the French giant. General Electric, the only American company left on the field, has partnered with Hitachi. They sold five reactors to U.S. utilities but fared poorly in the competition for federal loan guarantees. Two utilities have now cancelled those projects, and there are rumors that GE may quit the field entirely. GE doesn’t seem very enthusiastic about nuclear anyway. In the United States, we see GE ads for windmills. They’re all over the place. They have an ad for the smart grid, where the little girl says, “The sun is still shining in Arizona.” That was pretty good, too. But you won’t see any GE ads, in this day of concern about climate change, that 70% of our carbon-free electricity comes from nuclear power. I certainly haven’t. It is now completely absurd that so many groups have poisoned the minds of so much of the world against the cheapest, most abundant, and safest form of energy on the planet. Those of us who know better must begin a strong and enduring battle against these forces because our success will improve the plight of the least fortunate, poorest fed, clothed, sheltered, and educated on this planet. As energy goes, so goes the ultimate health of nations. Nuclear energy can solve the world’s energy problems, but only if those who know this have the courage to do battle against those who stand in opposition for whatever reason they perceive.