



EXTENDED NUCLEAR SECTIONS

A Closer Look

- Marie Curie 1867-1934
- Nuclear Accidents: Three Mile Island, Chernobyl, and Fukushima Daiichi
- Radon
- General Nuclear Medicine
- The Nuclear Navy
- France's Nuclear Energy Program
- Nuclear Proliferation



A Closer Look: Marie Curie 1867-1934

MARIE CURIE



Marie Curie was born in Warsaw, Poland on November 7, 1867. Born as Marya Skłodowska, she was the fifth child of Bronsitwa and Ladislas Skłodowski. After her mother Bronswita died, she became very close to her father, Ladislas, who was a professor of mathematics and physics. Marya was educated in local schools and was an excellent student. After her graduation from high school, she worked for eight years as a tutor and governess until she earned enough money to leave Poland and enter the Sorbonne in Paris.

When she enrolled at the Sorbonne in 1891, she changed her first name to Marie. She graduated first in her class from the Sorbonne in the spring of 1893. She stayed in Paris, obtained her master's degree in mathematics, and continued her experiments in physics. She met Pierre Curie, a highly acclaimed physicist, in 1894, and they were married a year later.

Marie and Pierre Curie were constantly working together. In 1897, their first daughter Irene was born. As soon as possible after Irene's birth, Marie continued her work with Pierre and started to pursue her doctorate degree through the Sorbonne. Her thesis focused on the source of the mysterious rays given off by uranium, first observed by Henri Becquerel in 1896. During her research, Marie and Pierre isolated two radioactive elements, polonium (named in honor of Marie's native country), and radium. In 1903, Marie was the first woman in Europe to be awarded a doctorate degree. That same year Marie and Pierre were awarded the Nobel Prize in physics.

After the birth of their second daughter, Eve, in 1904, Marie rejoined Pierre in the laboratory. The French government had created a special physics professorship position for Pierre at the Sorbonne and built and equipped a new physics lab for Marie. After Pierre was killed by a horse-drawn carriage in the streets of Paris, Marie assumed his position as Professor of General Physics at the Sorbonne, the first woman to hold such a post. Marie continued her work with the radioactive substances polonium and radium and was awarded a second Nobel Prize, this time in chemistry, in 1911. By 1914, she was head of two laboratories, one in Warsaw and the other at the Sorbonne. During World War One, she was unable to continue her experiments. However, she was given permission to set up and operate X-ray machines on the battlefield, and within two years, Marie had established two hundred permanent X-ray units throughout France and Belgium.

After World War One, Marie raised funds for a hospital and laboratory devoted to radiology. She toured the United States and returned to Europe with enough money to equip her new laboratory. During this time, Marie became a world-recognized celebrity. She continued to raise funds for the Radium Institute in Paris and spoke at various functions on behalf of world peace.

Starting in the late 1920's, Marie's health started to deteriorate. She suffered from chronic fatigue, dizziness, and a constant low-grade fever. In the early 1930's, Marie was diagnosed with a form of anemia that was directly caused by her exposure to radium. She died on July 4, 1934. Marie Curie's passion for knowledge and love of science laid the foundation for all of the later discoveries related to radioactivity and nuclear energy. She broke new ground for the women scientists that followed her. As stated in the New York Times: "Few persons contributed more to the general welfare of mankind and to the advancement of science than the modest, self-effacing woman whom the world knew as Madame Curie."

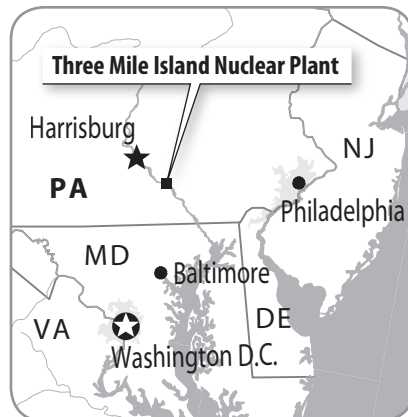


A Closer Look Nuclear Accidents: Three Mile Island, Chernobyl, and Fukushima Daiichi

Nuclear energy raises more public concern than other ways of generating electricity because of the inherent danger in the radioactive materials used as the energy source. Three significant incidents at nuclear power plants in particular that are concerning have also led to significant safety improvements. These occurred at Three Mile Island in Pennsylvania in 1979, at Chernobyl in Ukraine in 1986, and at Daiichi, Fukushima, Japan, in 2011.

Three Mile Island

In the early morning of March 28, 1979, an accident occurred at the Unit 2 Three Mile Island (TMI) reactor near Middletown, PA. The accident started when feed-water pumps that moved coolant into the reactor stopped running. The turbine and then the reactor automatically shut down as was designed in case of a coolant failure. Pressure then built up in the reactor. An automatic valve that was supposed to relieve the pressure stayed open after the pressure was relieved. This allowed coolant to flow out of the reactor causing it to overheat. To make matters worse, operators did not have adequate information in their instruments. Based on their experience, they believed that there was sufficient coolant in the reactor. Because there was not, the nuclear fuel started to melt. This type of nuclear accident is called a nuclear **meltdown**. In a worst-case scenario, a meltdown would cause the containment building to be breached and a release of radioactive substances into the atmosphere and possibly groundwater would occur. As soon as the Nuclear Regulatory Commission (NRC) was notified, government inspectors, nuclear engineers, and other nuclear officials reported to the site. They made sure that adequate coolant was flowing into the reactor. By evening, the reactor core was stabilized and a major disaster was prevented.



On March 30, operators released pressure from the plant's auxiliary building. This was done to keep coolant flowing into the reactor. This released some radiation into the atmosphere and caused concern among officials of the state. The Governor of Pennsylvania, Richard L. Thornburgh, called the Chairman of the NRC, Joseph Hendrie. The two officials agreed that it would be prudent for those most vulnerable to radiation to evacuate the area. A voluntary evacuation of pregnant women and pre-school-age children who lived within a five-mile radius of the plant was announced.

More problems arose on March 31 when a large hydrogen gas bubble was detected in the reactor vessel. Hydrogen gas is very explosive. Officials worried that a hydrogen gas explosion could tear a hole in the containment building and release large amounts of radioactive substances. However, on April 1, officials determined that the hydrogen gas bubble could not burn because there was

no oxygen present in the reactor vessel. Furthermore, the utility was able to reduce the size of the bubble and the chances of an explosion were now small. In spite of plant design problems, equipment failure and operator error, the safety features built into the containment building held.

Although this accident was the most serious in U.S. commercial nuclear power plant operating history, there were no serious injuries and only small amounts of radiation were released off-site. Evacuees were able to return to their homes. In the months following the accident, questions were raised about possible adverse effects from radiation on human, animal, and plant life in the TMI area. However, several independent studies showed that the maximum radiation exposure to most people in the area was one sixth the amount generated by a normal chest x-ray. Comprehensive investigations and assessments by several well-respected organizations have concluded that in spite of serious damage to the reactor, most of the radiation was contained and that the actual release had negligible effects on the physical health of individuals or the environment.

Chernobyl

Unfortunately, people living in the immediate area surrounding a nuclear reactor at Chernobyl in the Ukraine did not fare as well. On April 26, 1986, plant operators at the Chernobyl plant were conducting a test of reactor behavior at low power settings in spite of the fact that such situations caused



dangerous reactor conditions. Prior to the test all automatic safety features of the plant were turned off. During the test, the reactor became very unstable, and the design of the reactor caused a massive heat surge. Operators were unable to stop the surge. The fuel elements of the reactor ruptured, and a huge steam explosion occurred. The force of the explosion lifted off the cover plate of the reactor. This threw fission products into the atmosphere. A second explosion

CHERNOBYL POWER PLANT



The damaged reactor number four of Chernobyl Nuclear Power Plant

occurred, which threw out pieces of burning radioactive fuel and allowed air to enter the reactor. With the presence of oxygen, the graphite moderator burst into flames, and the entire unit became a part of the fire. Firefighters were sent into the plant to try to contain the fire. Most had no protective gear to wear. Eventually, over 5,000 tons of boron, dolomite, sand, clay, and lead were dropped on the burning core by helicopter in an effort to extinguish the fire and limit the release of radioactivity. Helicopter crews had no protection from the radioactive gases. Crews sat on sheets of lead in an attempt to shield themselves from the radioactivity. Twenty-seven helicopter crews were treated for radiation sickness.

Large amounts of radioactive gases and solids were released from the reactor. Thirty deaths occurred from the immediate accident, mainly among firefighters. An additional 134 cases of radiation poisoning were confirmed and treated. All of those patients recovered, although nineteen of these people later died from effects caused by the accident. Military personnel (such as the helicopter pilots) who became sick were never included in victims of the accident.

The area immediately around the plant became uninhabitable. About 160,000 persons living close by the reactor were evacuated within a week of the accident, and have not returned to the area. During the next several years, an additional 210,000 persons were resettled from areas within an approximate twenty-mile radius of the plant. Large areas of Belarus, Ukraine, and Russia were contaminated to varying degrees.

Today, in addition to unit four that was damaged by the fire, the other three reactors at the Chernobyl complex are shut down. Workers have been building a large arched structure covered in stainless steel and heavily insulated that will slide into place over unit 4, permanently enclosing the structure and all of its radioactive material. The arched structure is designed to last 100 years or more, and is being built to keep heat and moisture out. The structure will also prevent further environmental contamination in the event the weakened structure collapses. Elsewhere on site, a permanent storage facility is being constructed to hold the radioactive waste products left after reactors 1-3 were shut down. Construction storage facility should be finished by 2017 if the additional €100 million needed can be raised by donors.

Fukushima Daiichi

Tokyo Electric Power Company operated a total of six nuclear reactors at Fukushima Daiichi, which first went online in 1971 and for forty years safely generated electricity for the people of Japan. Then, on the afternoon of March 11, 2011, a magnitude 9.1 earthquake occurred about 75 miles offshore. This was a major seismic event that moved the floor of the Pacific Ocean eastward several feet and caused Honsu, the largest island in Japan, to shift between 8 and 10 feet. As they were designed to do, the power plants shut down automatically when the earthquake was detected. The earthquake did not cause significant damage to the power plant structures. However, the earthquake caused a massive tsunami, and this is where the problems began.

The tsunami arrived on the Honsu shore about 45 minutes after the quake. Fukushima Daiichi had been constructed to lie about 30 feet above sea level, which was about 12 feet higher than the tsunami standard of the time. However, the height of the tsunami from this earthquake was more than 70 feet at the epicenter, and over 40 feet when it reached the shore. The nuclear power plant's design included emergency backup generators which would provide power to the cooling systems in the event of a power loss or automatic shutdown. However, those backup generators were located in the basement of each of the turbine buildings adjacent to the reactors. When the area was flooded with sea water, the cooling pumps and generators were flooded and rendered inoperable. The electrical systems and DC battery systems were also destroyed by the flooding. Thus there was no way of pumping cooling water through the reactor and keeping the temperature down at a safe level.

The government ordered an evacuation of the area within 1.25 miles of the plant after declaring a Nuclear Emergency. Later the radius was expanded to nearly two miles. The next day, the Prime Minister extended the evacuation zone two more times, first to six miles and then to twelve miles. The tsunami had devastated many coastal villages, and many roads had been washed away, too.

The chain fission reactions in the reactor cores continued to release thermal energy as they had before the earthquake; the problem now lie in the fact that there was no cooling circulation to carry that energy out of the core. The pressurized vessels holding the

reactor cores each began to build up steam. Additionally, the fuel itself was covered in zirconium, which, when in contact with steam, would produce hydrogen gas. The safety pressure valves released the excess steam and hydrogen gas into the reactor building and the water level continued to drop around all of the reactor cores. The workers still on site were working desperately to get cooling water inside the reactor, ultimately resorting to fire pumps, but the temperature was rising faster than they could keep it cool.

Approximately five hours after the earthquake, the water surrounding the fuel in Unit 1 had been completely boiled away to steam, and the fuel melted to the bottom of the pressure vessel. At this point the temperature of the fuel began to drop, but the new problem was the presence of hydrogen.

Workers had been trying to manually vent all of the steam and other gases to outside but there was a failure in the system somewhere, and on March 12 a hydrogen explosion in the containment building blew the roof off of the building. Later, it was discovered that the fuel had become so hot that it had not only melted, but it had drained out of the reaction vessel and sank more than two feet into the concrete below.

On March 14, the system injecting water into Unit 2 failed, bringing the same problems to this reactor as had fallen on Unit 1. However, the workers at this unit did not want to have an explosion here as had happened two days earlier, and opened a panel near the top of the containment building. Most of the radiation that was released from Fukushima Daiichi is thought to have been from Unit 2.

Unit 3 had many of the same problems as in Units 1 and 2, with the fuel melting and likely sinking into the concrete below. As the workers were trying to vent off the steam and hydrogen gas, an explosion occurred that blew off the roof and spread a lot of radioactive debris in the area. Hydrogen from Unit 3 was also thought to have flowed into a fourth unit, which was not running at the time but had spent fuel stored inside. The hydrogen ignited and destroyed the top of this building as well.

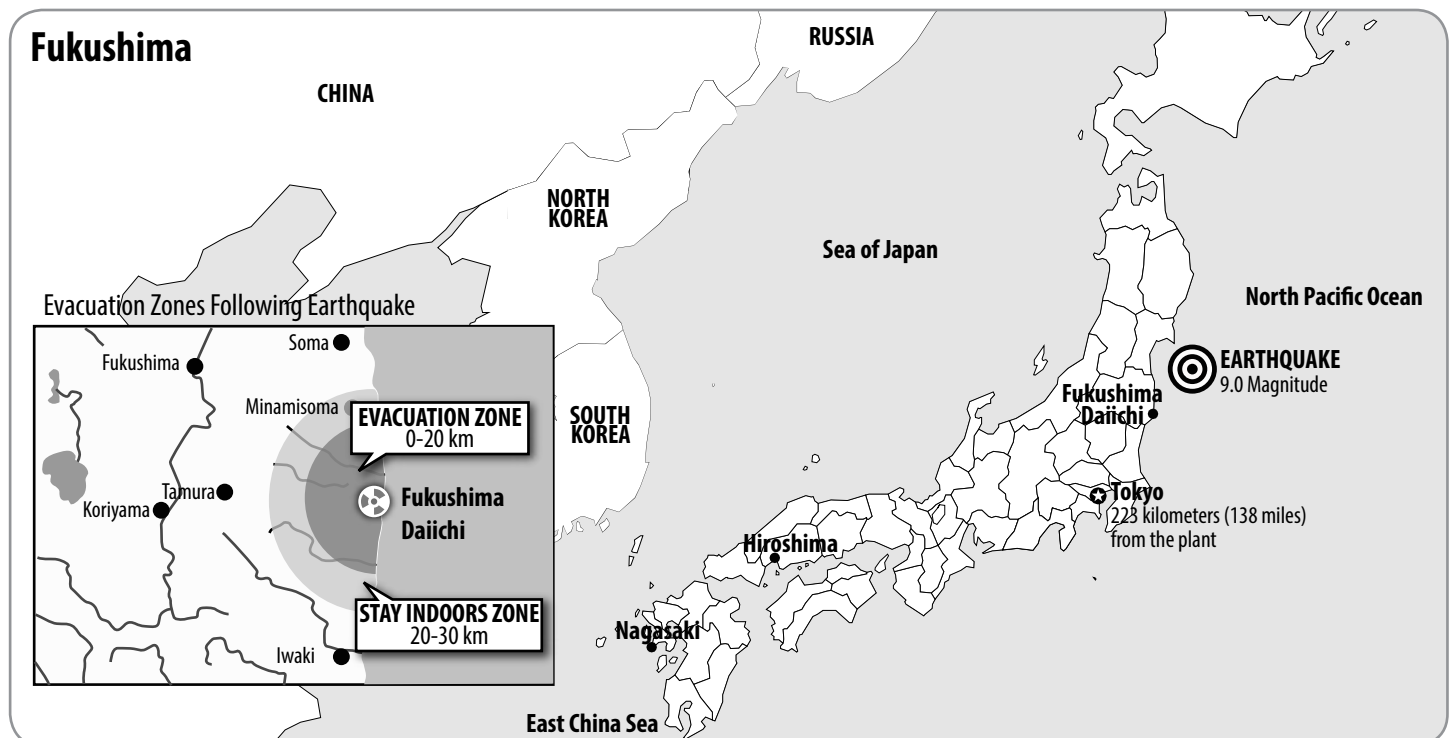
In all, four reactor buildings sustained core or explosion damage and released significant amounts of radiation into the atmosphere and surrounding land and water. All four of these reactors were damaged beyond repair and are being decommissioned. Emergency structures and repair measures were taken following the accident in an attempt to keep radiation contained. Many measures have been taken since then to prevent contaminated water and dust from being released into the environment, such as covering soil with concrete and building a deep sea wall at the sea side. The reactor containment buildings are being disassembled so the radioactive cores can be removed and properly disposed.

Lessons Learned

Though all three of these incidents are very different from each other, important lessons have been learned from them. Some of the problems that led to these incidents are related to human judgment and error, and others are the result of design flaws.

Three Mile Island exposed a lack of adequate training and instrumentation to allow operators to deal with this kind of situation. It also demonstrated a need for clear, consistent communication with news outlets and the general public to keep people informed. These deficiencies have led to significant improvements in performance at all nuclear power plants. That the fuel melted somewhat also provided opportunities to learn more about what happens when nuclear fuel melts, and demonstrated that a so-called "China Syndrome" is extremely unlikely.

Although the reactor of Unit 2 at TMI was destroyed, all radioactivity was contained as designed. The small amount of pressure that was vented did not increase radiation exposure to people outside the plant that exceeded normal, natural background radiation levels. No deaths or injuries occurred, and evacuations were precautionary, limited, and of short duration.



Scientists in the West knew that Soviet designed reactors like those at Chernobyl were dangerous. However, the magnitude of problems associated with the Soviet nuclear industry was not known. Prior to the Chernobyl accident, at least thirteen serious power reactor accidents had occurred. Information about the accidents was treated as state secrets of the Soviet Union, and information about them was never made public. The veil of secrecy continued as conditions at Chernobyl worsened. The accident happened early on Saturday morning, April 26. Officials in Moscow were informed of the problems that day. No announcement about the accident came from the Kremlin. It wasn't until Monday morning, April 28, that unusually high radioactive levels in Sweden indicated that a massive release of radioactivity from a nuclear reactor, probably located in the Soviet Union, had occurred. Soviet officials could no longer keep the Chernobyl accident a secret, and Western engineers and scientists monitored levels of radioactivity throughout Europe. Over the next few weeks, the serious situation at Chernobyl was learned by the outside world.

Although some Chernobyl-style reactors are still operating in Eastern Europe, they have been drastically improved. Furthermore, operators at Chernobyl were poorly trained. Training for nuclear plant operators in Eastern Europe has been significantly improved, and a focus on safety emphasized. Only one Chernobyl-style plant outside of Russia is still in operation (in Lithuania). However, there are still eleven Chernobyl-style plants operating inside of Russia.

Improved cooperation between nuclear engineers in the East and the West has occurred. In 1989, the World Association of Nuclear Operators, a body that links 130 operators of nuclear power plants in more than 30 countries, was formed. The International Atomic Energy Agency (IAEA) has carried out reviews of Chernobyl style plants, bringing together Western engineers with plant operators to focus on safety improvements. Western aid worth over 1 billion dollars has been donated for more than 700 safety-related projects in Eastern Europe.

Though Fukushima was caused by a natural disaster, some lessons for improvement can be gleaned from it. One lesson was to always question whether safety is being maintained. The operators of Fukushima Daiichi, the Japanese authorities, and the Japanese public in general were all overly confident about the safety of Japanese nuclear power plants. Thus, no one really called into question the design or procedures ensuring the safe operation of them. Following this event, a sharper focus on safety has been brought about in all nuclear power plants in Japan as well as around the world.

Since 2006, officials in Japan had known that flooding at the Daiichi site could cause a power blackout to the facility, yet no changes were made in its design or operating procedures. Had these changes been made, it is possible that the tsunami may not have wiped out all power to the control systems, and the meltdown and explosions may not have occurred. Japanese culture values chain of command and obedience to authority. Few, if any, question that authority, thus leaving a *status quo* system of operation and design in place. The report written about the incident by the Nuclear Accident Independent Investigation Commission, set up in Japan specifically to investigate the Fukushima disaster, stated inherent cultural issues were contributing factors to the incident. The Chairman wrote, "The consequences of negligence at Fukushima stand out as catastrophic, but the mindset that supported it can be found across Japan. In recognizing that fact, each of us (every Japanese citizen) should reflect on our responsibility as individuals in a democratic society."

It's never easy to look at a situation and place blame on oneself. However, it was important when each of these incidents occurred to be objective in evaluating their causes and what could have been done to prevent them. Learning from the mistakes made in these three incidents will hopefully lead to the nuclear power industry being even safer in the future.



A Closer Look: Radon

Radon is a colorless and odorless radioactive gas found throughout the United States. It is formed by the natural radioactive decay of uranium atoms in the soil, rocks, and water. Since uranium is found in many places and radon is a gas, it can get into the air of the buildings where we live, work, and play. According to the EPA, radon causes thousands of deaths from lung cancer each year. In fact, exposure to radon gas is the second leading cause of lung cancer in the U.S. behind smoking.

Most radon enters buildings from the soil. Radon enters building through cracks in solid floors, construction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, and cavities inside walls. Some radon can also enter a home through the water supply. Both new and older homes are susceptible to radon gas build-up. Since most exposure to radon occurs at home, it is important to measure the level of radon in your home, and limit radon exposure where necessary.

The EPA recommends that all homes be tested for radon. Simple test kits are available at most home improvement stores, are inexpensive, and are easy to use. Qualified testers can also be used, and are a good choice to perform tests when buying or selling a home.

Since there is no known safe level of radon, there can always be some risk. But the risk can be reduced by lowering the radon level in your home. There are several proven methods to reduce radon in your home, but the one primarily used is a vent pipe system and fan, which pulls radon from beneath the house and vents it to the outside. This system, known as a soil suction radon reduction system, does not require major changes to your home. Sealing foundation cracks and other openings makes this kind of system more effective and cost-efficient. Similar systems can also be installed in houses with crawl spaces. Radon contractors can use other methods that may also work in your home. The right system depends on the design of your home and other factors.

For more information, including a map of naturally occurring radon levels in the U.S., see

<http://www.epa.gov/radon/pubs/citguide.html>



A Closer Look: General Nuclear Medicine

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose or treat a variety of diseases, including many types of cancers, heart disease and certain other abnormalities within the body. Nuclear medicine includes the use of x-rays and radionuclide imaging. X-rays are a form of ionizing radiation capable of traveling through materials. X-ray technology is an invaluable tool in medicine, industry, scientific research, and security. For instance, it can be used to observe broken bones and swallowed objects, track blood flow in patients, and check for cavities. X-rays can also be used to diagnose cancer, kill bacteria in food, detect flaws in machinery or products, analyze the structure of crystals or distant stars, and scan baggage at airports. X-rays are highly energetic and can cause the material through which it is passing to become charged, or ionized. Ionization can damage cells or DNA in living matter. However, used with caution, the benefits of x-rays far outweigh their risks.

Radionuclide imaging procedures are noninvasive and usually painless medical tests that help physicians diagnose medical conditions. These imaging scans use radioactive materials called radiopharmaceuticals (radioactive drugs) or radiotracers. Depending on the type of nuclear medicine exam you are undergoing, the radiotracer is either injected into a vein, swallowed or inhaled as a gas. The tracer eventually accumulates in the organ or area of your body being examined, where it gives off energy in the form of gamma rays. This energy is detected by a gamma camera, a (positron emission tomography) PET scanner and/or probe. These devices work together with a computer to measure the amount of radiotracer absorbed by your body. They are able to produce special pictures offering details on both the structure and function of organs and tissues.

In many situations, nuclear medicine images can be combined with computed tomography (CT) or magnetic resonance imaging (MRI) to produce special views, a practice known as image fusion or co-registration. These views allow the information from two different types of images to be combined into one image. These lead to more precise information and accurate diagnoses. Nuclear medicine also offers therapeutic procedures such as radioactive iodine (I-131) therapy that uses radioactive material to treat cancer and other medical conditions affecting the thyroid gland.

According to radiologyinfo.org, common uses of nuclear medicine imaging scans include:

- analyzing kidney function
- visualizing heart blood flow and function scan lungs for respiratory and blood flow problems
- identifying inflammation in the gallbladder
- evaluating bones for fractures, infection, arthritis and tumors
- determining the presence or spread of cancer in various parts of the body
- identifying bleeding into the bowel
- locating the presence of infection
- measuring thyroid function to detect an overactive or underactive thyroid
- investigating abnormalities in the brain, such as seizures, memory loss and abnormalities in blood flow
- localizing the lymph nodes before surgery in patients with breast cancer or melanoma

Also, radiologyinfo.org describes the following Nuclear medicine therapies:

- Radioactive iodine (I-131) therapy is used to treat hyperthyroidism (overactive thyroid gland, for example, Graves' disease) and thyroid cancer
- Radioactive antibodies are used to treat certain forms of lymphoma (cancer of the lymphatic system)
- Radioactive phosphorus (P-32) is used to treat certain blood disorders
- Radioactive materials are used to treat painful tumor metastases to the bones

For more information, see <http://www.radiologyinfo.org/en/info.cfm?pg=gennuclear&bhcp=1>



A Closer Look: The Nuclear Navy

Nuclear reactors in the fleet of the United States Navy have outstanding performance and safety records. Limitations of submarines and aircraft carriers were found during World War Two. WW II-era subs were powered by fossil fuels and needed oxygen to burn the fuels. This required submarines to operate mainly at or near the ocean's surface, and they could only submerge for short periods of time. It was known at the end of the war that nuclear reactors could provide energy from radioactive fuel without using oxygen. In theory, a nuclear sub could travel at great depths and remain submerged for days or months at a time without surfacing.

The strategic importance of aircraft carriers was proven during WW II. These great ships had the ability to move planes into areas where the enemy could be attacked from the air as well as from the land or sea. However, the WW II-era aircraft carriers also had limitations. Because they were so massive, they needed large amounts of fossil fuels to power them. This required massive storage tanks for fuel which took up space that could be used to handle more aircraft and equipment. Furthermore, the carriers had to be accompanied by tankers so they could be refueled and other escort ships. Nuclear propulsion of aircraft carriers enhances military capability and provides high-speed endurance. A nuclear-powered aircraft carrier can be sent across great stretches of ocean at a moment's notice.

In 1946, at the conclusion of WW II, Congress passed the Atomic Energy Act which established the Atomic Energy Commission (AEC), putting the development of atomic energy under civilian control. At the same time, Captain (later Admiral) Hyman G. Rickover was responsible for the development of new ships for the navy. He recognized the advantages of nuclear energy in powering ships, and established a team to design them. Rickover and his team worked at the civilian AEC lab at Oak Ridge, TN to learn the fundamentals of nuclear reactor technology. Due to the unknowns of using nuclear reactors, Rickover's team worked on two different reactor designs, a pressurized water cooled reactor and a liquid metal cooled reactor.

On January 17, 1955, the first nuclear powered submarine, the USS Nautilus, put to sea for the first time using a pressurized water reactor. On her first cruise, the Nautilus remained submerged for 84 hours, and cruised 1300 miles, from New London, CT to San Juan Puerto Rico. This was the first time a submarine traveled at high speed submerged for over one hour. After operating on nuclear power for over two years and traveling 62,562 miles (approximately 2 1/2 times around the world), the Nautilus was refueled. In 1957, the USS Seawolf, powered by a liquid metal cooled reactor, was commissioned. It soon became evident that a pressurized water reactor was preferable for the navy. All subsequent naval nuclear reactors have been pressurized water reactors. Today's newest submarines do not need to be refueled. They contain enough fuel to last for their entire lifetime when they are commissioned.

The world's first nuclear-powered warship, the guided missile cruiser USS Long Beach was commissioned Sept 9, 1961. Two months later, the USS Enterprise was commissioned as the first nuclear-powered aircraft carrier in the world. The Enterprise's first refueling occurred after three years of service. During that time, the carrier traveled 207,000 miles, a distance equal to more than eight times around the world. Nuclear-powered ships in the U.S. fleet now include aircraft carriers, attack submarines, and fleet ballistic missile submarines.

Nuclear energy provides the U.S. Navy with great military capabilities. But the use of nuclear reactors in the navy also proved that nuclear reactors can operate safely and provide tremendous amounts of energy from small amounts of nuclear fuel. Designs of naval pressurized water reactors were used to develop reactors for civilian use. Today's nuclear reactors were born in Admiral Rickover's vision of powering naval vessels with nuclear energy. Currently the US Navy has 86 nuclear-powered vessels, including 75 submarines. Russia, China, France, and India have a combined 51 vessels, 45 of which are submarines.



A Closer Look: France's Nuclear Energy Program

Over 75% of France's electricity is today produced from nuclear energy. This is due to a long-standing policy based on energy security. Over thirty-five years ago, France learned that it was vulnerable to a cut-off of oil supplies. In the fall of 1973, Middle East countries drastically reduced oil supplies to the rest of the world. At that time, most of France's electricity came from oil burning plants. France had, and still has, very few natural energy resources. It had no oil or gas supplies of its own, and its coal supplies were almost exhausted. As oil prices drastically increased, the French government decided the country must become more energy independent.

In 1974, the French government decided that the best way for France to decrease dependence on foreign oil was to develop a comprehensive national nuclear energy program. France had a ready supply of engineers and a strong scientific community to help develop the program. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense at the time in minimizing oil imports and achieving greater energy security.

France currently has 58 nuclear reactors operating. As a result of its nuclear program, France is now the world's largest net exporter of electricity, most of it going to Italy. It also has developed a sophisticated industry which provides technology to other countries. France now claims a substantial level of energy independence in the electricity sector. Among the United Kingdom and sixteen European countries, France has the third lowest cost of electricity. In addition to nuclear power France also makes use of hydroelectric plants. With over 90% of electricity coming from these two sources France also has a low level of CO₂ emissions per capita from electricity generation.

The French nuclear program is based on American technology. After experimenting with its own gas-cooled reactors in the 1960s, France now uses three types of reactors, all Pressurized Water Reactors based on Westinghouse designs. This standardization provided a more efficient use of capital and engineering resources than occurred in the U.S. nuclear industry where there were many different designs managed by many different utilities. Using just a few designs also meant that changes in design or operation to improve safety and/or efficiency were quickly and easily made in all the affected plants.

Although the French nuclear industry has not had a major nuclear accident like that of Chernobyl or a near melt-down like Three Mile Island, it has experienced some problems. In 1981, a serious fire at the Beaumont- Hague plant released a radioactive element into the air. After the fire, the government created local committees to monitor the operations of French energy sites.

Sixteen years later, anti-nuclear activists said they found radiation levels higher than typical for the region at an exposed portion of pipe carrying treated waste water from the Beaumont-Hague plant to the sea. Normally, the pipe would be covered by the sea, which would shield the radiation. At particularly low tides, it was exposed for short periods releasing radiation into the area. The pipe has

since been covered and the surrounding ocean floor cleaned, but some increases in radiation levels on near-by beaches have been found. The French government continues to monitor the area. Small radiation leaks have occurred at other reactors but have been easily contained.

Probably the greatest concern among the French is the issue of nuclear waste disposal. First, nuclear waste is now "stocked", implying that the waste is not permanently stored. Instead, the government assures its citizens that the waste will be monitored, and possibly recycled as nuclear industry technologies continue to develop. Secondly, France has developed a nuclear reprocessing industry and recycles all of its used fuel once. This cuts down on the volume of high level radioactive waste. France not only reprocesses its own nuclear waste, but also reprocesses waste for other countries like Japan. However, there is concern that reprocessing nuclear waste separates plutonium which can be used for weapons, potentially making reprocessing plants in France the targets of terrorists. Furthermore, non-proliferation activists and environmental groups strongly voice concerns about the safety of shipments of reprocessed fuel to Japan. Although the shipments occur on armed vessels with armed escorts, protesting groups state that shipments could be hijacked and the reprocessed fuel fall into the hands of terrorists.

France is currently researching sites for permanent storage in stable geologic areas, and believes it will be able to permanently bury much of its "stocked" waste in the future. In spite of waste storage problems, the French government is committed to a strong nuclear industry, and it believes it can solve storage problems. In spite of incidents and opposition to waste disposal, polls of French public opinion have found that about two-thirds of the population is strongly in favor of nuclear power. A poll of French people taken by Decision Research in Eugene, Oregon, discovered that many French people have similar fears of radiation and disaster as Americans. However, certain characteristics of French society lead to this general acceptance of nuclear energy. According to the French General Director for Energy and Raw Materials at the Ministry of Industry, there are three reasons that French citizens are more accepting of nuclear power than American citizens. First, the French people are disturbed at the thought of being completely dependent upon Middle Eastern countries for all of their energy needs. French citizens generally accept that since they have no deposits of oil, coal, or natural gas, nuclear energy is a necessity. Second, French citizens generally like large, technological projects, and hold scientists and engineers in high regard in France. The government believes this regard leads to more trust of scientific projects than might be seen in America. Third, the French government has proactively publicized the positive benefits of its nuclear industry. This includes large television advertising campaigns that links nuclear power with the production of electricity and the French standard of living.

French companies like AREVA and EDF are involved in nuclear projects throughout the world including the United States. However, France intends to reduce its use of nuclear power in the near future. In 2014, the Energy Transition for Green Growth bill was passed. It mandates that nuclear power provide only 50 percent of France's total power generation by 2025 and that greenhouse gas emissions be reduced by 40 percent by 2030. To make up for the loss in electricity generated by nuclear power and fossil fuels, in the same time frame the bill requires renewable energy sources account for 32 percent of electricity generated by 2030. This will allow France to remain independent for electricity generation while reducing the need for long-term storage solutions for spent nuclear fuel.



A Closer Look: Nuclear Proliferation

Proliferation Risks of Nuclear Power Programs

As discussed in the Backgrounder, proliferation of nuclear weapons has been a global concern since the end of WW II. The four issues described by Ferguson (2007) that have occurred within the last ten years that have caused many world leaders to become concerned that nuclear materials designed for peaceful nuclear power uses could be used for weapons, bear repeating. They are threats of nuclear terrorism, the possibility of Iran making substantial progress in enriching uranium and building a nuclear research reactor that could produce plutonium which could be used in a nuclear weapon, A. Q. Khan, a Pakistani scientist was sold nuclear secrets to other countries and groups, and the renewed interest in nuclear power as a way to reduce greenhouse gases has led to many countries expressing interest in starting or increasing nuclear power programs.

The same technologies that make fuel for nuclear reactors can also produce fissionable materials for nuclear weapons. There are two pathways available to make fuel or bomb material, the uranium and plutonium pathways. Mining, processing, and preparation of uranium for nuclear reactor fuel have already been discussed. This process prepares low-enriched uranium (LEU) which contains between 0.72% and 20.0% U-235. This grade of uranium cannot be used for nuclear weapons. Uranium with a U-235 concentration greater than 20% is needed for nuclear weapons. This form of uranium is called highly-enriched uranium (HEU).

Uranium Enrichment

One method for preparing enriched uranium is the centrifuge. You will remember that a series of centrifuges, called cascades, are necessary for the preparation of the uranium. The arrangement of the cascades determines whether low-enriched uranium or highly-enriched uranium will be produced. A centrifuge facility can be designed so that the arrangement of the cascades can easily be changed to shift from LEU to HEU production. Depending on the plant design, this shift could occur in a relatively short time, less than a month. Generally, uranium enrichment plants are accessible to inspectors to make sure that weapons grade material is not being produced. However, if the cascade arrangement can be quickly changed, the plant could be converted to manufacture bomb material immediately after inspections occur. Furthermore, if the nation that possesses the enrichment plant wants to make bomb materials, it can simply not allow inspectors access to the plants.

Plutonium from Reprocessed Spent Nuclear Fuel

Plutonium does not occur in nature but is produced in nuclear reactors by the absorption of neutrons in U-238. Pu-239 is the fissile isotope of plutonium that can be used in nuclear weapons. Pu-239 has a half life of 24,000 years (which means it will be around for a very long time!) and is not found in geologic formations. Spent nuclear fuel contains a mixture of radioactive products, including small amounts of Pu-239. A reprocessing plant is designed to safely

extract plutonium from the spent fuel mixture. The spent fuel is chemically treated to remove the fuel cladding from the spent fuel. The different fission products, including plutonium, are extracted from the fuel (mostly U-238). Once the plutonium is separated, it is mixed with uranium to create a fuel mixture usable in reactors. It is easy to block the radioactivity emitted by plutonium which means that it is hard to detect. This means that if this plutonium is not secured, it could be stolen and used by terrorists or a "rogue" nation to manufacture a nuclear weapon. Therefore, separated plutonium should be guarded as if it were a nuclear weapon.

Like uranium, plutonium has different grades that determine its suitability for weapons. Essentially, the greater the concentration of plutonium-239, the more suitable it is for weapons. Weapons-grade plutonium has an isotopic composition of greater than 94% Pu-239, while non-weapons grade (often called reactor-grade) plutonium has a concentration less than 94% Pu-239. However, according to the Department of Energy and the U.S. National Academy of Sciences, even reactor-grade plutonium can be used to make nuclear weapons but would not be ideal because of some engineering challenges. Thus, a country's military would prefer not to use reactor-grade plutonium for nuclear weapons but could conceivably do so. Nonetheless, if terrorists obtained reactor-grade plutonium, they would probably not have the technical skills to make a nuclear bomb but could disperse the plutonium in a radiological weapon to cause radioactive contamination. This is a type of a so-called "dirty bomb," which uses conventional explosives to disperse radioactive materials.

Controlling the Proliferation Risks

The eight countries currently known to possess nuclear weapons are the United States, Russia, France, the United Kingdom, China, India, Pakistan, and North Korea. There is also a strong possibility that Israel also has nuclear weapons. There are many international concerns about nuclear weapons falling into the hands of terrorists and "rogue" states. Controlling the proliferation of nuclear weapons materials and technology involves political, financial, and technical solutions. With respect to the political dimension, the first issue to be understood is that national governments want to protect their right to control what happens inside their states' territories. They also want to ensure they keep all of their rights assigned to them under international treaties.

An important international treaty related to nuclear technology is the nuclear **Non-Proliferation Treaty** (NPT). Article IV of the NPT, declares that a state has the "right" to peaceful nuclear technologies as long as the state maintains safeguards on its peaceful nuclear program and does not manufacture nuclear explosives. The rights of countries under the NPT are not clearly defined. This article does not specifically mention uranium enrichment and plutonium reprocessing technologies as part of a state's right to peaceful nuclear technologies. Many countries want to interpret the NPT as giving them the right to enrich uranium and extract plutonium from nuclear wastes. Thus, non-nuclear-weapon countries such as

Argentina, Brazil, and Japan, for example, have pursued enrichment or reprocessing or both, and have maintained safeguards on these programs. Iran claims that it wants to be like Japan and have a peaceful nuclear program that includes enrichment and possibly reprocessing. However, the International Atomic Energy Agency (IAEA) and the UN Security Council have ruled that Iran is not in compliance with its safeguards commitments.

Iran's non-compliance creates international security risks. This dilemma has renewed interest in political and financial incentives that might persuade countries not to enrich and reprocess. One incentive is to offer fuel services contracts that are very economically competitive. Under such a contract, a country or group of countries would guarantee that another country in need of nuclear fuel would always have access to fuel from external suppliers as long as the state did not enrich uranium or reprocess plutonium. The fuel services contract could also include spent fuel management where certain countries act as service providers who remove the spent fuel and safely and securely store it. This would remove the material the country would need to extract plutonium for a weapons program. A country's sovereign rights would be maintained if the service contract is worded to ensure that the country keeps its rights to enrich or reprocess but chooses not to do so as long as the contract is in force.

A country desiring a large nuclear power program may still want to enrich and reprocess fuel so that it can operate nuclear plants. Generally, if a country has fewer than eight nuclear plants, it is not economically sound for that country to make its own nuclear fuel. In this case, a group of countries could form a multinational partnership to make fuel. One option is that nuclear-fuel-making activities would take place in each of the partnership countries. Another option is that only one country or a select few would actually make the fuel on their territories. In either option, each of the partnership countries would have ownership of the fuel making facilities and would have sufficient access to the facilities of the other countries to be assured that the facilities are not misused for weapons programs. Theoretically, this should reduce the proliferation risk because more than one country would be involved in those activities, and each country would keep watch over its partners. This extra monitoring would increase the likelihood of catching clandestine nuclear weapons activities in the country of concern.

As with the fuel services proposal, countries can accept or reject multinational ownership and control of fuel making facilities. This process would work only if economic incentives are large enough. However, if an economic incentive is too large, it could stimulate the development of large nuclear power programs in countries where other energy sources are available. This could unnecessarily increase the danger of **nuclear proliferation**.

Because certain countries will enrich uranium or reprocess spent nuclear fuel, the nuclear industry should work to significantly reduce proliferation risks in those activities. Currently reprocessing methods that do not isolate plutonium from fission products or other radioactive materials such as **transuranics** are being investigated. This would leave higher amounts of radioactive materials near the plutonium making it more dangerous to steal or store. International safeguards and inspections would need to be maintained since a country could continue to reprocess the fuel and extract more plutonium.

Proliferation could be substantially reduced if nuclear power were phased out. However, as we have seen, nuclear power has many advantages over other forms of energy. Some countries are planning to expand their nuclear power programs. Italy has recently reversed its decision to phase out nuclear power. Germany and Spain are still committed to a phase out but could reverse these decisions depending on a change in government. Although their decisions may be reversed, other countries such as Italy, Germany, and Spain are currently committed to phasing out nuclear power programs or have made the decision not to acquire them. In the end, the international community must balance the benefits of nuclear energy with its risks. Faced with the continued use of nuclear energy in the foreseeable future, the international community must be vigilant about controlling the risks of proliferation.