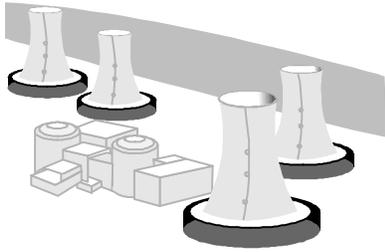


UNIT TEN

INTRODUCTION TO NUCLEAR REACTORS



The licensees of nuclear facilities have primary responsibility for planning and implementing emergency measures *within* their site boundaries. These emergency measures include corrective actions at the site and protective measures and aid for persons onsite. Since facility licensees cannot do this alone, it is a necessary part of the facility's emergency planning to make advance arrangements with State and local organizations for special emergency assistance such as ambulance, medical, hospital, fire and police services. State and local governments have responsibility for planning and implementing protective actions *outside* the site boundaries. Radiological response team members from State and local emergency services will be better prepared to carry out these responsibilities with some knowledge of nuclear power plant structure, operations and emergency response procedures.

The teaching points included in this unit should be recognized as a review by those who have completed the FEMA radiological series prerequisites or who have experience in the nuclear power industry.

You are notified of a site area emergency at a nuclear power plant located nine miles from your town. The meteorologist has confirmed that if a release occurs, the town will be directly in the path of the plume. Part of the town is in the plume exposure pathway and the rest is within the ingestion pathway.

How do you interpret this information?

GATE FRAME QUESTION



ANSWER

Your answer should include the adjacent information

A site area emergency means that events are in process or have occurred that involve actual major failures of plant functions needed for protection of the public. Any releases are not expected to exceed EPA PAG exposure levels except near the boundary. You will be periodically updated on emergency actions and notified to stand by for further instructions.

If a release occurs, the first 10 miles from the plant is considered to be the plume exposure pathway, or the path for airborne radioactive material in the plume. The plume would commonly contain radioactive noble gases and might also contain radioiodines and radioactive particulate materials. Many of these materials emit gamma radiation and can expose people nearby as the plume passes.

For a 50-mile radius, an ingestion exposure pathway has been defined as the most likely area where radioactive material would settle out from the plume and fall to earth. Principal exposure in this emergency planning zone (EPZ) would come from ingestion of contaminated water, milk, and food.

If your answer included all or most of the above points, you should be ready for the Summary Questions at the end of this unit. Turn to page 10-23.

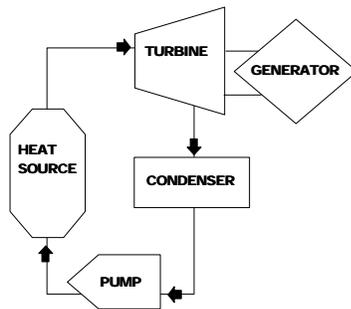
If your answer did not include these points, it would be advisable for you to complete the programmed instruction for this unit. Turn to page 10-3.



NUCLEAR POWER PLANT STRUCTURE AND OPERATIONS

Virtually all commercial nuclear power reactors in the United States are either *pressurized water reactors* (PWRs) or *boiling water reactors* (BWRs). In both types of reactors the reactor core is covered with water to allow the nuclear reaction to take place and to keep the core cool.

A nuclear power plant is a facility at which energy released by the fissioning of atoms is converted to electrical energy under strictly regulated operating conditions. The major processes are the same as those in non-nuclear (conventional) power plants except that the coal- or oil-fired boiler is replaced by a nuclear reactor.

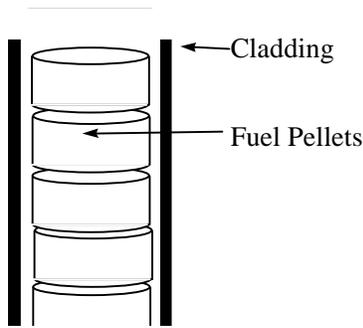


A *heat source* provides heat to generate steam. In a nuclear power plant, the heat source is the nuclear reactor, often called the reactor core. A *turbine generator* uses the energy of the steam to turn a turbine that generates electricity.

The *condenser* condenses the steam back to water so that it can be returned to the heat source to be heated again. A power plant's condenser uses cool water pumped from a nearby lake, river, or ocean to condense the steam from the turbine. Because the water used to cool the condenser is warmer after use, a cooling tower is sometimes used to prevent a harmful temperature rise in the water supply.

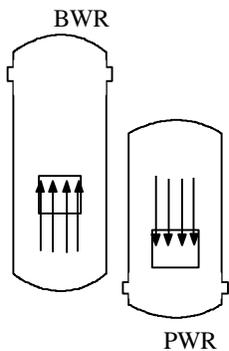
The *pump* provides the force to circulate the water through the system.





Nuclear power plants produce a great deal of heat through a chain reaction of fissions of uranium atoms. The uranium is contained in uranium dioxide *fuel pellets*. These pellets are stacked end-to-end to form a 12 foot long fuel rod that is encased in a metal tube called *fuel cladding*. Fuel cladding prevents radioactive fission products from escaping the fuel pellets into the reactor cooling water.

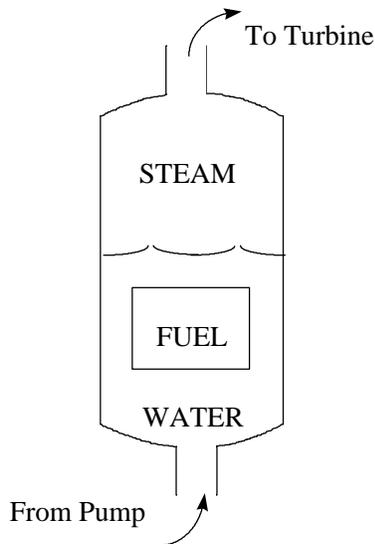
REACTOR SCRAM



Rapid insertion of control rods to shut down the fission chain reaction

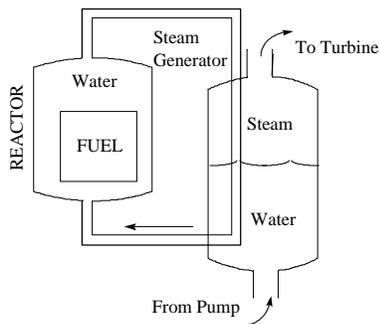
The nuclear chain reaction may be regulated by *control rods*. Control rods absorb neutrons, the atomic particles needed for the chain reaction to continue. When all of the control rods are inserted into the reactor core, it is called a *reactor shutdown* or *scram*.

Both BWRs and PWRs require that the reactor core be covered with water for the nuclear chain reaction to continue. This *reactor cooling water* removes the heat generated in the reactor. In an accident resulting in a loss of the water covering the core, the reactor would scram.



The system that contains the reactor cooling water is called the *primary coolant system*. In BWRs, water is allowed to boil directly in the reactor core. The boiling water generates steam, which is drawn away from the reactor and used to rotate the turbine.





In PWRs, the primary coolant is maintained at a much higher pressure. Heat is removed by sending the primary coolant through a series of metal tubes while secondary cooling water flows around the tubes. Heat is thereby transferred from the primary cooling system, which is radioactive, to the nonradioactive secondary system.

The secondary coolant is maintained at a much lower pressure so that as the heat is transferred, the secondary coolant flashes to steam. That steam is used to rotate the turbine which generates electricity.

To check your understanding of these concepts, answer the following question.

QUESTION

Circle the correct answer

A conventional power plant is fueled by

- a. a nuclear reactor.
- b. fossil fuel.

Turn the page to check your answers.



ANSWERS

- a. No, while the major processes in non-nuclear (conventional) and nuclear power plants are the same, a conventional power plant uses a coal- or oil-fired boiler.

Try the next question.

- b. Yes. You know the difference between nuclear and fossil fuel power plants.

Proceed to the next section.

QUESTION

Circle the correct answer

The purpose of the fuel cladding around uranium dioxide fuel rods is to

- a. prevent radioactive fission products from escaping the fuel rods into the reactor cooling water.
- b. remove the heat generated in the reactor.

Turn the page to check your answers.



ANSWERS

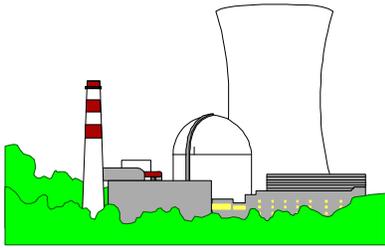
- a. Yes. You are familiar with this structural measure designed to control the radiation generated through a chain reaction of fissions of uranium atoms.

Turn to page 10-8.

- b. No, the reactor cooling water removes the heat generated in the reactor and the fuel cladding controls the fission products.

You should review this section before moving on to page 10-8.





THREE MILE ISLAND

DEFINING THE HAZARD

There are two basic sources of safety problems at an operating nuclear power plant. One is the very large amounts of volatile radioactive materials that, if released, could cause offsite health effects. The typical light water reactor has about 4 billion curies in its core 30 minutes after shutdown. Although all of this radioactive material would never escape, even a small fraction of the total inventory would amount to a large release. The other source of safety problems is the heat energy in the core that, if not controlled, could release the fission products by damaging the containment structures.

Despite the many elaborate safety systems designed for plant operation, problems have occurred and undoubtedly will reoccur. The worst commercial accident in the United States occurred at the **Three Mile Island** nuclear station in 1979. As a result of equipment failures and operator error, a valve that was stuck open allowed coolant water that covered the reactor core to escape from the reactor system for over two hours. This radioactive water, nearly a million gallons, ended up on the basement floors of the containment building and auxiliary buildings.

The loss of coolant water in the reactor core continued to the point that the fuel was no longer submerged in water. Without the cooling provided by the water, the cladding and some of the fuel pellets melted. Large quantities of radioactive material were released into the containment building. The containment building performed as designed and radioactive releases to the atmosphere were small. The releases resulted from leakage of the radioactive water that was carried outside the containment building.

CHERNOBYL

Another serious commercial power reactor accident occurred in 1986 at the **Chernobyl** nuclear power plant in the U.S.S.R. That accident released large amounts of radioactive fission products to the environment. It was caused by a variety of factors. Operator error was



aggravated by deliberate failure to follow procedures, a circumstance caused by in-progress safety limit testing. In the Chernobyl graphite moderated reactor, loss of coolant increased the chain reaction rather than decreasing it, causing such a buildup of pressure that the reactor was blown apart. This type of accident is not possible in a pressurized water or boiling water reactor in the U.S. because the loss of water would have shut down the reactor.

Answer the following question to check your understanding of these concepts.

QUESTION

Circle the correct answer

One of the major sources of safety problems in a nuclear reactor is

- a. the energy in the core.
- b. the risk of a nuclear detonation.

Turn the page to check your answers.



ANSWERS

- a. That's correct. The other major source is the potential for release of large amounts of radioactive material.

Turn to page 10-12.

- b. No. A nuclear power plant could not detonate like a nuclear weapon. The potential problem is a fire or non-nuclear explosion.

Try the next question.

QUESTION

Circle the correct answer

The accident at the Three Mile Island nuclear station was a result of

- a. poor reactor design.
- b. equipment failures and operator error.

Turn the page to check your answers.



ANSWERS

- a. No, the accident occurred when a relief valve stuck open and operators failed to react to signals that coolant water was escaping.

Review this section before moving on.

- b. Right. The resulting loss of coolant allowed temperatures to get so hot that some of the uranium fuel melted.

Turn to page 10-12.



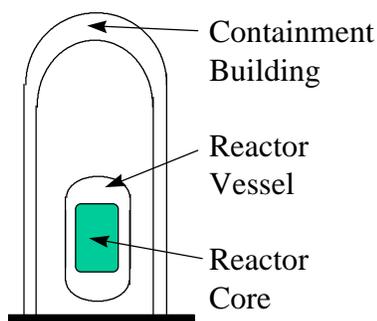
NUCLEAR PLANT SAFETY

Nuclear power plants are designed with two principal safety objectives in mind. One is to contain radioactive fission products to prevent offsite health effects. The other is to ensure that heat generated by the reactor, including heat generated by the decay of fission products after reactor shutdown, is removed.

Three barriers prevent the release of radioactive fission products from the reactor core to the environment: fuel rods, reactor vessel and primary cooling system, and containment.

Fuel rods trap 99 percent of all fission products in the fuel pellets and the remaining 1 percent in the fuel cladding that encases the fuel. If the core is not sufficiently covered with water to provide cooling, it could overheat and cause a breakdown in the fuel cladding. Additional overheating could result in the release of the fission products in the fuel structure. Still more overheating could cause a fuel meltdown.

Even if the fuel cladding were to fail, two more restraints prevent a release to the atmosphere. The reactor core is located within a *reactor vessel* that has walls of steel up to 10 inches thick. The large pipes of the *primary coolant system* also contain the reactor cooling water and any radioactive materials present.



The *containment building* is the third barrier between the fission products and the environment. It is a building that generally is made of high-density, reinforced concrete as much as six feet thick. The containment building is built to withstand severe accidents and natural and technical hazards. Even if the first two barriers are damaged, the containment building should prevent the release of most fission products to the environment.

Turn the page and answer the question.



QUESTION

Circle the correct answer

Nuclear power plants are designed with what two principal safety objects in mind?

- a. to contain radioactive fission products to prevent offsite health effects and to ensure that heat generated by the reactor is removed.
- b. to contain the reactor cooling water and any radioactive materials present.

Turn the page to check your answers.



ANSWERS

- a. Yes. You understand the purpose of onsite safety systems.

Turn to page 10-16.

- b. No. These steps are required in order to accomplish the principal safety objectives of preventing offsite releases of radiation and removal of reactor heat.

Try the next question.

QUESTION

The containment building could sustain the effects of a hurricane or tornado.

Circle the correct answer

- a. true.
b. false

Turn the page to check your answers.



ANSWERS

- a. Yes. The design is intended to withstand such hazards.

Turn to page 10-16.

- b. Containment buildings are built to withstand severe accidents and natural and manmade hazards.

You should review this section before proceeding to page 10-16.



OFF-SITE PROTECTIVE ACTIONS



In addition to the safety measures designed into nuclear power plants, government emergency preparedness agencies require another degree of protection for the public. Plant operators and all levels of government maintain emergency plans to deal with direct exposure from a plume of airborne radioactive material or from radioactive material deposited on the ground, internal or external contamination caused by direct contact with the plume, and ingestion of radioactive material.

- Guidelines for this planning effort are found in the document *Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants*, NUREG-0654/FEMA-REP-1.

There are four levels of emergencies covered by these plans. Each level requires specific actions be taken by plant operators and local governments.

Notification of Unusual Event occurs when there is a potential degradation of safety at the plant but no releases requiring offsite monitoring or emergency action have occurred. Fire or security assistance may be required onsite.

An *Alert* is the result of events that involve actual or partial degradation of the level of safety at the plant. Any releases are expected to be limited to small fractions of the EPA Protective Action Guidelines (PAGs), which were reviewed in Unit Five. Resources and emergency personnel are brought to standby status, and offsite monitoring is performed if an actual release occurs. Assistance may be required onsite.

A *Site Area Emergency* means that events are in process or have occurred that involve actual major failures of plant



functions needed for protection of the public. Any releases are not expected to exceed EPA PAG exposure levels except near the boundary. The public should be periodically updated on emergency actions and be notified to stand by for further instructions. Monitoring teams and communication personnel are dispatched to assignments.

A *General Emergency* is declared in the event of an actual or imminent substantial core degradation or melting with potential for breach in containment or radioactive releases expected to exceed acceptable levels off-site. Such an event calls for offsite monitoring and immediate protective actions by the public.

Protective actions should be outlined in the jurisdiction's radiological emergency plan or annex to the emergency operations plan. As discussed in Unit Five, protective actions might include such measures as evacuation or shelter. These protective actions are triggered by the EPA Protective Action Guides.

To assess your understanding of these concepts, answer the following question.

QUESTION

Circle the correct answer

Emergency planning for nuclear power plant accidents is undertaken by

- a. plant operators only.
- b. plant operators and State and local governments.

Turn the page to check your answers.



ANSWERS

- a. Partly correct. Plant operators are required to develop radiological emergency response plans *in conjunction with, and in addition to*, State and local government plans.

Try another question.

- b. That is correct. NUREG-0654/FEMA-REP-1 provides the guidance for developing these plans.

Turn to page 10-20.

QUESTION

Circle the correct answer

An uncontrolled loss of coolant water would probably be classified by the utility as

- a. an Unusual Event.
- b. a Site Area Emergency.

Turn the page to check your answers.



ANSWERS

- a. No, an uncontrolled loss of coolant water constitutes more than a “potential degradation of safety” at the plant.

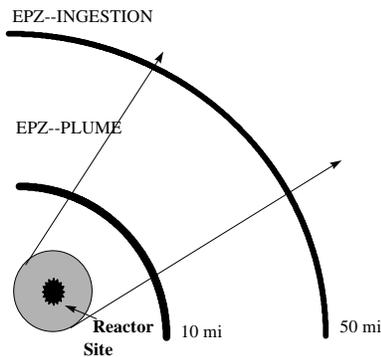
You should review this section before beginning the next one on page 10-20.

- b. That’s correct. An uncontrolled loss of coolant is an event that involves a major failure of plant function needed for protection of the public. The accident is not reclassified to General Emergency unless there is an actual or imminent substantial core degradation or melting with potential for breach in containment or radioactive releases expected to exceed acceptable levels off-site.

Turn to 10-20.



PLUME EXPOSURE PATHWAY



At every commercial nuclear reactor site in the country there are *emergency planning zones* (EPZ) that have been plotted and carefully investigated to determine who and what within those zones might be affected by an accidental release.

The first EPZ, *plume exposure pathway*, extends 10 miles out from the plant and, for most accidents, would be the path for airborne radioactive material in the plume. The plume would commonly contain radioactive noble gasses (helium, neon, argon, krypton, xenon, and radon), characterized by their stability and extremely low reaction rates. The plume may also contain radioiodines and radioactive particulate materials. Many of these materials emit beta and gamma radiation that can expose people nearby as the plume passes.

The radius from 0-50 miles, the *ingestion exposure pathway*, has been defined as the most likely area where, in a single release, radioactive material settles out from the plume and falls to earth. Principal exposure in this EPZ would come from ingestion of contaminated water, milk, and food.

The size of the EPZs were established at 10 and 50 miles because government and industry calculations have determined that even in the most severe accident a release would generally not exceed the EPA PAGs at these distances.

To check your understanding answer the following question.

QUESTION

Circle the correct answer

The pathway that is limited to a 10 mile EPZ is the plume exposure pathway.

- a. False.
- b. True.

Turn the page to check your answers.



ANSWERS

- a. Wrong. The plume exposure pathway is the pathway limited to the 10 mile EPZ. The ingestion exposure pathway can extend further because radioactive contamination may enter the food supply chain.

Try another question.

- b. Correct.

Turn to page 10-23 for the Summary Questions.

QUESTION

Circle the correct answer

The principal exposure hazard from 10-50 miles away from the plant is from

- a. contaminated water, milk, and food.
- b. contaminated air.

Turn the page to check your answers.



ANSWERS

- a. That's right. This is where, in a single release, radioactive material settles out from the plume and falls to earth, creating the potential for contaminated milk, water and food.

Proceed to the Summary Questions on page 10-23.

- b. While there is undoubtedly radioactive material settling out at this distance, the plume is much dispersed and the hazard from airborne radiation is much decreased.

Please review this section before turning to page 10-23.



SUMMARY QUESTIONS

QUESTION

Circle the correct answer

1. As a local or State radiological response team (RRT) member, when might your services be requested during a nuclear power plant accident?
 - a. only when the radioactive plume passes beyond the boundaries of the plant.
 - b. the onsite and offsite radiological emergency response plans describe when local or state radiological response teams are utilized.

Turn the page to check your answers.



ANSWERS

- a. This is partially correct but there are other possibilities.

Review your radiological emergency response plan to clarify your potential responsibilities. Also answer the next question.

- b. That is a good answer. You should be familiar with what your plan outlines before an emergency occurs.

Move ahead to the next Summary Question.

QUESTION

Circle the correct answer

2. What type of monitoring would be appropriate to determine the offsite radiation level of the plume resulting from an accidental release from a nuclear power plant?
- a. Air sampling.
- b. Area survey.



ANSWERS

- a. That's correct. A plume is an airborne release of radioactive material.

Go ahead to Unit Eleven.

- b. Incorrect. You might get some reading on a survey meter, but if the reading is not taken in the plume or the plume is far enough overhead, the reading may not correctly characterize the hazard.

Review pages 10-20 before proceeding to the next unit.

