Chapter 17

NUCLEAR ENERGY AND THE ENVIRONMENT

> **Case Study: Japan 2011: Aftermath of a Nuclear Disaster**
> The accident at the Fukushima Number One Nuclear Power Plant demonstrated that despite foreknowledge of earthquake and tsunami risk as well as the implementation of technological efforts to prevent damage due to these risks, significant harm still occurred. This has left Japan and ~~well as~~ the rest of the world studying what role nuclear power should play in the future. Students may want to compare this accident with past accidents to see whether these incidents have truly led to improvements in plant design.

17.1 CURRENT ROLE OF NUCLEAR POWER PLANTS IN WORLD ENERGY PRODUCTION

Nuclear power produces about 14% of total electricity in the world and 4.8% of total energy from 435 operating plants.

17.2 WHAT IS NUCLEAR ENERGY?

There are two kinds of nuclear processes: nuclear fission and nuclear fusion. Fission is the splitting and fusion is the fusing of atomic nuclei, done commercially in nuclear reactors. Both reactions release an enormous amount of energy, but fusion reactors remain only a-theoretical possibility.

● Conventional Nuclear Reactors

The first human-controlled nuclear fission occurred in 1942 at the University of Chicago. Nuclear power generation occurs in fission reactors using ^{235}U (pronounced “U-235”) as a fuel. 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 pellets are stacked in fuel rods that are packed together in a reactor core. Fission produces neutrons, which strike other atoms and produce a chain reaction that must be controlled by raising and lowering control rods that absorb and block the neutrons, thus slowing the reaction.

There is an enormous amount of heat generated, which is carried away from the core by a circulating fluid (primary coolant). If water is used, it may be turned to steam by the heat and used to turn a turbine, but often a heat exchanger is used to transfer heat from a coolant such as liquid sodium to water to turn it to steam. This isolates the steam from the nuclear reaction. The term meltdown refers to a buildup of heat in the reactor, often due to a failure of the cooling system, that causes extensive damage to the reactor core with possible release of radioactive material.

The 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 of a typical burner reactor decay (as opposed to a breeder reactor, see below), the concentration of ^{235}U declines, and the concentrations of other dangerous radioisotopes rises. The waste products include radioisotopes of plutonium, iodine and strontium.

17.3 NUCLEAR ENERGY AND THE ENVIRONMENT

The nuclear fuel cycle encompasses mining, refining, fuel assembly, operation, and waste. There are risks and challenges associated with each step.

● Problems with the Nuclear Fuel Cycle

The mining operation produces radioactive tailings and exposes workers to rather high doses of radiation; waste is also produced by enrichment and assembly fabrication. In the Western United States, 20 million metric tons of radioactive mine tailings will produce radiation for 100,000 yrs.

Site selection of power plants is extremely important, as in the Case Study regarding Indian Point, NY.

Nuclear power plants are vulnerable to catastrophic accidents.

There are numerous problems associated with the handling, transportation and disposal of nuclear waste; there still is no permanent and operational repository for nuclear waste in the U.S. The U.S. does not reprocess nuclear fuel, but may be on the verge of doing so.

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.

Nuclear material may be stolen and used to produce weapons. Although construction of a nuclear bomb by terrorists or rogue governments is unlikely due to the amounts of material, technical skill, and facilities needed, “dirty bombs” are very much in the realm of possibility.

17.4 NUCLEAR RADIATION IN THE ENVIRONMENT AND ITS EFFECTS ON HUMAN HEALTH

● Ecosystem 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. Some of these are natural, mainly from rocks, soil and cosmic sources, but between 50% and 75% of a typical American’s exposure is due to human activities. (See the Personal Annual Radiation Dose Calculator in the Web Links.)

● Radiation Doses and Health

The LD_{50} in humans is about 5,000 millisievert (mSv). (See A Closer Look 17.2 for explanation of radiation units.) Exposure to 1,000-2,000 can cause significant health problems, including sterility, abortion, and vomiting. At 500 mSv, physiological changes can be detected. A typical American dose of radiation is 3 mSv/year, but this varies depending on altitude, type of building one lives in, and exposure to medical procedures.

There is much uncertainty in the assessment of health hazard or low doses of radiation.
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 to the onset of disease, including cancer.

17.5 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 estimated at once every 7 years.

● Three Mile Island

On March 28, 1979, the worst accident in U.S. nuclear history occurred at Three Mile Island near Harrisburg, Pennsylvania. 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, and 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. 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 plant in what is now Ukraine spread radioactivity across ~~Europe~~ Northern Hemisphere and fear of nuclear power increased. Three Mile Island is clearly seen on Google Earth.

● 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 - the cost will likely exceed $200 billion. The accident site is blurry on Google Earth (at the time of this writing), but the abandoned city of Prypiat is an eerie site.

● Japan's Nuclear Accident, 2011

This accident, addressed in the chapter's opening Case Study, was caused by the flooding of the Fukushima Number One reactor by a series of tsunami generated by an offshore earthquake. Loss of cooling water led to partial meltdowns in several reactors. While structures to prevent flooding were in place, it is likely that additional measures to prevent this type of accident could have been taken. The questions now is, should plants be built with more failsafes, or should nuclear power be simply abandoned?

17.6 RADIOACTIVE WASTE MANAGEMENT

Radioactive wastes are by-products of the use of nuclear fuel for electricity generation. There are two main types of radioactive waste: low-level and high-level.

● Low-Level Radioactive Waste

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 radioactive waste includes contaminated clothing, gloves, medical equipment, laboratory waste, solutions from processing, etc. The Nuclear Regulatory Commission divides them into three classes (A, B, and C) based on degree of potential hazard.

Transuranic waste is composed of human-made radioactive elements heavier than uranium. Most transuranic waste produces low levels of radiation, but isolation is necessary because of the very long half-life of these products. Plutonium, for example, must be isolated from the environment for about 250,000 years. This waste type includes trash and contaminated equipment, and is generated mainly at nuclear weapons facilities.

● High-Level Radioactive Waste
High level radioactive waste consists of commercial and military nuclear fuel, including uranium and plutonium. The waste is highly radioactive and toxic. Presently many thousands of tons of waste is piling up at more than 100 sites in 40 states until a final repository is developed.

Study Questions

1. If exposure to radiation is a natural phenomenon, why are we worried about it?
Ans: The most important question in studying radiation exposure in people is: At what point does the exposure or dose becomes a hazard to health? Although there is vigorous, ongoing debate about the nature and extent of the relationship between radiation exposure and cancer mortality, most scientists agree that radiation can cause cancer. Some scientists believe that there is a linear relationship, such that any increase in radiation beyond the background level will produce an additional hazard. Others believe that the body can handle and recover from low levels of radiation exposure but that health effects (toxicity) become apparent beyond some threshold.

2. What is a radioisotope, and why is knowing its half-life important?
Ans: A radioisotope is a form of a chemical element that spontaneously undergoes radioactive decay. During the decay process, the radioisotope changes from one isotope to another and emits one or more kinds of radiation. An important characteristic of a radioisotope is its half-life, the time required for one-half of a given amount of the isotope to decay to another form. Isotopes with very short half-lives are present only briefly, whereas those with long half-lives remain in the environment for long periods.

3. What is the normal background radiation that people receive? Why is it variable?
Ans: We receive natural background radiation from cosmic rays entering Earth's atmosphere from space, and from naturally occurring radioisotopes in soil and rock. The average American receives about 2 to 4 mSv/yr. Of this, about 1 to 3 mSv/yr, or 50–75%, is natural. The differences are primarily due to elevation and geology. More cosmic radiation from outer space (which delivers about 0.3–1.3 mSv/yr) is received at higher elevations.

4. What are the possible relationships between exposure to radiation and adverse health effects?
Ans: Depending of dose and length of exposure, health problems, could include vomiting, fatigue, potential abortion of pregnancies of less than two months' duration, and temporary sterility in males. Most scientists agree that radiation can cause cancer and science has shown that radiation can destroy human cells. Chronic health problems related to low-level exposure to radiation are neither well known nor well understood.

5. What processes in our environment may result in radioactive substances reaching people?
Ans: The nuclear fuel cycle consists of mining and processing uranium, generating nuclear power through controlled fission, reprocessing spent fuel, disposing of nuclear waste, and decommissioning power plants. Each part of the cycle is associated with characteristic processes, all with different potential environmental problems.

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6. Suppose it is recommended that high-level nuclear waste be disposed of in the geologic environment of the region in which you live. How would you go about evaluating potential sites?

Ans: Evaluation of the safety and utility of a new waste repository would have to consider factors such as the following:

- The probability and consequences of volcanic eruptions.
- Earthquake hazard.
- Estimation of changes in the storage environment over long periods.
- Estimation of how long the waste may be contained and the types and rates of radiation that may escape from deteriorated waste containers.
- How heat generated by the waste may affect moisture in and around the repository and the design of the repository.
- Characterization of groundwater flow near the repository.
- Identification and understanding of major geochemical processes that control the transport of radioactive materials.

7. Are there good environmental reasons to develop and build new nuclear power plants? Discuss both sides of the issue.

Ans: Its advocates argue that nuclear power is good for the environment because (1) it does not contribute to potential global warming through release of carbon dioxide and (2) it does not cause acid rain. They also argue that developing breeder reactors for commercial use would greatly increase the amount of fuel available for nuclear plants, that nuclear power plants are safer than other means of generating power.

The argument against nuclear power is based on political and economic considerations as well as scientific uncertainty about safety issues. They argue that converting from coal-burning plants to nuclear power plants for the purpose of reducing carbon dioxide emissions would require an enormous investment in nuclear power to make a real impact. Furthermore, they say, given that safer nuclear reactors are only just being developed, there will be a time lag, so nuclear power is unlikely to have a real impact on environmental problems— such as air pollution, acid rain, and potential global warming— before at least the year 2050.