Reactor

Operators Manual

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1

Use of this Manual

To ensure that procedures will be properly executed, facility personnel and others should be knowledgeable in the current procedures related to the tasks for which they are responsible. Before a procedure is used, training of operating personnel and others who are intended to implement the procedure shall be conducted. Training should take the form of oral or written instructions, demonstrations, drills, training classes, or comprehensive training courses, and where applicable, using mock-ups.

Retraining in the use of procedures should be included in the retraining program for operating personnel and others. Retraining should be conducted according to a prescheduled plan, especially for emergency and infrequently performed procedures. Typical examples of these are:

- operation of emergency core cooling systems
- operation of confinement air cleaning system
- testing of leaktightness of the reactor building
- handling of highly radioactive materials under abnormal conditions

- fuel shipment
- emergency actions such as response to fire or evacuation alarms in the reactor building, personal injury, release of airborne radioactive materials, and weather warnings.

The facility personnel should be required to demonstrate their knowledge and understanding of operating procedures for which they are responsible.

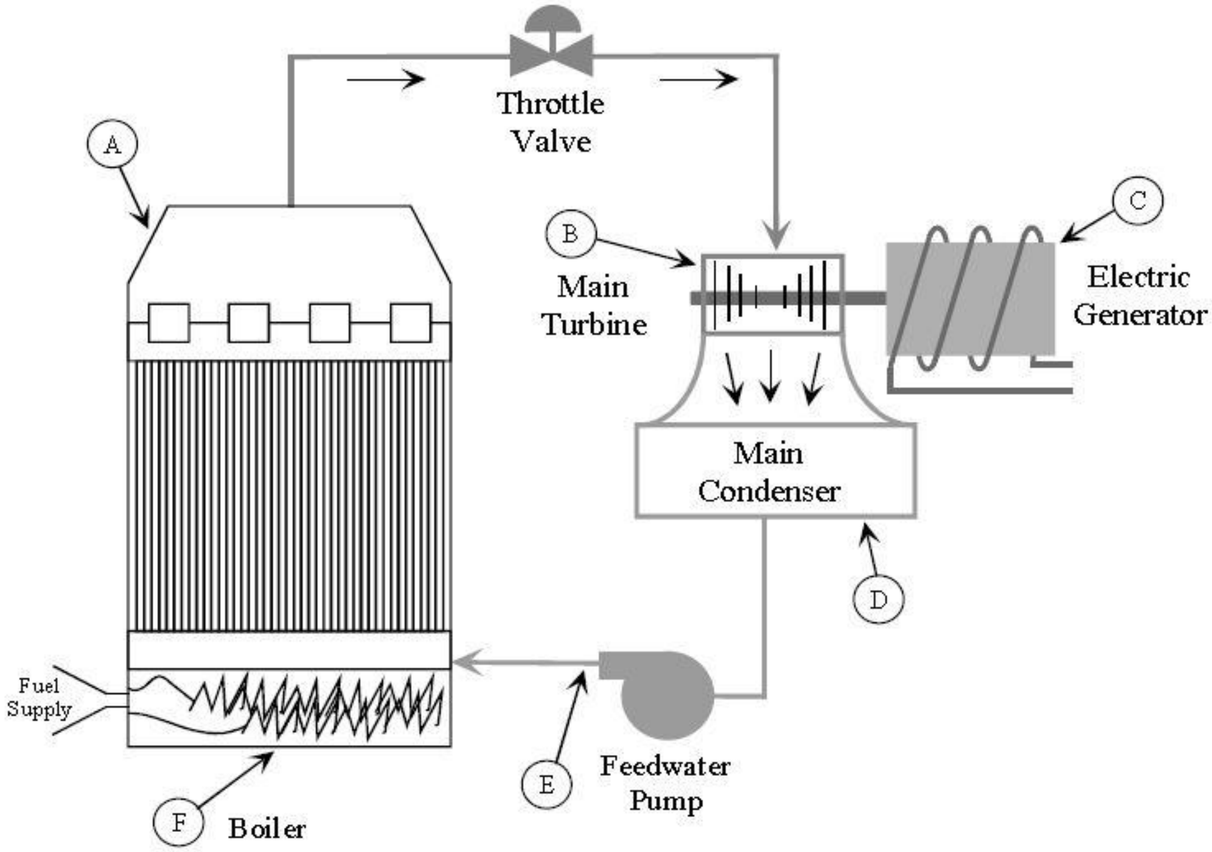
2

Nuclear Power Plant Overview

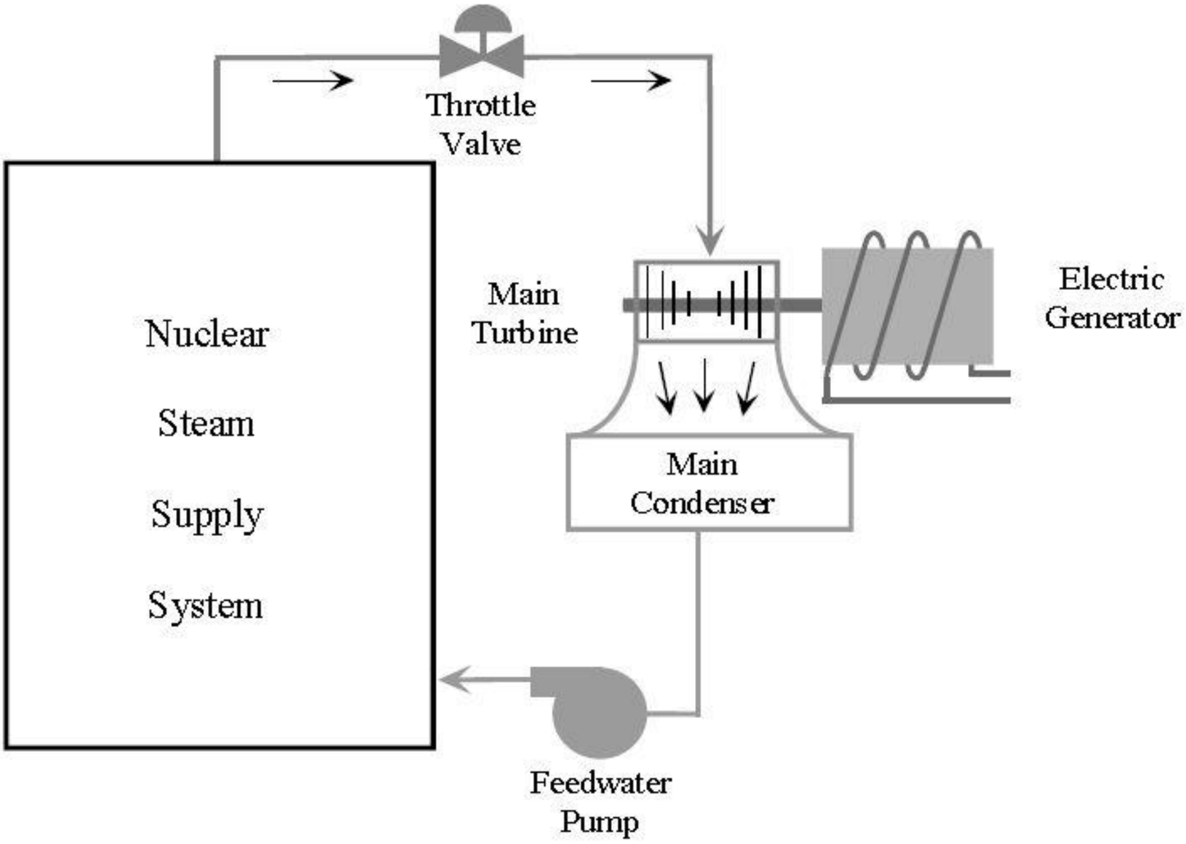
It may help understanding to compare two types of power plants.

In a fossil-fueled power plant, heat, from the burning of coal, oil, or natural gas, converts (boils) water into steam (A), which is piped to the turbine (B). In the turbine, the steam passes through the blades,which spins the electrical generator (C), resulting in a flow of electricity. After leaving the turbine, thesteam is converted (condensed) back into water in the condenser (D). The water is then pumped (E)back to the boiler (F) to be reheated and converted back into steam. See the following figure.

Fossil Fuel Steam Plant



In a nuclear power plant, many of the components are similar to those in a fossil-fueled plant, except that the steam boiler is replaced by a Nuclear Steam Supply System (NSSS). The NSSS consists of a nuclear reactor and all of the components necessary to produce high pressure steam, which will be used to turn the turbine for the electrical generator. See the following figure. *Nuclear Fuel Steam Plant*



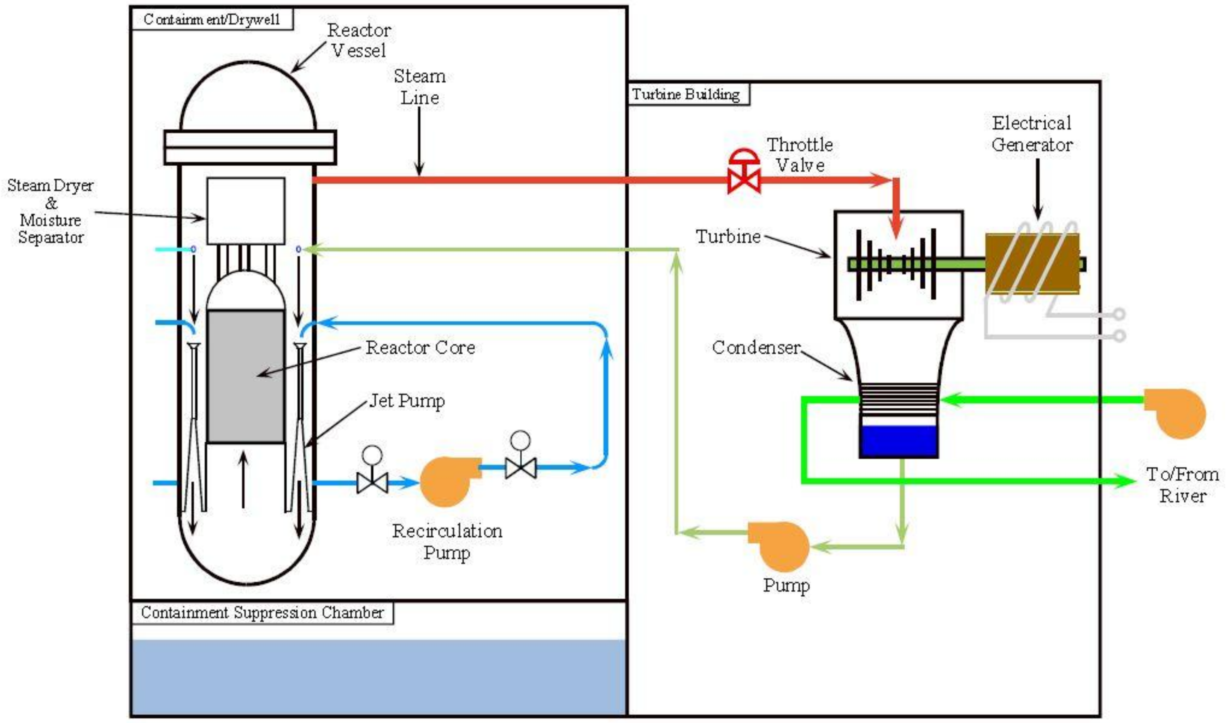
Like a fossil-fueled plant, a nuclear power plant boils water to produce electricity. Unlike a fossil-fueledplant, the nuclear plant’s energy does not come from the combustion of fuel, but from the fissioning(splitting) of fuel atoms.

2.1 Types of Reactor Plants

There are two basic types of reactor plants being used in the United States to produce electricity, the boiling water reactor (BWR) and the pressurized water reactor (PWR).

The boiling water reactor operates in essentially the same way as a fossil-fueled generating plant. Inside the reactor vessel, a steam/water mixture is produced when very pure water (reactor coolant) moves upward through the coreabsorbing heat. The major difference in the operation of a boiling water reactor as compared to othernuclear systems is the steam void formation in the core. The steam/water mixture leaves the top of thecore and enters two stages of moisture separation, where water droplets are removed before the steamis allowed to enter the steam line. The steam line, in turn, directs the steam to the main turbine, causingit to turn the turbine and the attached electrical generator. The unused steam is exhausted to thecondenser where it is condensed into water. The resulting water (condensate) is pumped out of thecondenser with a series of pumps and back to the reactor vessel. The recirculation pumps and the jet pumps allow the operator to vary coolant flow through the core and to change reactor power.

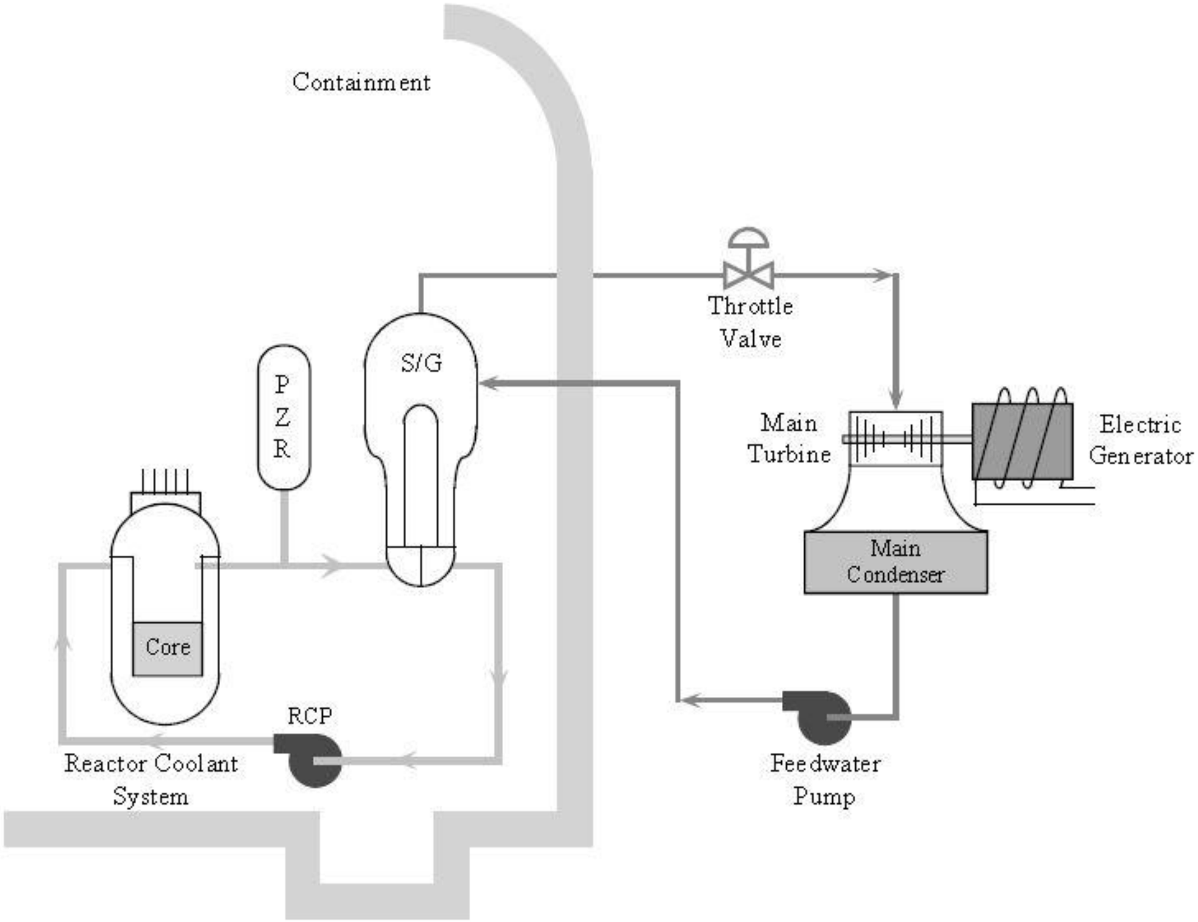
Boiling Water Reactor



Boiling water reactors comprise about one-third of the power reactors in the United States.

The pressurized water reactor (PWR) differs from the boiling water reactor in that steam is produced in the steam generator rather than in the reactor vessel. The pressurizer keeps the water that is flowing through the reactor vessel under very high pressure (more than 2,200 pounds per square inch) to prevent it from boiling, even at operating temperatures of more than 600EF. Pressurized water reactors make up about two-thirds of the power reactors in the United States.

pressurized water reactor



2.2 Enrichment

The most common fuel for the electrical producing reactor plants in the United States is uranium. Theuranium starts out as ore, and contains a very low percentage (or low enrichment) of the desired atoms(U-235). The U-235 is a more desirable atom for fuel, because it is easier to cause the U-235 atoms tofission (split) than the much more abundant U-238 atoms. Therefore, the fuel fabrication processincludes steps to increase the number of U-235 atoms in relation to the number of U-238 atoms(enrichment process).

Ore to Pellets

Uranium Ore (0.7%)

Fuel Pellet (3.5%)

The following is the process overview.

1. CHEMICAL CONVERSION TO UF6
2. ENRICHMENT
3. PELLETIZING
4. ROD LOADING
5. BUNDLE ASSEMBLY
6. BUNDLE FINAL INSPECTION
7. PACKAGING & SHIPPING
8. SITE INSPECTION & CHANNELING

Once the fuel has been enriched, it is fabricated into ceramic pellets. The pellets are stacked into 12-footlong, slender metal tubes, generally made of a zirconium alloy. The tube is called the “fuel cladding.”When a tube is filled with the uranium pellets, it is pressurized with helium gas, and plugs are installedand welded to seal the tube. The filled rod is called a “fuel rod.” The fuel rods are bundled together into“fuel assemblies” or “fuel elements.” The completed assemblies are now ready to be shipped to the plantfor installation into the reactor vessel.

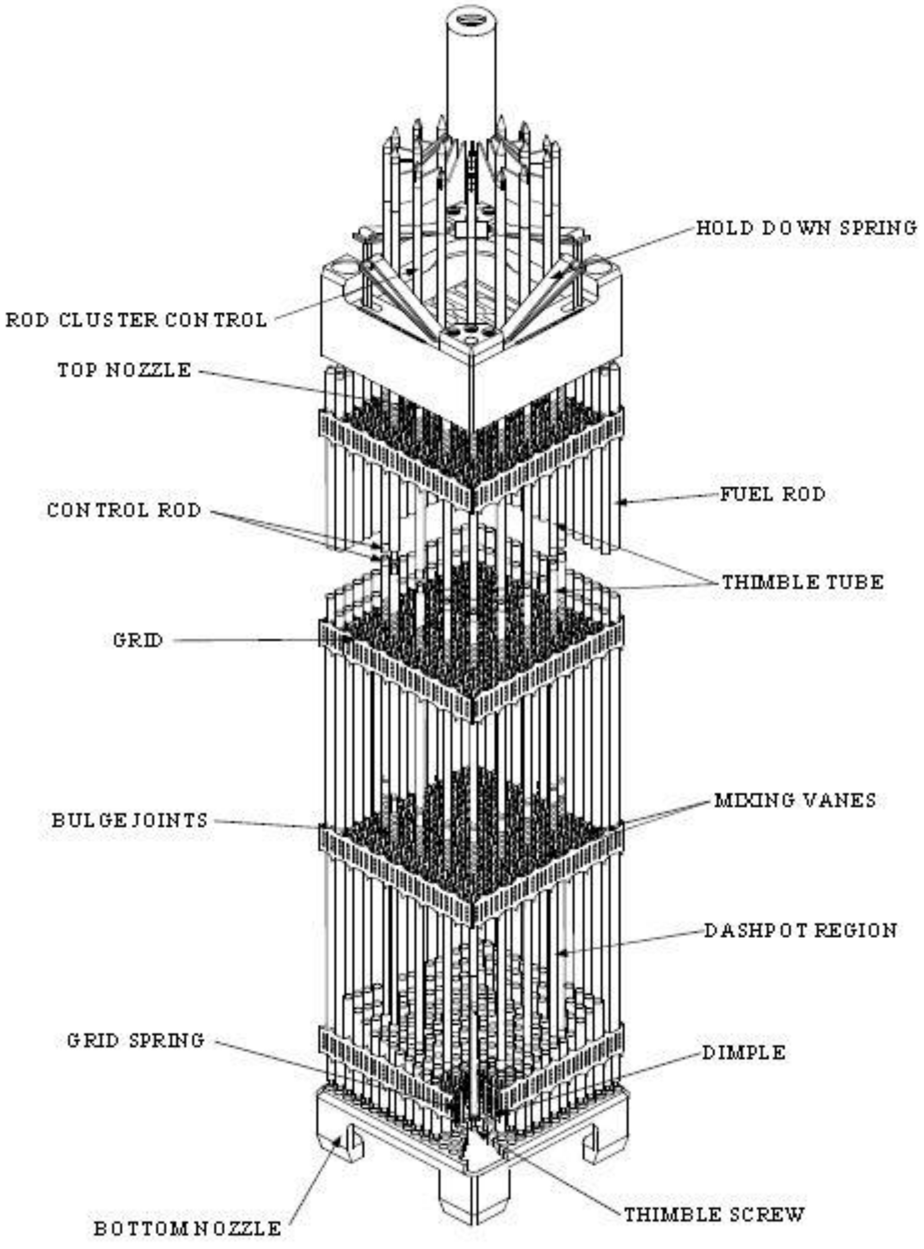
Uranium-235 is useful as a reactor fuel because:

1. It will readily absorb a neutron to become the highly unstable isotope U-236.
2. U-236 has a high probability of fission (about 80% of all U-236 atoms will fission).
3. The fission of U-236 releases energy (in the form of heat) which is used to produce high pressure steam and ultimately electricity.
4. The fission of U-236 releases two or three additional neutrons which can be used to cause other fissions and establish a “chain reaction.”

2.3 Reactor Rod Assemblies

Both boiling water reactor and pressurized water reactor fuel assemblies consist of the same majorcomponents. These major components are the fuel rods, the spacer grids, and the upper and lower endfittings. The following fuel assembly drawing shows these major components (pressurized waterreactor fuel assembly).

Reactor Rod Assemblies



The fuel rods contain the ceramic fuel pellets. The fuel rods are approximately 12 feet long and containa space at the top for the collection of any gases that are produced by the fission process. These rods arearranged in a square matrix ranging from 17 x 17 for pressurized water reactors to 8 x 8 for boiling waterreactors.

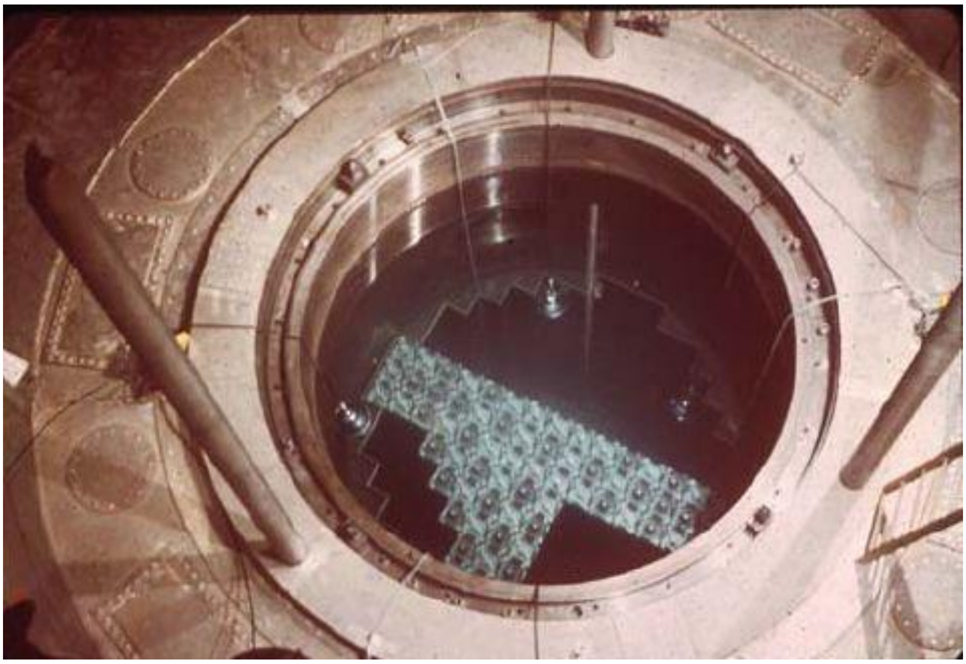
The spacer grids separate the individual rods with pieces of sprung metal. This provides the rigidity ofthe assemblies and allows the coolant to flow freely up through the assemblies and around the fuel rods.Some spacer grids may have flow mixing vanes that are used to promote mixing of the coolant as it flows around and though the fuel assembly.

The upper and lower end fittings serve as the upper and lower structural elements of the assemblies. Thelower fitting (or bottom nozzle) will direct the coolant flow to the assembly through several small holesmachined into the fitting. There are also holes drilled in the upper fitting to allow the coolant flow toexit the fuel assembly. The upper end fitting will also have a connecting point for the refuelingequipment to attach for the moving of the fuel with a crane.

For pressurized water reactor fuel, there will also be guide tubes in which the control rods travel. Theguide tubes will be welded to the spacer grids and attached to the upper and lower end fittings. Theguide tubes provide a channel for the movement of the control rods and provide for support of the rods.

At the nuclear power plant, the fuel assemblies are inserted vertically into the reactor vessel (a large steeltank filled with water with a removable top). The fuel is placed in a precise grid pattern known as the“reactor core.”

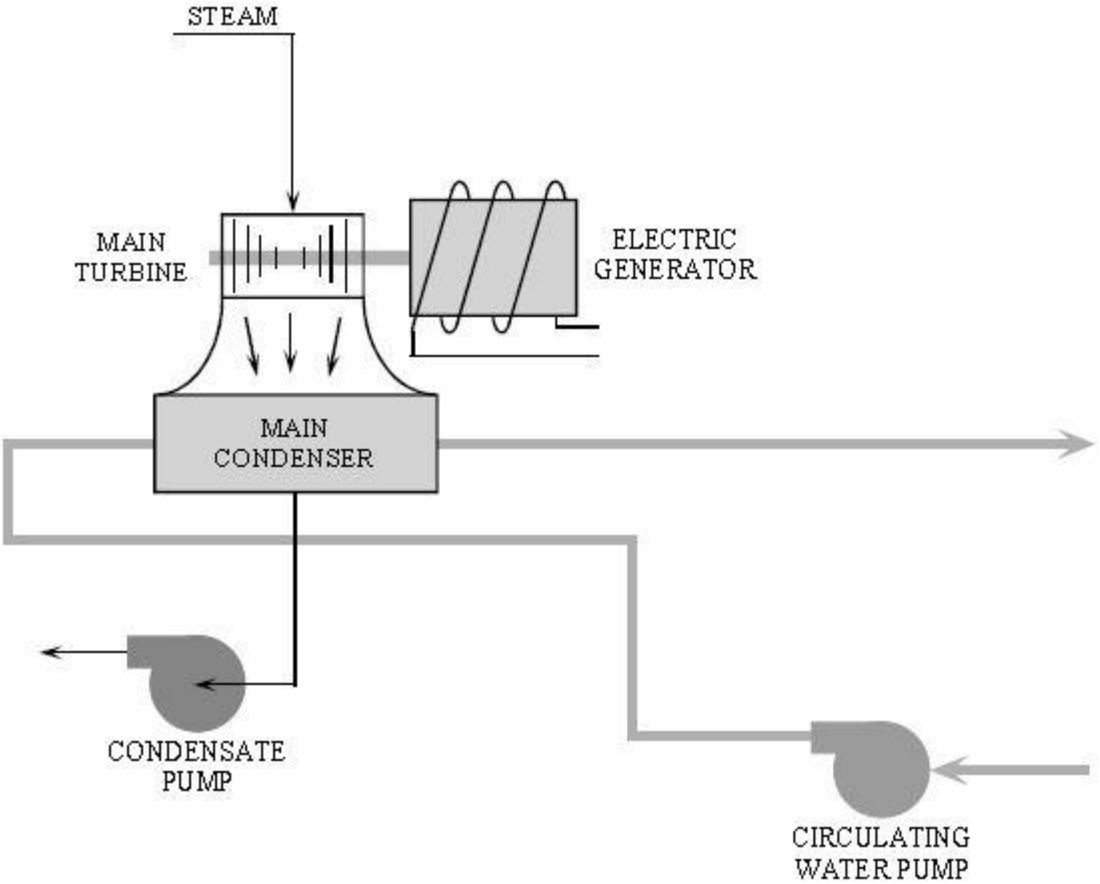
Reactor Vessel



2.4 Circulating Water System

To operate properly, all steam plants, whether nuclear or fossil-fueled, need a circulating water system to remove excess heat from the steam system in order to condense the steam, and transfer that heat to the environment. The circulating water system pumps water from the environment (river, lake, ocean) through thousands of metal tubes in the plant's condenser. Steam exiting the plant's turbine is very rapidly cooled and condensed into water when it comes in contact with the much cooler tubes. Since the tubes provide a barrier between the steam and the environment, there is no physical contact between the plant's steam and the cooling water. Because a condenser operates at a vacuum, any tube leakage in this system will produce an "inflow" of water into the condenser rather than an "outflow" of water to the environment.

Water System



Power plants located on the ocean (or other large bodies of water) will often discharge their circulating water directly back to the ocean under strict environmental protection regulations. Water is taken from the ocean, pumped through the thousands of small tubes in the condenser to remove the excess heat, and is then discharged back into the ocean. The expected temperature increase from circulating water inlet to outlet is about 5 to 10 degrees Fahrenheit.

Most nuclear power plants not located on the ocean need cooling towers to remove the excess heat from the circulating water system. One type of cooling tower is the forced draft cooling tower. The circulating water is pumped into the tower, after passing through the condenser, and allowed to splash downward through the tower, transferring some of its heat to the air. Several large electrical fans, located at the top of the cooling tower, provide forced air circulation for more efficient cooling.

The taller hourglass shaped, natural convection cooling towers do not require fans to transfer the excess heat from the circulating water system into the air. Rather, the natural tendency of hot air to rise removes the excess heat as the circulating water splashes down inside the cooling tower. These towers are typically several hundred feet tall.

The “steam” vented from the top of a cooling tower is really lukewarm water vapor. IT IS NOT RADIOACTIVE. As the warm, wet air from inside the cooling tower contacts the cooler, dryer air above the cooling tower, the water vapor which cannot be held by the cooler air forms a visible cloud. This is because the colder the air is, the lower its ability to hold water. The released cloud of vapor will only be visible until it is dispersed and absorbed by the air.

2.5 Reactor Scram

A reactor “scram” (or “trip”) is the rapid (two to four seconds) insertion of the control rods into the core to stop the fission chain reaction. Even though all of the fissioning in the core is not stopped, the chain reaction is broken down, which causes a significant decrease in reactor power in just a few seconds. When the reactor is shut down (all rods inserted), the amount of heat being generated due to the fissions which are not stopped and the decay heat is much less than that which can be removed by the plant systems. Therefore, the fuel can be protected from an over-temperature condition.

In a boiling water reactor, the control rods are inserted from the bottom of the reactor vessel into the core. In a pressurized water reactor, the control rods are inserted (dropped) from the top of the reactor vessel into the core.

3

Fission

Every fission releases a tiny amount of heat. Trillions of fissions per second are necessary to produce the high temperature, high pressure steam for the production of electricity. The rate at which the uranium atoms are fissioned determines the rate at which heat (and power) are produced.

Since neutrons are necessary to cause the fission event, and since each fission releases neutrons, there is the potential to set up a self-sustaining chain reaction. For this to occur, there must be sufficient material capable of fissioning, and the material must be arranged such that the neutrons will reach other fuel atoms before escaping.

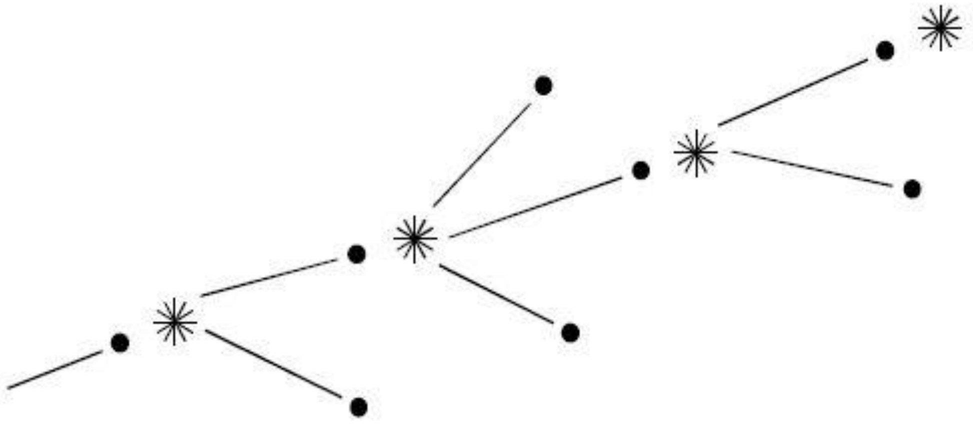
3.1 Neutron Life Cycle

U-235 does have a high probability of absorbing a neutron. However, the probability increases even more if the neutron is moving slower. Therefore, in the reactor, it is desired to slow the neutrons down and then let the U- 235 absorb them. This slowing down process is accomplished by the same water that is used to remove the heat from the fuel. Therefore, the water circulating through the reactor (called the reactor coolant system) has two important functions. First, the water carries the heat from the reactor core to produce the steam used in the turbine. This prevents the fuel from becoming too hot, which could lead to fuel damage. Second, the water is used to control the fission process by slowing the neutrons down and by acting as a reflector to bounce back any high energy neutrons that try to escape. This conserves the neutrons so that even more fissions may occur. The “slowing down” process is called “thermalization” or “moderation.”

3.2 Criticality

If the conditions in the core allow, the chain reaction will reach a state of being self-sustaining. At this point, for every fission event that occurs, a second event occurs. This point of equilibrium is known as “criticality.” This just means that the number of neutrons produced by the fission events is equal to the number of neutrons that cause fission plus the number of neutrons that do not cause fission. Therefore, the reactor has reached a state of equilibrium. That is, the amount of power, and therefore heat, being produced is constant with time.

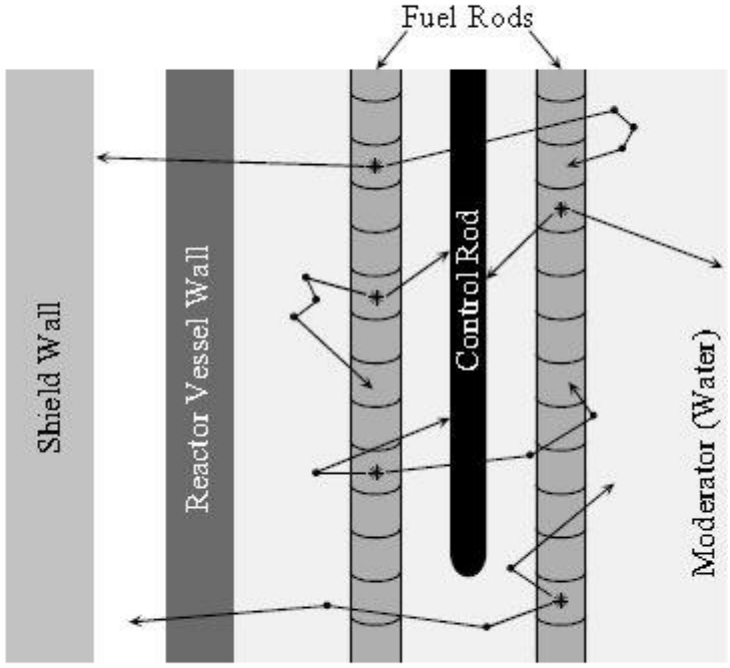
Steady Rate of Power Generation



3.3 Neutrons that Do Not Cause Fission

Because all neutrons that are produced by the fission process do not end up causing subsequent fissions, enough neutrons must be produced to overcome the losses and to maintain the “critical” balance needed for a constant power level. The neutrons that are lost to the fission process either “leak out” of the fuel area (escape) or are absorbed by materials that do not fission. The materials that absorbed neutrons and do not fission are called “neutron poisons.”

Control Rods



Some of the neutrons released by fission will “leak” out of the reactor core area to be absorbed by the dense concrete shielding around the reactor vessel. All the neutrons that remain in the core area will be absorbed by the materials from which the various core components are constructed (U-235, U-238, steel, control rods, etc.).

3.4 Neutron Poisons

Any material that absorbs neutrons and does not fission is a “poison” to the fission process. The reactor vessel, structural components, and the reactor coolant all absorb neutrons. Several fission products (the elements that are formed from the splitting of the large U-235 nucleus) absorb neutrons (for example, xenon-135 and samarium-149). Uranium-238 will sometimes fission after absorbing a fast neutron. When it does not, it acts as a neutron poison. These neutron poisons are uncontrollable by the operator.

Reactor operators can manipulate the total amount of poisons in the reactor by adjusting the position of the control rods. Also, in a pressurized water reactor, the operator can adjust the amount of boron that is dissolved in the reactor coolant. The control rods and the soluble boron are called controllable neutron poisons.

1. Control rods are concentrated neutron absorbers (poisons) which can be moved into or out of the core to change the rate of fissioning in the reactor. Rod insertion adds neutron poisons to the core area, which makes fewer neutrons available to cause fission. This causes the fission rate to decrease, which results in a reduction in heat production and power. Pulling the control rods out of the core removes poisons from the core area allowing more neutrons to cause fissions and increasing reactor power and heat production.
2. The use of water as a neutron moderator helps produce a steady rate of reactor power by slowing the neutrons down that will be absorbed by the U-235 and by reflecting many of the neutrons that try to leak out of the reactor back into the core. The water can also remove neutrons from the fission chain. First, water has a limited capacity to absorb neutrons, thus acting as a neutron poison. But an even greater effect is the changing of the moderator temperature. If the reactor coolant temperature increases, the water becomes less dense. This means that the water becomes less effective at slowing the neutrons down and more will leak out of the core. Conversely, if the coolant temperature decreases, the water becomes a better moderator, and the number of neutrons available for fission will increase. If the only action to occur was a change in the temperature of the moderator, power would also change. This moderator temperature effect is a major factor in the control of the fission process and heat production of the reactor.

Since the moderator density plays such an important part in the control of the fission rate and the power production in the reactor, the formation of steam bubbles, or “voids,” must also be considered. A steam bubble is an area of very low density water.

In a boiling water reactor, the conversion of water into steam produces a dramatic change in the density of the water from the bottom to the top of the core. Water at the bottom of the core is far more dense than the watersteam mixture at the top. Therefore, neutron moderation is much better towards the bottom of the core. In a pressurized water reactor, the high pressure of the reactor coolant will prevent all but just a very minimum amount of steam bubbles from being formed. Therefore, the effects of voids on the power production in a pressurized water reactor are very minimal.

Because of the unique properties of the nuclear fuel, there are some byproducts of the heat producing process. “Fission products” are the smaller atoms produced when the larger uranium atoms are split during the fission process. Some of these fission products are neutron poisons, and therefore, must be compensated for by removing some of the controllable poisons (such as the control rods for boiling water reactors or control rods or boron for pressurized water reactors) as they are produced. The fission products are usually very highly radioactive. They emit a large amount of radiation, and therefore, must be contained within the plant. A system of “barriers” has been developed to prevent these atoms from escaping into the environment. These barriers are the fuel pellet and cladding, the reactor coolant system pressure boundary, and the containment.

Another problem with the fission products is the generation of decay heat. When an atom decays, it gives off energy or particles to become more stable. The energy or particles then interact with the surroundings to generate heat. This heat will be collected inside the fuel pellet area. If this heat (decay heat) is not removed, it could possibly cause damage to the fuel pellets or other parts of the “barrier” system. Therefore, we have systems designed to remove this heat after the plant is shut down (residual heat removal system, for example).

3.5 Fuel Rod and Coolant Temperatures

When a reactor is operating at full power, the approximate temperatures of the fuel centerline, pellet surface, cladding surface, and coolant are shown above. The average fuel pellet temperature under normal operating conditions is about 1400 degrees F. The melting temperature of the ceramic fuel is approximately 5200 degrees F. The fuel cladding can be damaged by temperatures in excess of 1800 degrees F. Significant fuel damage can be expected at sustained temperatures above 2200 degrees F. The plant systems, both normal operating and emergency, must be designed to maintain the fuel temperature low enough to prevent fuel damage. For example, if conditions approach an operating limit, the reactor protection system will rapidly insert the control rods to shut down the fission chain, which removes a major heat production source. This rapid insertion of rods into the core is called a reactor trip or scram.

4

Reactor Loading Procedure

1. A new loading for the bulk sheilding reactor will be undertaken only when a reactor supervisor is present. However, a single opperator may reload a known fuel-element configuration.
2. Perform chamber tests, Appendix F.
3. Whenever a new loading is required by an experimental arrangement, the reactor frame (unloaded) will be positioned.
4. Then as fuel elements are added the approach to criticality will be carefully determined by the method of subcritical multiplication.

   The excess reactivity will be limited to that required by the operating conditions of the experiment and will be less than 2.5% unless specific authorization is requested from the Atomic Energy Commission.

5. Whenever experimental apparatus is placed against the reactor (and not permanently attached) in such a manner as to significantly reduce the reactivity , the fuel added to maintain criticality will be unloaded before the reactor is left unattended.
6. Before the initial installation of experiments, a review will be made by the Experiment Review Committee. This committee is composed of the reactor supervisors. If the review is favorable, at least two members of the above committee shall sign the reactor log book at the description of the experiment.
7. If questions arise which are not resolved by this group, they shall be referred to the Neutron Physics Division Reactor Operations Review Committee.

5

Reactor 0peration Procedure

Note *No reactor operations will be carried out under the duress of a time limit.*

1. Startup will be carried out by one of the reactor operators or supervisors. The detailed procedure to be followed is described in Appendix C.
2. Check all items on the abbreviated check list is posted on the reactor console during the startup operation.
3. When operation at a steady power level has been achieved, announce the nominal power level over the public address (PA) system.
4. Connect the fission chamber monitoring the reactor flux with the PA system and the operator may work elsewhere within the Bulk Shielding Facility.

6

Reactor Operation Checklist

To take the reactor critical, the operator should follow the procedure outlined below.

Note *If any instrument or circuit is not functioning in accordance with this procedure the reactor is not to be taken critical.*

1. Calibrate the log N meter as follows.
    a. Turn selector switch from operate to ground position.

       Log N meter should read 0.001 (extreme left black mark on meter dial).

       To change meter position, turn adjustment marked ground set.
    b. Turn selector switch to low calibration.

       The meter pointer should now be in line with the low calibration red mark on the left side of the meter face.

       To correct meter pointer position, turn adjustment worked calibrate.
    c. Turn selector switch to high calibration.

    The meter pointer should now be aligned with a high calibration red mark on the right side of meter face. To correct meter pointer position, turn adjustment control marked gain.

    d. If adjustment is needed in any position, the whole procedure should be repeated until the meter shows the correct readings.
    e. Return selector switch to operate position.

2. Turn on power switches number two and number four at the left rear panel of the reactor.
3. Clear the annunciator board by pushing acknowledge and reset buttons.
4. Insert key (furnished only to approve personnel) in lock and turn on power.
5. Check to see that the positive voltages of the ionization chamber power supplies are within the operating range and that magnet supplies indicate current flow.
6. Turn on instrument recorders.
7. calibrate fission-chamber log count-rate meter.
8. Visually check the neutron source location.
9. Test scram circuits.
10. Set demand helipot on servo amplifier for desired scale reading on the demand meter.
11. Set servo micro ammeter to the most sensitive range.
12. Clear annunciator board. The board must either be clearer or the exact cause of any abnormality known.
13. Take the reactor critical.
14. Write the data, time, experiment number, run number, and scale factor on the log charts.
15. Fill out reactor log sheets at hourly intervals.

7

Procedure for Moving Bridge

1. The reactor bridge will be moved to a new location only under the direction of one of the reactor supervisors.
2. It may be repositioned in a previously used configuration by reactor operator
3. The key to the reactor bridge will be handled in the same manner as the reactor controls key (see appendix C.).
4. The reactor will be partially unloaded whenever it is moved into a new position which changes the reflector of adjacent to the reactor or whenever there is a possibility of interaction with experiments being conducted with the pool critical assembly (PCA).
   The possibility of such interaction is minimized by permanent mechanical stops which limit the motion of the reactor bridge.

8

Emergency Operating Procedure

This procedure should be followed for either a personnel or an automatic safety device scram.

1. Whenever the operator or another person is in doubt about the safety of a reactor operation should scram the reactor.

   Scram buttons are located in the positions listed in appendix D.

   A list of typical conditions that might require a scram is given in appendix E.

   Note *Restarting the reactor after emergency shutdown may take several weeks and costs many millions of dollars in lost production and replacement of parts damaged during the shutdown procedure.*

   a. Press the large red button labelled IMMEDIATE SHUTDOWN COMMENCE on the Emergency Shutdown panel, which initiates an emergency shutdown.

   b. Confirm by pressing the CONFIRM button on the Emergency Confirm panel. (This is to prevent accidental shutdown of the plant.)

      The CONFIRM button is normally green, but glows red after the IMMEDIATE SHUTDOWN COMMENCE button has been pressed to remind the operator.

Emergency shutdown causes explosive bolts to blow that drive control rods into the reactor completely stopping the nuclear reaction.

2. After any scram for emergency reasons, the operator should not start up again unless the cause of the conditions leading to the scram or completely understood.
3. Emergency operating procedures for this facility for emergencies involving high radiation levels are set forth in the emergency procedure for building 5, area 2.

9

New Procedure Requirements

9.1 Operation Procedure Requirements

Operational procedures should be prepared for all activities performed by the operating personnel for normal operation of the reactor and for anticipated operational occurrence (e.g. electrical power failure).

In practice, many of the commissioning procedures become operational procedures (e.g. fuel loading, startup, calibration of reactivity control mechanisms, thermal power level determination, etc.).

Normally, procedures are performed one at a time. If not, the potential safety implications of the simultaneous performance of several procedures shall be included in the procedure by specifying special precautions.

For operations which are performed frequently, procedures should be reviewed periodically and whenever there is a change made in the configuration of the applicable reactor system or components. For operations which are performed infrequently, existing procedures should be reviewed before use and revisions made, as appropriate.

Operational procedures should specify the required actions in the event of unexpected results in the performance of the procedure.

Operational procedures should include the requirements of work permits, if necessary.

9.2 Maintenance Procedure Requirements

In the preparation of maintenance procedures, particular attention shall be given to the impact of the procedure on safety systems and on reactor operation. Some procedures may be performed during reactor operation with no impact on reactor safety. Others may require shutdown of the reactor. The maintenance process shall not reduce reactor safety below the operational limits and conditions.

A system of work permits shall be used for maintenance, including appropriate check-offs, during and after the conduct of the work in accordance with the QA program. This is to ensure that all work is conducted with the knowledge and permission of the person in operational control of the reactor and that both the safety of the reactor and the safety of the personnel doing the work have been considered. Therefore, maintenance procedures may incorporate the requirement of this work permit as a prerequisite to performing the maintenance.

Maintenance procedures should clearly delineate any changes from the normal reactor operating configuration (e.g. valve lineups) and have provisions for restoration of changes to the normal configuration after maintenance (e.g. procedures for taking mechanical and electrical equipment out of service and restoring it to service). Therefore, a general procedure shall be developed or special provisions shall be made in individual procedures to accomplish configuration control.

Reference to updated drawings, manufacturer's manuals and manufacturer's recommendations should be included in the procedures.

9.3 Physical Security Procedures

Physical security procedures should be developed after evaluation and analysis of all aspects of the security situation. The instructions in security procedures should be brief and give details of the essential steps for coping with the security problem.

If the services of off-site organizations such as police and army are required by security procedures, formal letters of agreement should be maintained and periodically updated.

Experts should be consulted in preparing security procedures (e.g. security specialists, specialized personnel from the police, army, etc.).

Index

No index entries found.