Chapter 20

NUCLEAR ENERGY AND THE ENVIRONMENT

Case Study: Nuclear Energy and Public Opinion

On March 28, 1979, the worst accident in US nuclear history occurred at Three Mile Island near Harrisburg, Pa. A mechanical failure compounded by human error caused a loss in the water needed to cool the reactor and led to a partial meltdown of its core. Three Mile Island never became a major public health threat, but for a few apprehensive days the utility and the Nuclear Regulatory Commission were unsure how to contain the accident. Public acceptance of nuclear power plummeted. In the early 1980s investing in nuclear power made little economic sense. The accident at Three Mile Island and movies like The China Syndrome made many Americans apprehensive about nuclear energy. Then the April 1986 explosion at the Chernobyl nuclear in what is now Ukraine spread radioactivity across Europe and fear of nuclear power increased. Plant safety is no longer the most important issue facing the nuclear industry, nuclear waste is. If nuclear energy were phased out, or frozen, would it make a difference? It does supply 20% of electrical energy in the U.S., and it is greenhouse neutral. In the face of rolling brown outs and spiraling energy costs in California and blackouts in the North East, Americans seem to be warming to nuclear energy.

20.1 NUCLEAR ENERGY

● There are two kinds of nuclear processes: nuclear (NOT pronounced nuculur) fission and nuclear fusion. Fission is the splitting and fusion is the fusing of the nuclei of atoms. The first human-controlled nuclear fission (discounting failed attempts in Nazi Germany) occurred in 1942 at the U. of Chicago. Nuclear power generation occurs in fission reactors using ^{235}U as a fuel (pronounced U238). Uranium in ore is about 99% ^{238}U and about 0.7% ^{235}U. At that concentration no fission occurs. In processing facilities the ^{235}U is concentrated in uranium fuel pellets to a final concentration of about 3%, which makes fission possible when the fuel rods are packed together in a reactor core. The reaction can be controlled by raising and lowering control rods to block the neutrons. There is an enormous about of heat generated, which is used to produce the steam that turns the turbines. This steam must be condensed back into water, and this is accomplished with cooling water drawn from a nearby source. The cooling water leaves the reactor as hot water, and this is evaporated or discharged directly back into the source. As the fuel in the rods decay, the concentration of ^{235}U declines, and the concentrations of other dangerous radioisotopes rises. The waste products include radioisotopes of plutonium, iodine and strontium.

● Breeder reactors are designed to produce more fissile material than it consumes. The reactor core, at its center, has concentrations of ~20% fissile ^{239}Pu and 80% nonfissile ^{238}U. Surrounding fuel rods are 100% ^{238}U which is transmuted to ^{239}Pu. After a year of operation, the center rods will have 15% ^{239}Pu and 85% ^{238}U, with the surrounding material having 95% ^{238}U and 5% ^{239}Pu . This results in a net slight net production of ^{239}Pu. Plutonium has a 24,360 year half, is extremely toxic, and can be made into a bomb. In 1977 President Carter called for an indefinite suspension of the construction of our first and only breeder reactor on the Clinch River, TN because of concerns about

A CLOSER LOOK 20.1: RADIOACTIVE DECAY

● The fundamental difference between one element an another is the number of protons in the nucleus. For example, a carbon atom, and only a carbon atom, has 6 protons. The elements usually have an equal number of neutrons, but some variation occurs. These variants are called **isotopes**. Most carbon atoms have 6 neutrons, given an atomic weight of 12. This is one kind of carbon isotope, and this is written as ^{12}C, where the superscript 12 refers to the atomic weight. There are two other carbon isotopes. They are ^{13}C and ^{14}C with 7 and 8 neutrons, respectively. Some isotopes are stable, others are not. ^{14}C is unstable, whereas ^{12}C and ^{13}C are stable. When an isotope is unstable it will decay; when it decays it releases radiation. Unstable isotopes are **radioactive** and are referred to as **radioisotopes**, meaning that they release radiation when their atoms decay. The decay occurs exponentially at a constant rate that is specific to the isotope. Decay rates are measured in units of half-lives. The half-life of ^{14}C is about 5600 years. (see Tables 20.1 and 20.3). Some radioactive isotopes are **fissionable**, meaning that they can be coaxed into decomposing spontaneously when hit by the alpha particles emitted by an adjacent, decaying atom. Thus, a **chain reaction** is possible when you pack enough radioisotopes together. When a chain reaction occurs, there is an enormous release of energy. When the chain reaction is uncontrolled, it is an exploding bomb. There are 3 kinds of radiation emitted when a radioisotope decays. These are alpha, beta, and gamma radiation.

proliferation, and the Senate finally killed the CRBR project in 1983. Breeders are important energy sources in some nations, e.g. France.

20.2 NUCLEAR ENERGY AND THE ENVIRONMENT

● The full nuclear fuel cycle encompasses mining, refining, fuel assembly, operation, and waste. There are risks and challenges associated with each step.
The mining operation produces radioactive tailings and exposes workers to rather high doses of radiation. Site selection of power plants is important (see Critical Thinking Issue below).Nuclear power plants are vulnerable to catastrophic accidents.
The U.S. does not reprocess nuclear fuel, but is on the verge of doing so.
● There are numerous problems associated with the handling and disposal of nuclear waste. There still is no permanent and operational repository for nuclear waste in the U.S. Nuclear plants have a limited life, and there is a high cost associated with decommissioning the plant and protecting the site that continues long after the plant is closed.
● Effects of radioisotopes - A release of radioisotopes into the environment exposes organisms to radiation externally and internally. Exposure to radiation from external sources is usually episodic, but internal exposure to radiation can be chronic. Internal

exposure occurs when radioactive particles are inhaled and lodge in the lung, or when radioisotopes are consumed. Radioisotopes can enter the food chain.
● Radiation dose and human health – the LD_{50} is about 5,000 mSv. Exposure to 1,000-2,000 can cause significant health problems, including sterility, abortion, vomiting. At 500 mSv physiological changes can be detected. The maximum allowable dose of radiation per year for workers in the nuclear industry is 50 mSv, which is about 30 times the average natural background. Studies have shown that there is a delay of 10-25 years between the time of exposure on the onset of disease, including cancer.

A CLOSER LOOK 20.2: RATION UNITS AND DOSES

● The Curie (Ci) is a common unit of radioactive decay equivalent to 3.7×10^{10} disintegrations per second. In the SI system, the analogous unit is the Becquerel (Bq), which is one radioactive decay per second.
● Exposure is measured in units of rads (rd) and rems. One rad is equal to an absorbed dose of 0.01 joule/kilogram (=0.01 gray). The SI system uses grays (Gy) and sieverts (Sv). 100 rd = 1 Gy and 1 Sv = 100 rems. The rem is equivalent to an absorbed dose in rads multiplied by a quality factor that depends on the type of radiation.

20.3 NUCLEAR POWER PLANT ACCIDENTS

● The NRC estimates that the probability of a meltdown is 0.01%, but if/when we have 1,500 nuclear reactors (4x present world total), the probability of a meltdown somewhere is once every 7 yrs.
● TMI - March 28, 1979 – the most significant nuclear accident in U.S. history occurred at TMI near Harrisonburg, PA. The accident resulted because of an improbable combination of malfunctions and operator errors. It resulted in a partial meltdown. During the accident, an unexpected bubble of hydrogen gas collected inside the reactor building that threatened to blow up the building. The operators had to vent the hydrogen and a great deal of radioisotopes to the atmosphere. This accident and the social consequences are fascinating.
● Chernobyl - Unit number 4 of the Chernobyl NPP exploded in the spring of 1986. The reactor core burned for days until the fire was eventually smothered by helicopters. The nearby city of Prypyat was evacuated within days of the disaster. Small towns in the surrounding countryside were also evacuated. A large area around the reactor will remain uninhabitable for decades. The accident, which happened as the result of a safety experiment, resulted in a large loss of life. Childhood leukemia is high and the mortality rate in the overall population of Ukraine has risen significantly since the accident. The reactor today is still hot, and the building is enclosed in an unstable structure known in Ukraine as the 'object shelter' and known here as the "sarcophagus". There are dozens of waste dumps all around the countryside where highly radioactive equipment was hastily buried, and not inventoried. Radioisotopes are leaking into the groundwater and have been detected as far as the Black Sea. Chernobyl is on a major flyway for migrating birds that stop and feed, and then carry radiation off site. The area is also subject to serious

flooding from the Dnieper and Prypiat Rivers. One could say that the accident here is still in progress.

20.4 RADIOACTIVE WASTE MANAGEMENT

● In western states 20 million metric tons of radioactive mine tailings will produce radiation for 100,000 yrs.
● Low level radioactive wastes are defined as being sufficiently low in radioactivity to be buried in shallow pits, one of which is located in Barnwell, SC. Low level rad waste includes contaminated clothing, gloves, medical equipment, laboratory waste, etc.
● Transuranic waste is composed of human-made radioactive elements heavier than uranium. It includes plutonium which must be isolated from the environment for about 250,000 years. Most transuranic waste is generated at nuclear weapons facilities. There is a pilot project at Carlsbad, NM to bury transuranic waste 2000 ft deep in salt caverns.
● High level radioactive waste consists of commercial and military nuclear fuel, including uranium and plutonium. The waste is highly radioactive and toxic. Presently many 1000s of tons waste is piling up at more than 100 sites in 40 states until a final repository is developed. This repository is scheduled to open in Yucca Mountain, NV. The repository is years behind schedule, over budget, and is opposed by the Sate of Nevada. In July 2004 a Federal Appeals Court threw the future of the Yucca Mountain repository in doubt by ruling that the federal government must devise a new plant to protect the public against radiation releases beyond the next 10,000 years. However, DOE remains confident that it can come up with an acceptable plan.
●There are at least 3 significant problems. One is transportation. When a repository finally opens there will be large scale movements of high level waste across the Nation's highway system and rails. A second problem is that the repository must remain geologically stable and hydrologically isolated for several hundred thousand years. The third problem is ensuring that future populations will understand that the repository is not to be disturbed. How can we communicate this message to people 1000s of years into the future?

20.5 THE FUTURE OF NUCLEAR ENERGY

● Advocates argue that:
  It does not contribute to global warming by release of GHGs
  It does not cause acid rain pollution or nitrogen deposition
  If breeder reactors are used, the amount of fuel will be increased
● Critics argue that:
  There are safety concerns and economic and political issues
  Nuclear is not likely to have any impact on global warming any time soon
  Some nations may use nuclear power as a path to developing weapons
● The future of nuclear energy is uncertain

CRITICAL THINKING ISSUE

●The Shoreham plant on New York's Long Island was ordered in the mid-'60s and cost over $5 billion to complete. Its construction was delayed by activists concerned about safety issues. One question was how to evacuate the population of Long Island in the event of an accident. Shoreham was finally completed and won its operating license, but with the company on the verge of bankruptcy, the plant was never operated. Gov. Mario Cuomo, an opponent of a Shoreham startup, negotiated a deal that allowed the power company to pass the cost of Shoreham along to the utility's consumers in exchange for closing the plant. Today, a perfectly good facility, capable of serving hundreds of thousands of homes, sits rusting. Who was at fault?

● What is the future of nuclear energy? Should we or shouldn't we? What are the costs and benefits?

Web Resources

http://www.nrc.gov/ The NRC home page with links to maps of nuclear power plants, educational material, and statistics.
http://www.nei.org/ The home page of the Nuclear Energy Institute, with links to statistics and educational material.
http://www.uic.com.au/nip22.htm An excellent account of the Chernobyl accident
http://www.uic.com.au/nip.htm A comprehensive collection of facts from the Uranium Information Centre in Melbourne. Excellent.