

USNRC  
NUCLEAR REACTOR CONCEPTS COURSE

40

Schedule

Day 1

**Registration and Opening Remarks**

**Nuclear Power and Electrical Generation**

A discussion of electrical power generation systems, including the Boiling Water Reactor (BWR) and the Pressurized Water Reactor (PWR).

**The Fission Process and Heat Generation**

A general discussion of how the heat is generated in a reactor and how the heat is controlled. An explanation of the unique properties and byproducts of the nuclear chain reaction is included.

**Lunch**

**BWR Systems**

A discussion of the major systems, structures, and components of Boiling Water Reactors.

**PWR Systems**

A discussion of the major systems, structures, and components of Pressurized Water Reactors.

A-40

## Schedule

### Day 2

#### **Radiation and its Biological Effects**

The basic language of the radiation field, including the types and properties of naturally occurring and man-made radiations. Special emphasis is placed on radiation sources and protective measures involved with nuclear plant operation. The risks associated with exposure to radiation are discussed and methods utilized for the protection of radiation workers and the general public are reviewed.

#### **Radioactive Waste**

Radioactive waste sources, processing operations, and disposal options and issues are reviewed.

#### **Nuclear Materials Transportation**

Issues dealing with the handling and transporting of radioactive materials are reviewed.

#### **Lunch**

#### **Refueling Operations**

A brief discussion about the general operations that occur during a refueling outage, including a film that shows most of these operations taking place.

#### **Reactor Emergencies**

A discussion of the types of emergencies which could occur at BWR/PWR facilities and the systems, structures, and components designed to prevent or mitigate the consequences of reactor accidents. Established Emergency Action Levels will be reviewed.

#### **Chernobyl**

A film discussing the Chernobyl accident will be shown with a discussion of the accident after the completion of the film.

#### **Decommissioning**

A discussion of plant decommissioning will be held, time permitting.

### **Closing Remarks**

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UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
TECHNICAL TRAINING CENTER



REACTOR CONCEPTS MANUAL



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## Course Information

### COURSE RELATED ITEMS

1. Classroom presentations are scheduled to start at 8:00 a.m. and end at 4:00 p.m. A break for lunch will begin between 11:30 a.m. – 12:00 p.m. at the discretion of the instructor. Students will be allowed one hour for lunch to allow time to eat and catch up on office matters.
2. All course related materials (pencil, paper, manuals, notebooks, and markers) are provided. If there is a need for additional material or administrative service, please coordinate with the Course Instructor.
3. Student registration for all TTC courses is accomplished through Training Coordinators. The TTC staff does not register students directly.

## **COURSE OBJECTIVES**

### **(R-100)**

The course provides a basic introduction to the following concepts: nuclear power and electrical generation; the fission process and heat generation; boiling water reactor systems overview; pressurized water reactor systems overview; radiation and biological effects; radioactive waste; nuclear materials transportation; refueling operations; and emergency action levels.

This course is supplemental training for the NRC staff and is provided in support of the NRC Orientation Program. It is widely attended by nontechnical personnel and others with a need to obtain the nuclear power overview provided by the course.

## Student Information Sheet

PLEASE PRINT THE FOLLOWING INFORMATION:

Course Title: \_\_\_\_\_

Course Dates: \_\_\_\_\_

Name: \_\_\_\_\_  
(How you want it to appear on Training Certificate)

Social Security No: \_\_\_\_ / \_\_\_\_ / \_\_\_\_ Job Title: \_\_\_\_\_

Phone No: \_\_\_\_\_ Mailing Address: \_\_\_\_\_

\_\_\_\_\_  
(No P.O. Boxes please)

Motel where you are staying: \_\_\_\_\_ Room No: \_\_\_\_\_

Name and number of person to call in an emergency:

\_\_\_\_\_  
\_\_\_\_\_

Estimated Travel Cost (including transportation costs): \_\_\_\_\_

Name of Immediate Supervisor: \_\_\_\_\_

Name of Division Director: \_\_\_\_\_ Name of Division: \_\_\_\_\_

Please provide the following background information: (Please circle one)

1. Highest Level of Education:

Doctorate      Masters      Bachelors      Associate      Other

2. Subject Matter Specialty:

Engineering      Physical Science      Math or Statistics      Other Science      Other

3. Years of Nuclear Experience:      >9      7-9      4-6      1-3      <1

4. Type of Nuclear Experience:

Commercial BWR      RO/SRO      Navy      Test Reactor      Other  
Commercial PWR

5. Years with NRC:      >9      7-9      4-6      1-3      <1

6. Previous TTC sponsored training attended: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

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## Course Outline for R-100

Day	Title	Chapter
1	Course Introduction	
	Nuclear Power for Electrical Generation	1
	Fission Process and Heat Production	2
	Boiling Water Reactor Systems	3
	Pressurized Water Reactor Systems	4
2	Radiation Terminology	5
	Natural and Man-Made Radiation Sources	7
	Radiation Sources at Nuclear Plants	8
	Dose Standards and Methods for Protection Against Radiation and Contamination	9
	Biological Effects of Radiation	6
	Radioactive Waste Management	10
	Transportation of Radioactive Material	11
	Refueling Operations	12
	Emergency Action Levels	13
	Chernobyl Accident	15

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# TTC 100 LEVEL COURSE EVALUATION

**Course Title/Name:** \_\_\_\_\_

**Location:** \_\_\_\_\_

**Course Dates:** \_\_\_\_\_

## Instructions

In order to maintain and improve the quality and applicability of TTC courses it is necessary to obtain feedback from attending students. Please rate the following subject areas. Amplifying comments are desired but not required. Please place your amplifying comments in the section for written comments. Please print your name at the bottom of this form to allow for follow-up and amplification of significant issues or suggestions.

	Strongly Disagree	Disagree	Agree	Strongly Agree
1. Stated course objectives were met				
2. Learning objectives were helpful in identifying important lecture concepts.				
3. Classroom presentations adequately covered the learning objectives				
4. The course manual adequately covered course topics.				
5. The course manual will be useful as a future reference.				
6. Visual aids reinforced the presentation of course materials.				
7. Completion of this course will assist me in my regulatory activities.				

	Unsatisfactory	Marginal	Satisfactory	Good	Excellent
8. Overall Course Rating					

**Name:** \_\_\_\_\_

(Note: Additional questions on back of form)



9. What did you like best or find most helpful about the course?

10. What did you like least about the course?

11. What subjects might be added or expanded?

12. What subjects might be deleted or discussed in less detail?

13. How will this course aid you in your ability to do your job as a regulator?

14. What could be done to make this course more useful in aiding you in your ability to do carry out your regulatory activities?

15. Additional comments:


 Manually Operated Valve

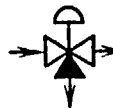
 Air Operated Valve

 Motor Operated Valve


 Solenoid Operated Valve

 Check Valve

 Relief Valve

 Three-Way Valve  
(Lower port shown closed)

 Butterfly (Damper) Valve

 Needle (Throttle) Valve

 Diaphragm Valve

 Valve Normally Closed

 Valve Normally Open

 Centrifugal Pump

 Positive Displacement Pump

 Pressure Breakdown Orifice

 Venturi Nozzle

 Cooler or Heat Exchanger

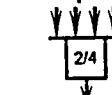
 Temperature Transmitter

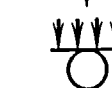
 Pressure Transmitter

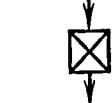
 Level Transmitter

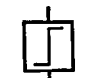
 Flow Transmitter

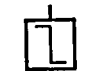
 Meter Gage

 Logic Symbol (AND box)  
2 or 4 available inputs must be present to produce an output

 Logic Symbol (OR box)  
Any one of several available inputs will produce an output

 Logic Symbol (NOT box)  
Input present produces no output, no input produces an output

 Bistable  
(Trips on increasing input signal)

 Bistable  
(Trips on decreasing input signal)

 Summing Unit  
(Algebraically adds all inputs)

 Isolation Amplifier (I/I amplifier)

 Contact Pick-up Relay

 Contacts (normally open)

 Contacts (normally closed)

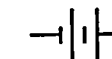
 Transformer

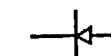
 Disconnect Switch

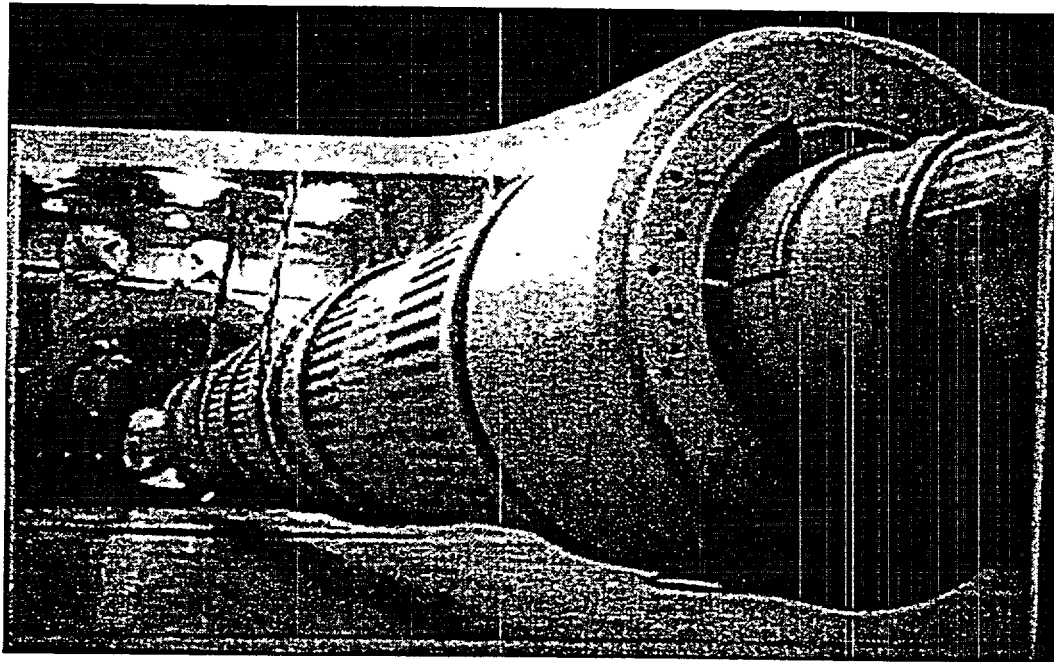
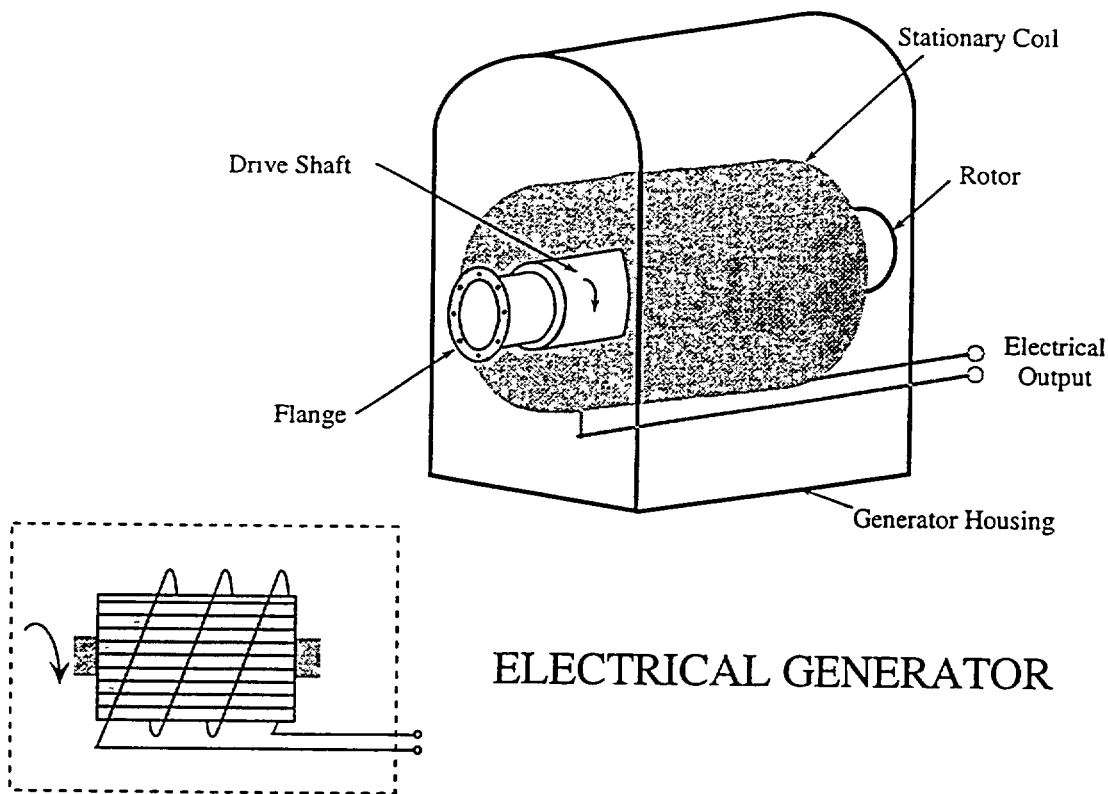
 Circuit Breaker (normally open)

 Circuit Breaker (normally closed)

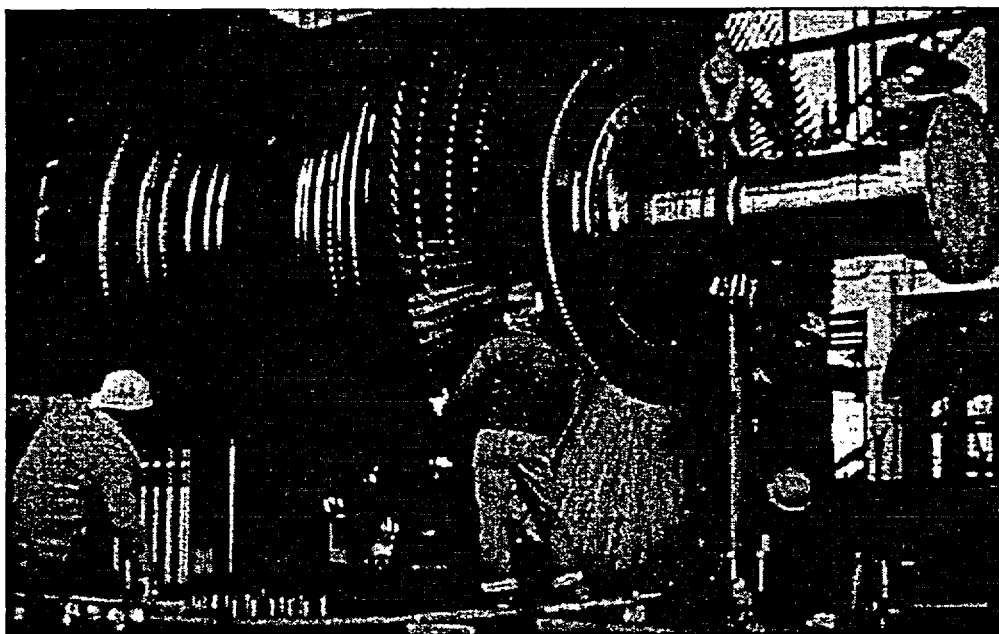
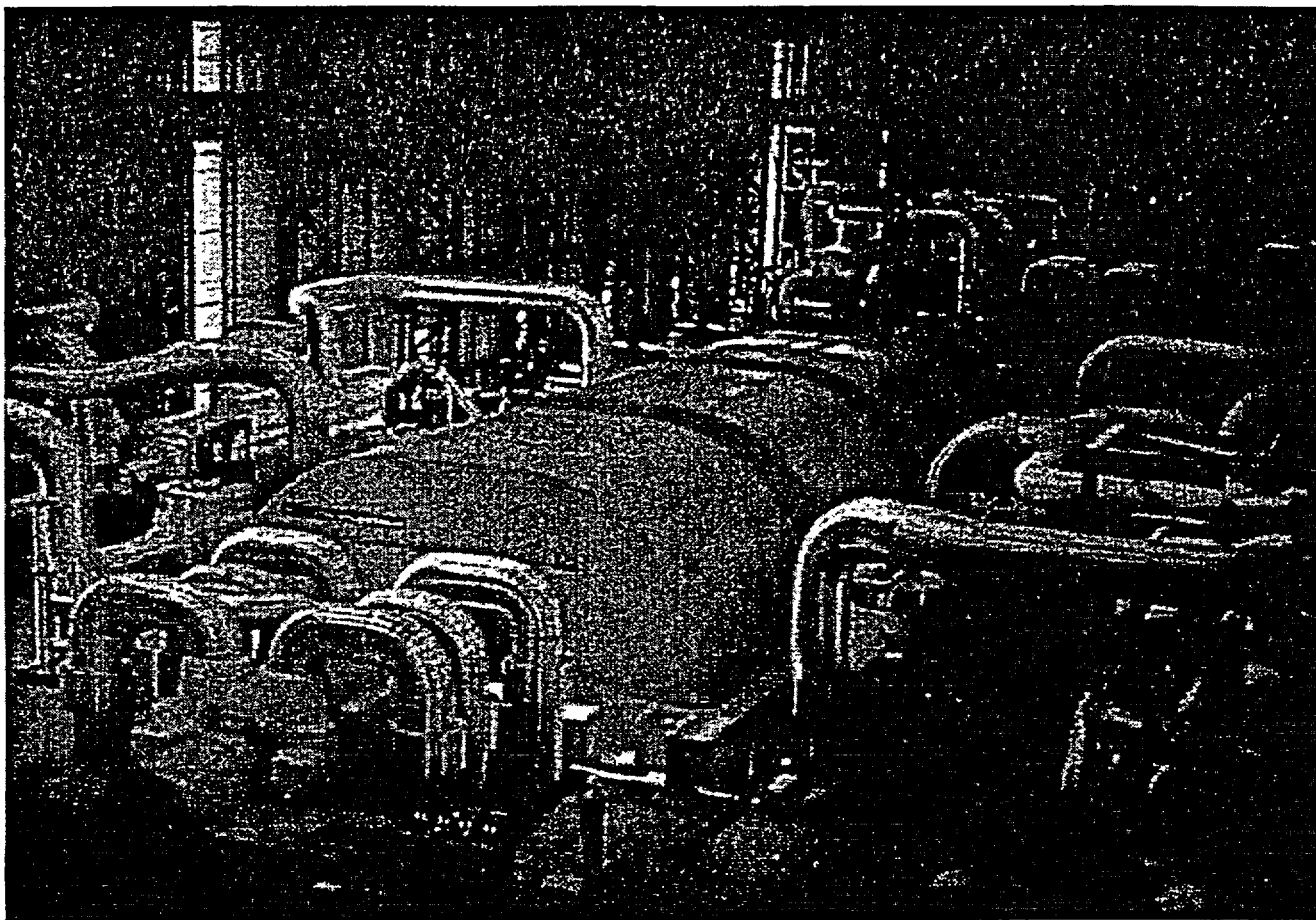
 Transfer Switch

 Battery

 Diode

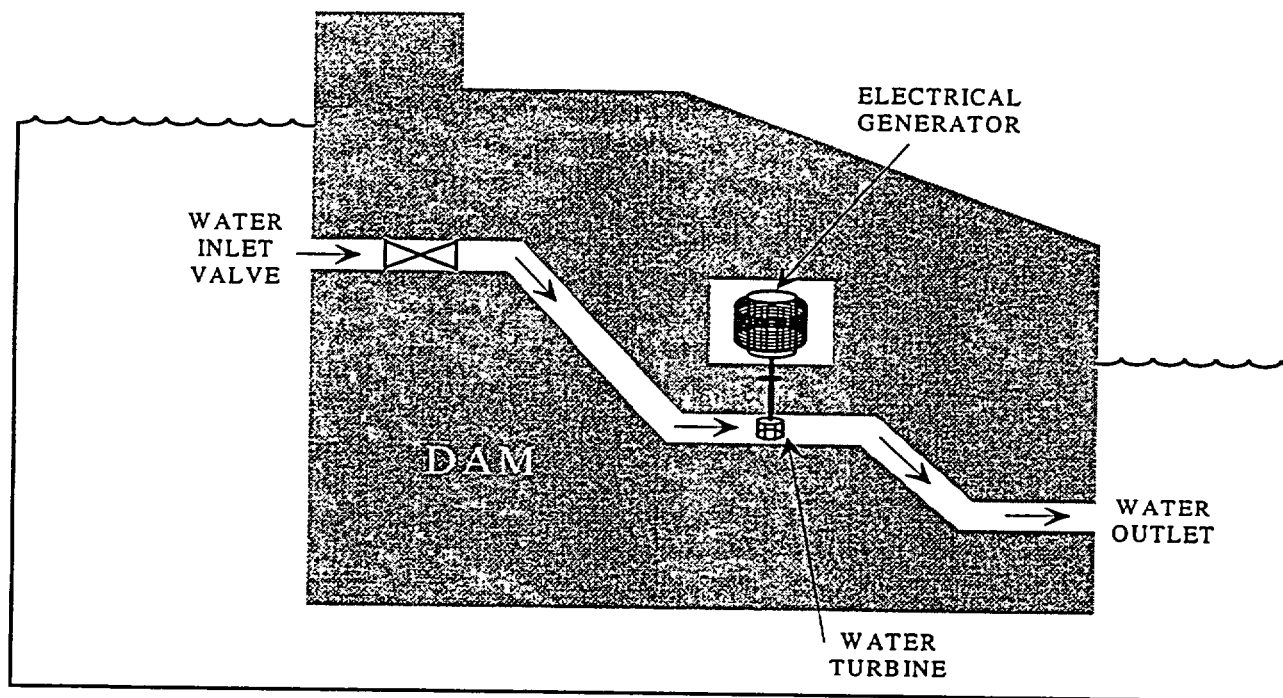


Of the several known methods to produce electricity, by far the most practical for large scale production and distribution involves the use of an "electrical generator." In an electrical generator, a magnet (rotor) revolves inside a coil of wire (stator), creating a flow of electrons inside the wire. This flow of electrons is called electricity. Some mechanical device (wind turbine, water turbine, steam turbine, diesel engine, etc.) must be available to provide the motive force for the rotor.

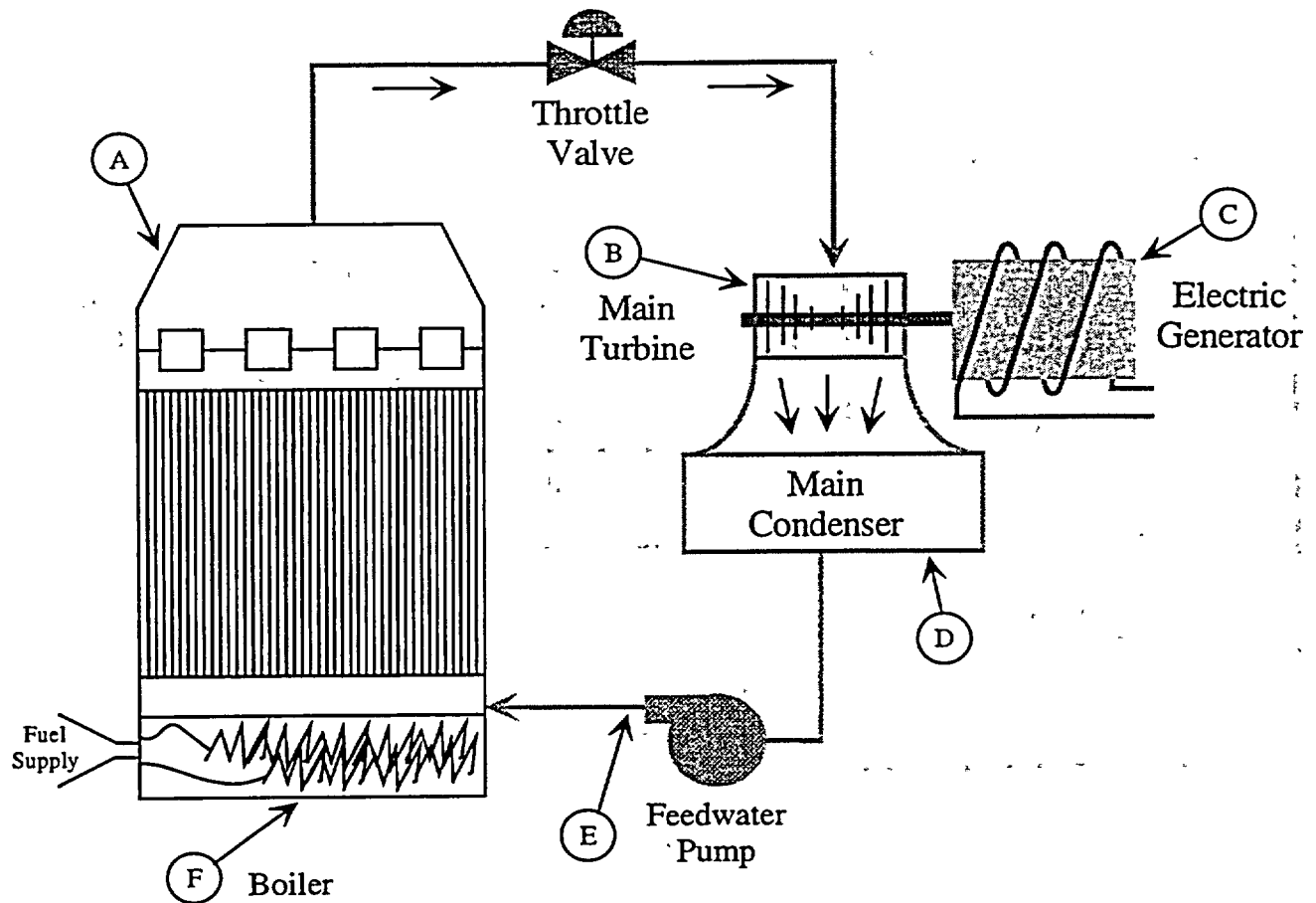


When a turbine is attached to the electrical generator, the kinetic energy (i.e., motion) of the wind, falling water, or steam pushes against the fan-type blades of the turbine, causing the turbine, and therefore, the attached rotor of the electrical generator, to spin and produce electricity.

# HYDROELECTRIC PLANT

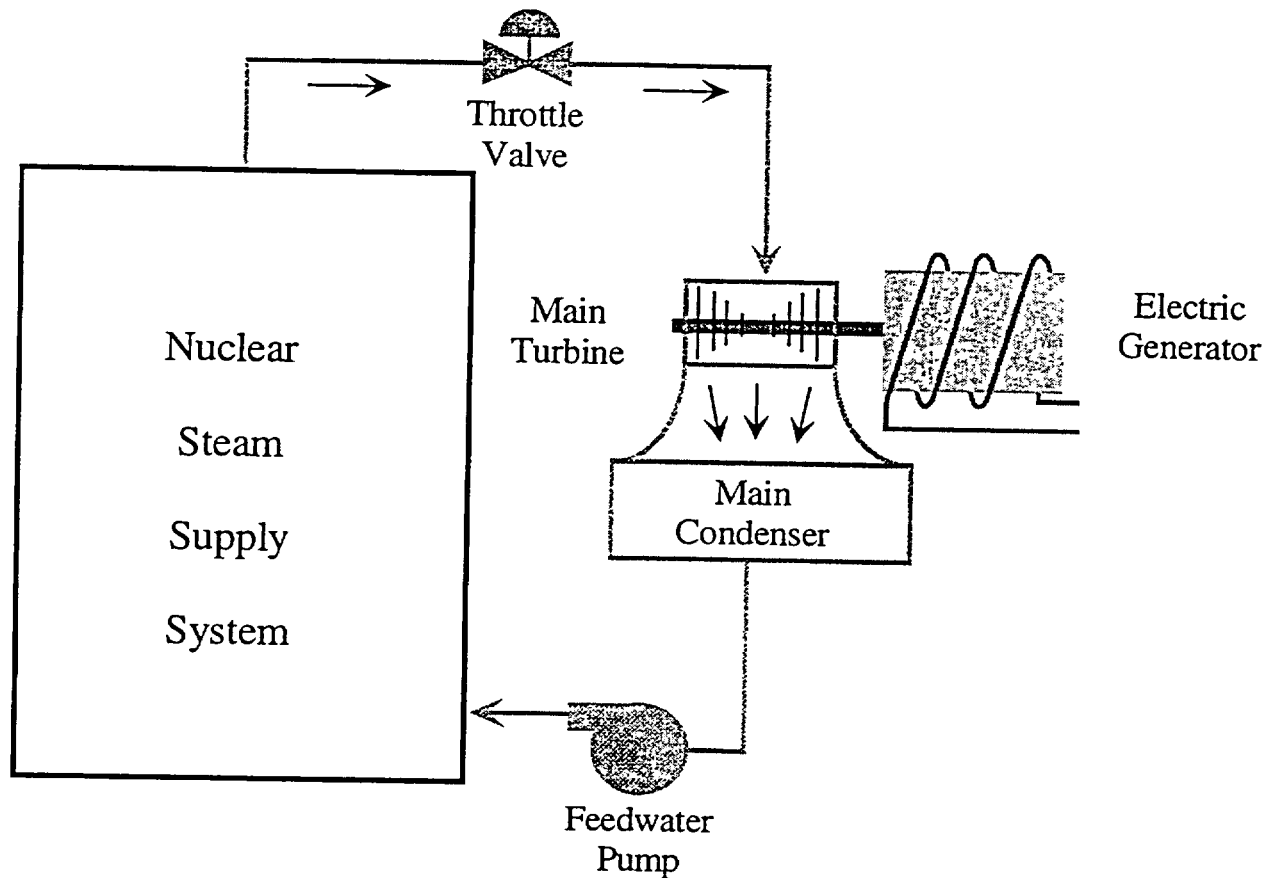


In a hydroelectric power plant, water, flowing from a higher level to a lower level, travels through the metal blades of a water turbine, causing the rotor of the electrical generator to spin and produce electricity.



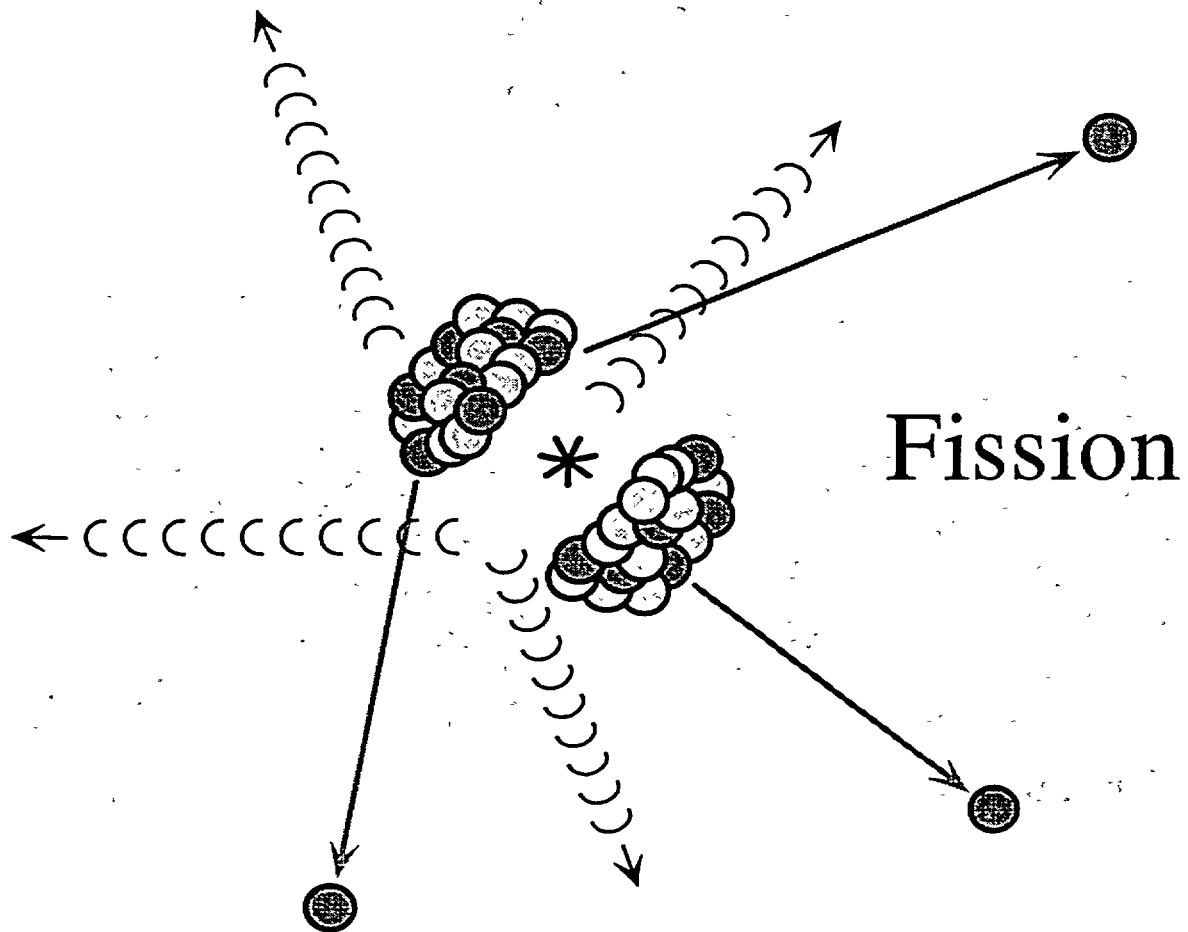
## FOSSIL FUEL STEAM PLANT

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, the steam 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.



## Nuclear Fuel Steam Plant

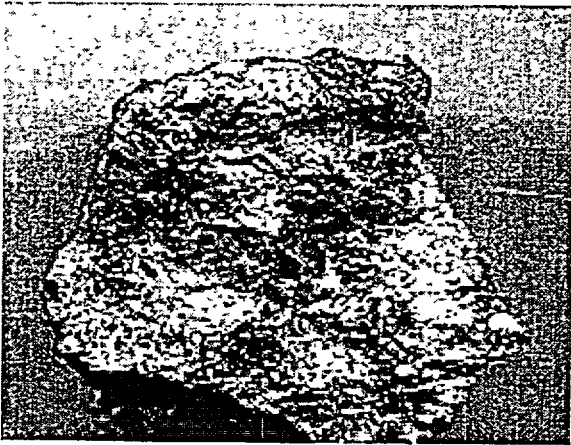
In a nuclear power plant, many of the components are similar to those in a fossil-fueled plant, except that the steam boiler is replaced by a Nuclear Steam Supply System (NSSS). The NSSS consists of a nuclear reactor and all of the components necessary to produce high pressure steam, which will be used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



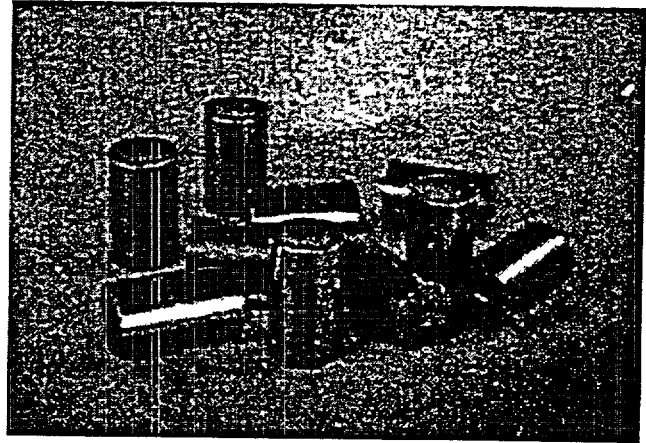
Like a fossil-fueled plant, a nuclear power plant boils water to produce electricity. Unlike a fossil-fueled plant, the nuclear plant's energy does not come from the combustion of fuel, but from the fission (splitting) of fuel atoms.



## ENRICHMENT (% U-235)

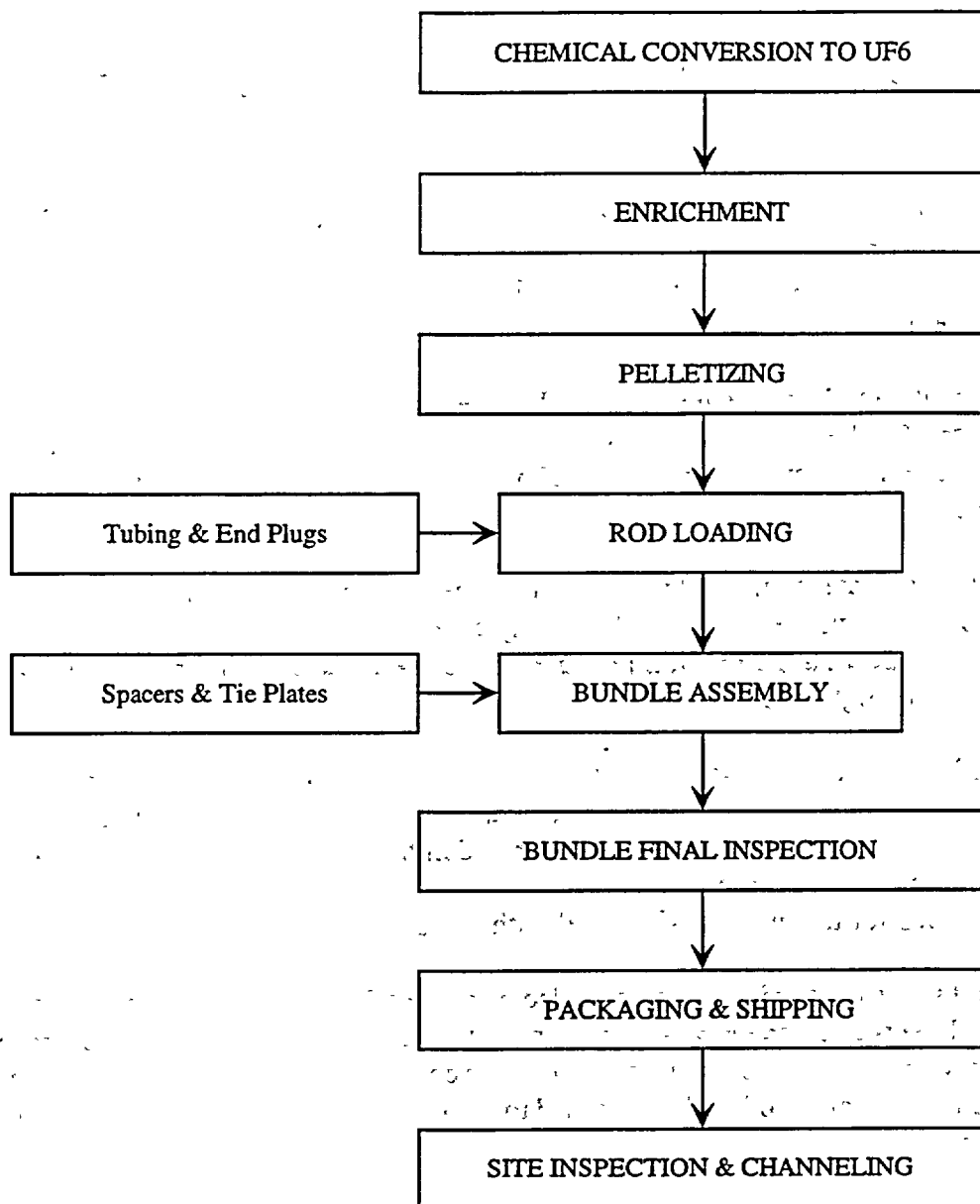


Uranium Ore (0.7%)



Fuel Pellet (3.5%)

The most common fuel for the electrical producing reactor plants in the United States is uranium. The uranium 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 to fission (split) than the much more abundant U-238 atoms. Therefore, the fuel fabrication process includes steps to increase the number of U-235 atoms in relation to the number of U-238 atoms (enrichment process).



Once the fuel has been enriched, it is fabricated into ceramic pellets. The pellets are stacked into 12-foot long, 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 installed and 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 plant for installation into the reactor vessel.

# REACTOR FUEL ASSEMBLIES

Both boiling water reactor and pressurized water reactor fuel assemblies consist of the same major components. These major components are the fuel rods, the spacer grids, and the upper and lower end fittings. The fuel assembly drawing on page 1-11 shows these major components (pressurized water reactor fuel assembly).

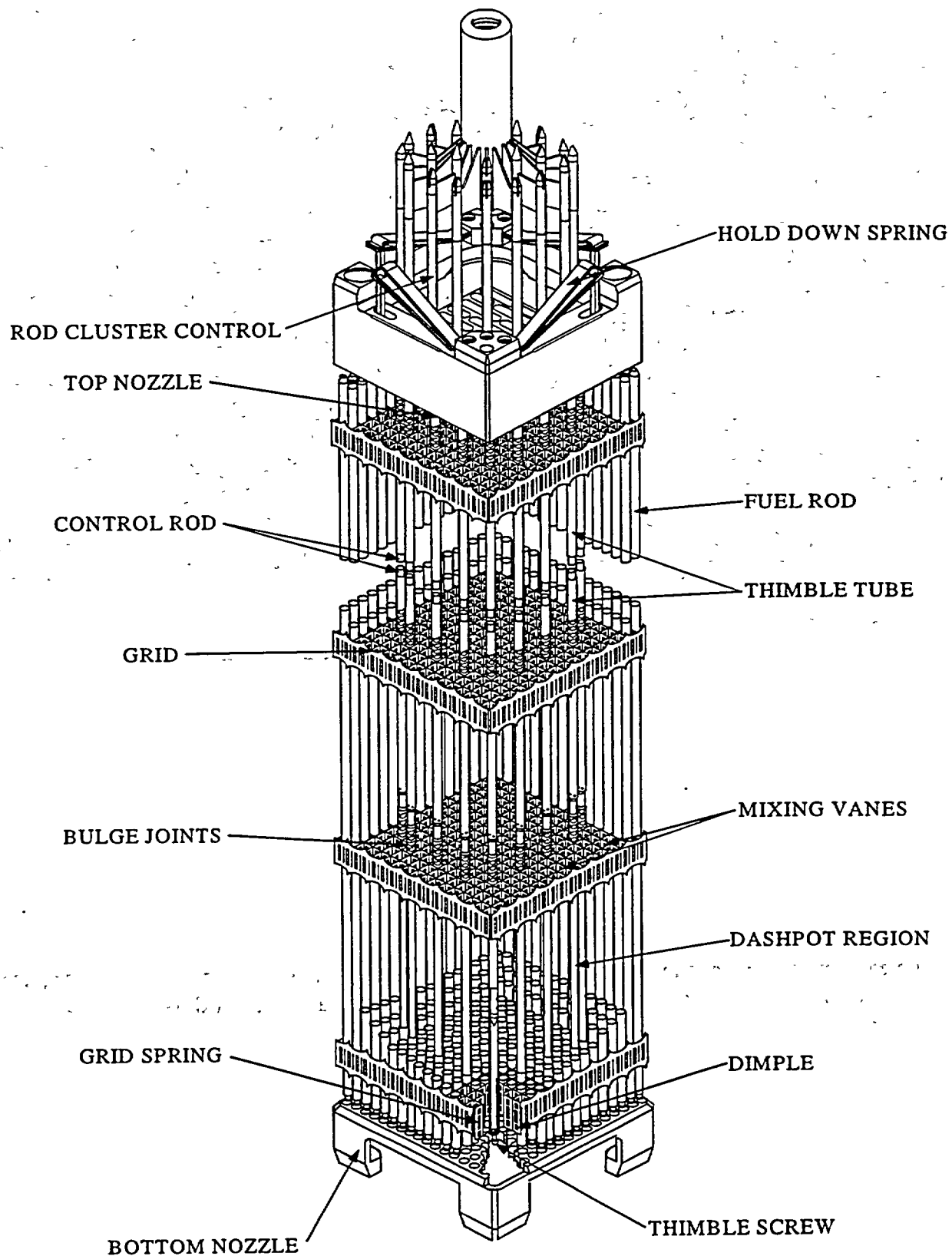
The fuel rods contain the ceramic fuel pellets. The fuel rods are approximately 12 feet long and contain a space at the top for the collection of any gases that are produced by the fission process. These rods are arranged in a square matrix ranging from 17 x 17 for pressurized water reactors to 8 x 8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

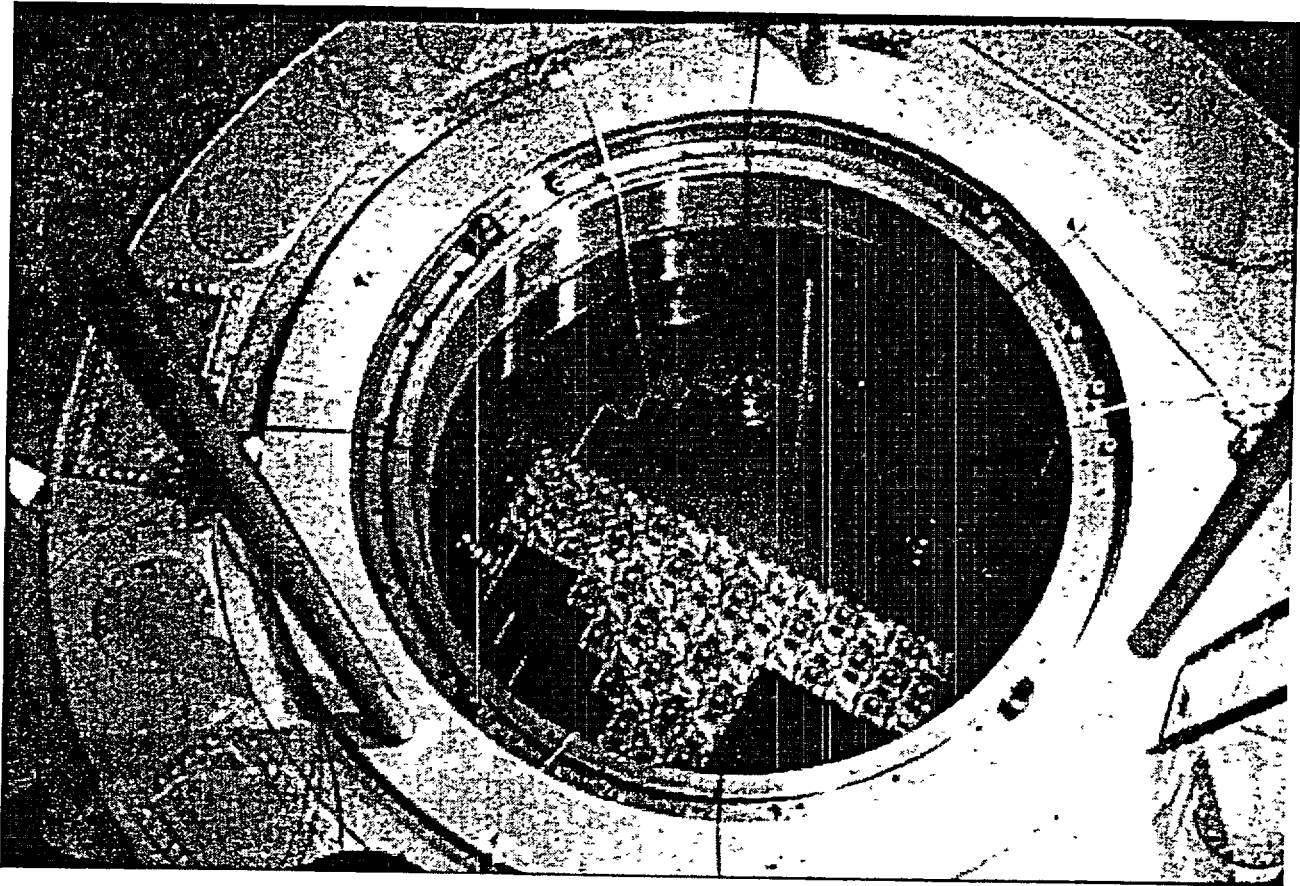
The spacer grids separate the individual rods with pieces of sprung metal. This provides the rigidity of the assemblies and allows the coolant to flow freely up through the assemblies and around the fuel rods. Some spacer grids may have flow mixing vanes that are used to promote mixing of the coolant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

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

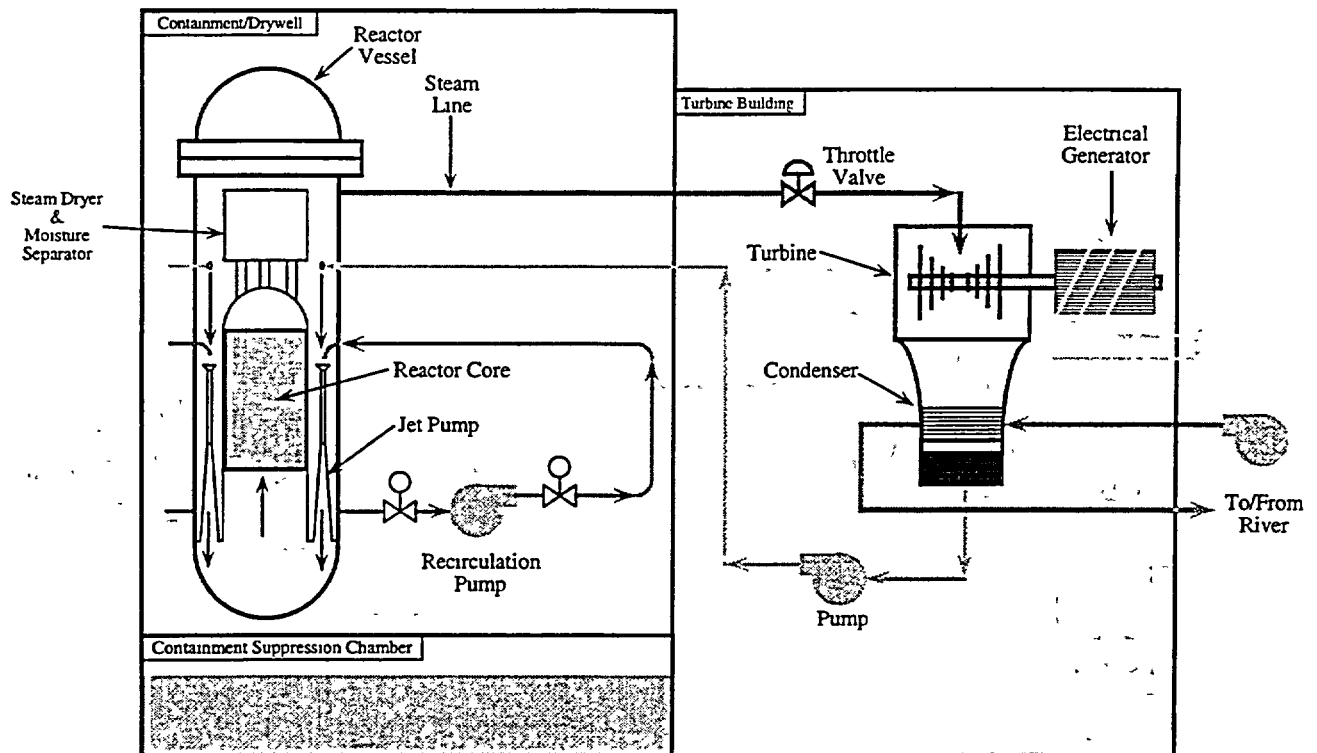
For pressurized water reactor fuel, there will also be guide tubes in which the control rods travel. The guide tubes will be welded to the spacer grids and attached to the upper and lower end fittings. The guide tubes provide a channel for the movement of the control rods and provide for support of the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

A brief description and a picture of boiling water reactor fuel can be found in Chapter 3 (pages 3-3 and 3-7).





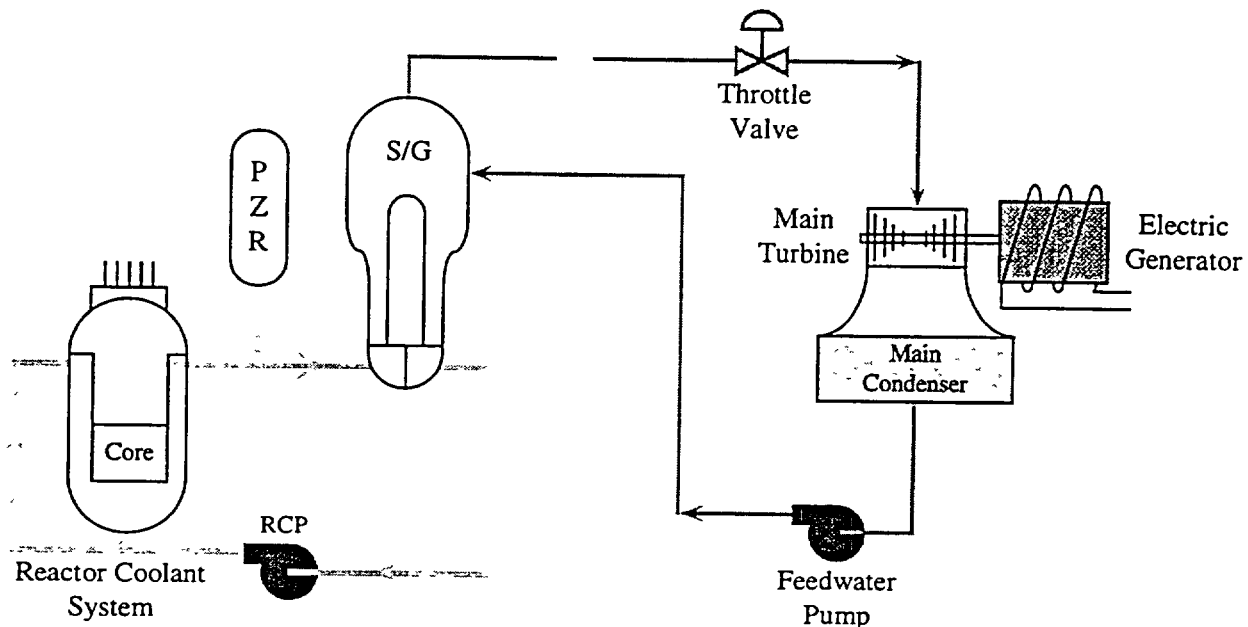
At the nuclear power plant, the fuel assemblies are inserted vertically into the reactor vessel (a large steel tank filled with water with a removable top). The fuel is placed in a precise grid pattern known as the "reactor core."



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), a steam/water mixture is produced when very pure water (reactor coolant) moves upward through the core (B) absorbing heat. The major difference in the operation of a boiling water reactor as compared to other nuclear systems is the steam void formation in the core. The steam/water mixture leaves the top of the core and enters two stages of moisture separation (C), where water droplets are removed before the steam is allowed to enter the steam line (D). The steam line, in turn, directs the steam to the main turbine (E), causing it to turn the turbine and the attached electrical generator (F). The unused steam is exhausted to the condenser (G) where it is condensed into water. The resulting water (condensate) is pumped out of the condenser with a series of pumps and back to the reactor vessel. The recirculation pumps (I) and the jet pumps (J) allow the operator to vary coolant flow through the core and to change reactor power.

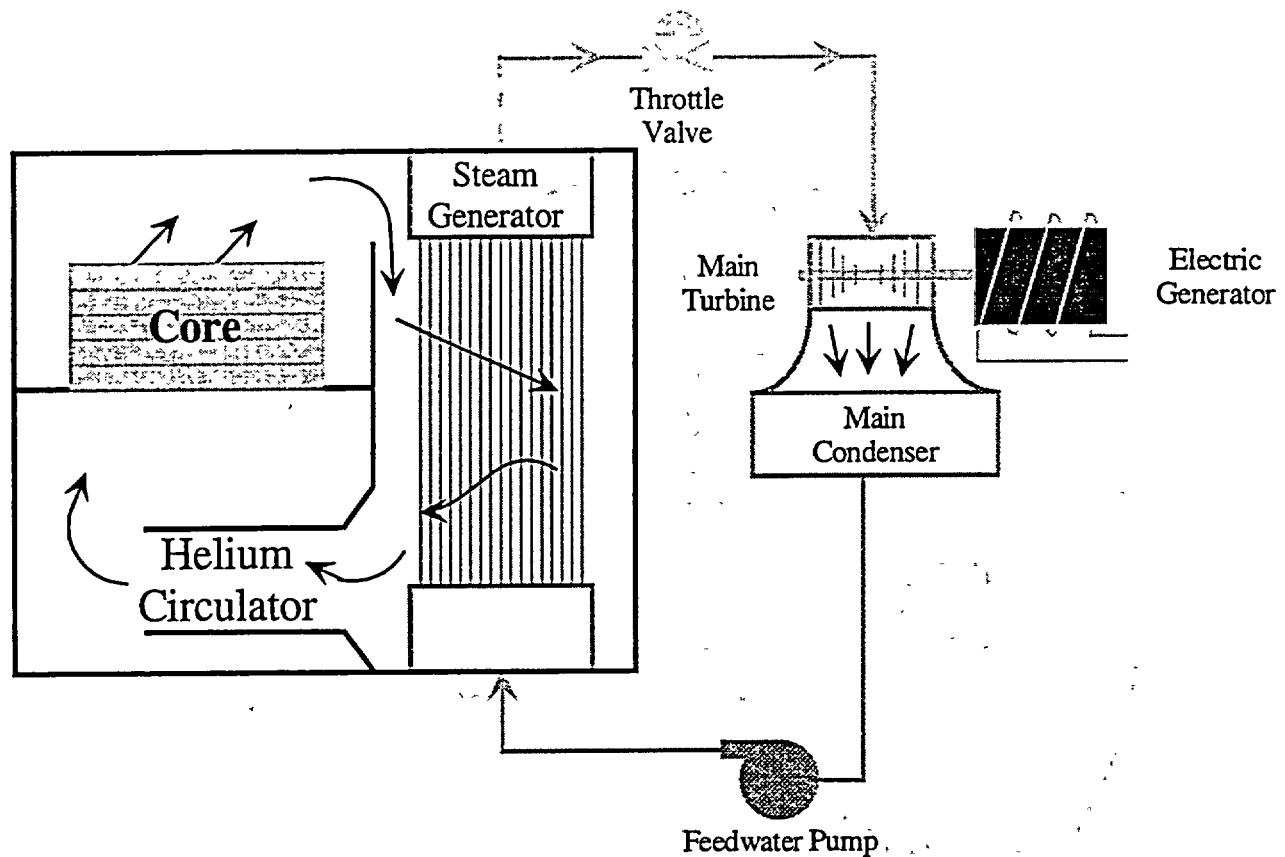
Boiling water reactors are manufactured in the United States by the General Electric Company, San Jose, California. Boiling water reactors comprise about one-third of the power reactors in the United States.

## Containment



The pressurized water reactor (PWR) differs from the boiling water reactor in that steam is produced in the steam generator (B) rather than in the reactor vessel (A). The pressurizer (C) 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 600°F. Pressurized water reactors make up about two-thirds of the power reactors in the United States.

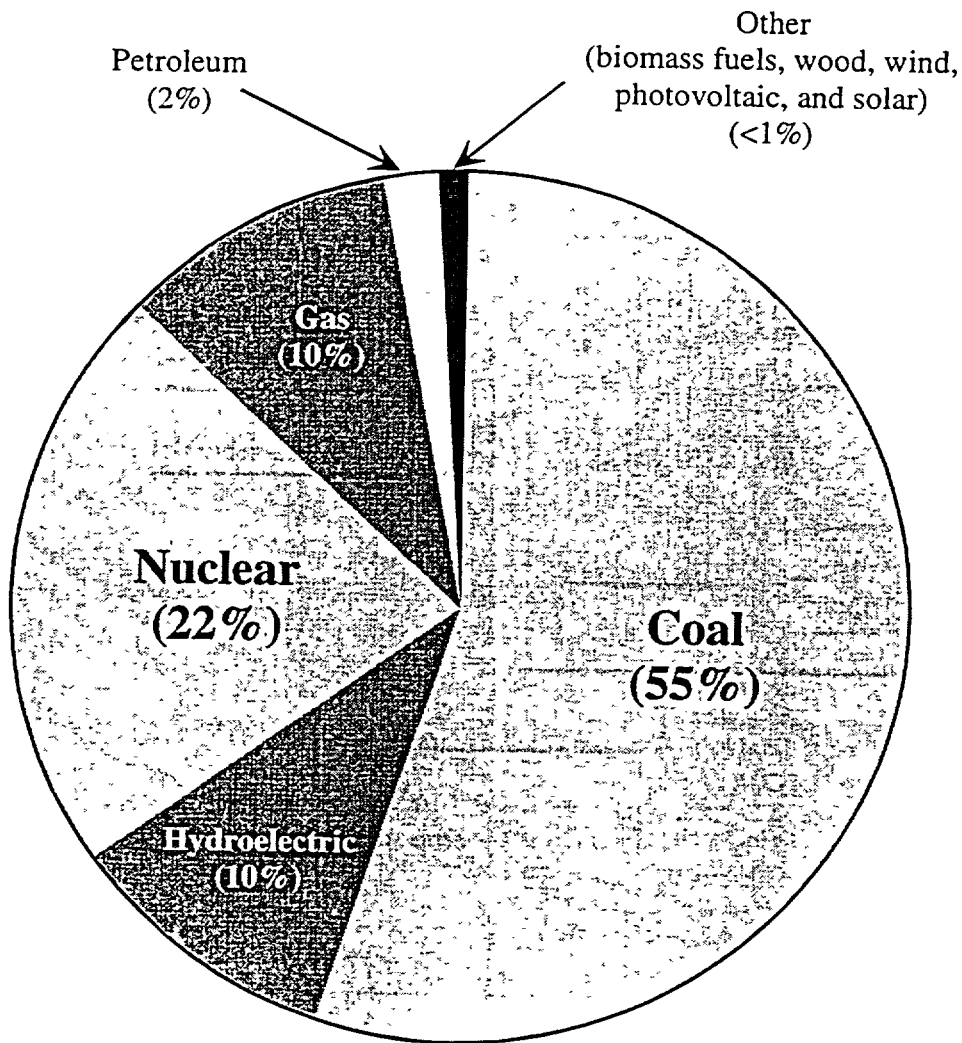
Pressurized water reactors were manufactured in the United States by Westinghouse Electric Corporation (Pittsburgh, Pennsylvania), Babcock and Wilcox Company (Lynchburg, Virginia), and the Combustion Engineering Company (Windsor, Connecticut).



## High Temperature Gas-Cooled Reactor (HTGR)

Another type of reactor uses helium gas instead of water as its media for removing heat from the core. The only high temperature gas-cooled reactor (HTGR) in the United States was the Fort St. Vrain plant in Colorado. The plant was manufactured by General Atomic Company of La Jolla, California. High temperature gas-cooled reactors are widely used in other countries.



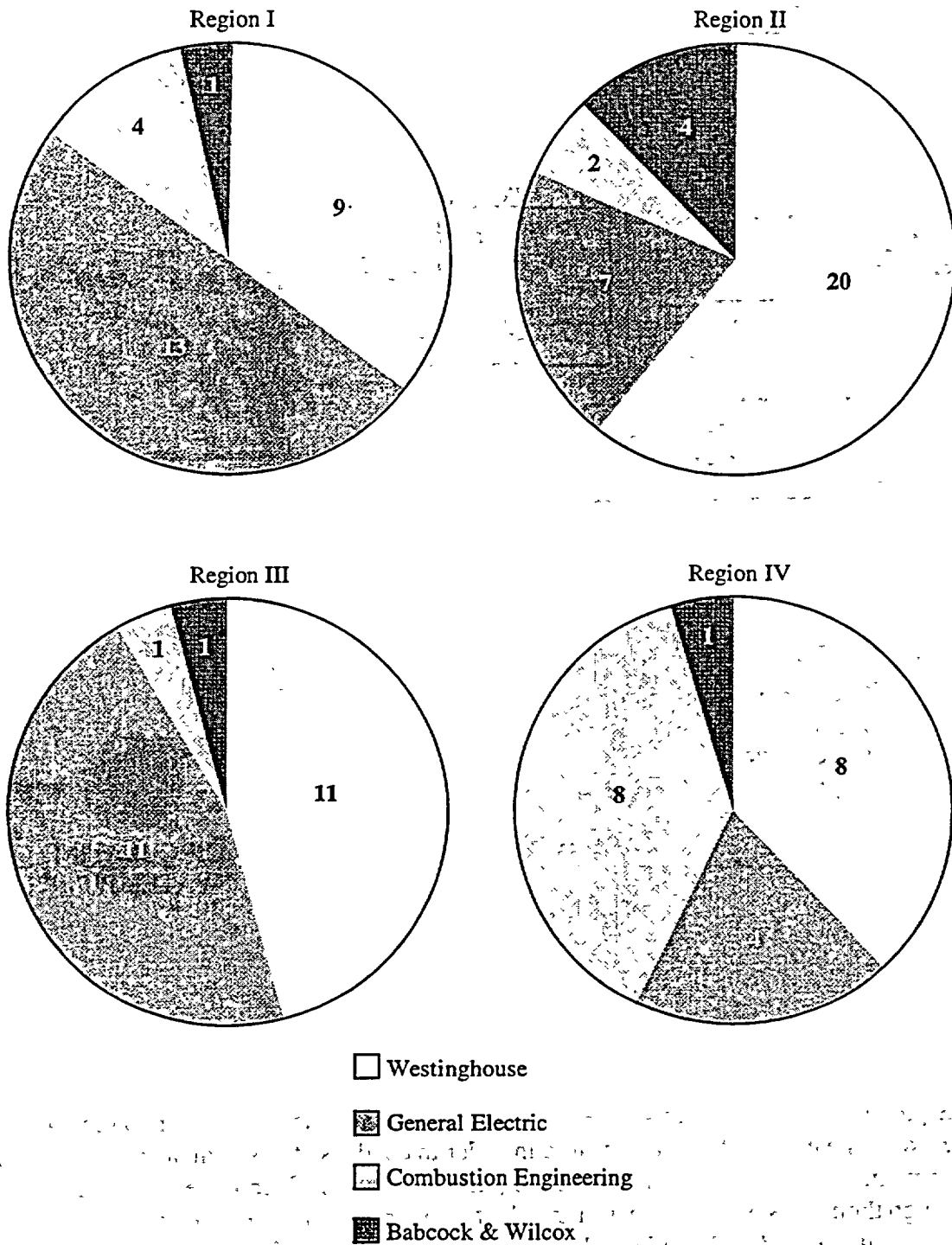


## Electrical Production by Type

Commercial nuclear power plants generate approximately 22% of the electricity produced in the United States. The total generation is approximately 3,000 thousand gigawatt-hours.

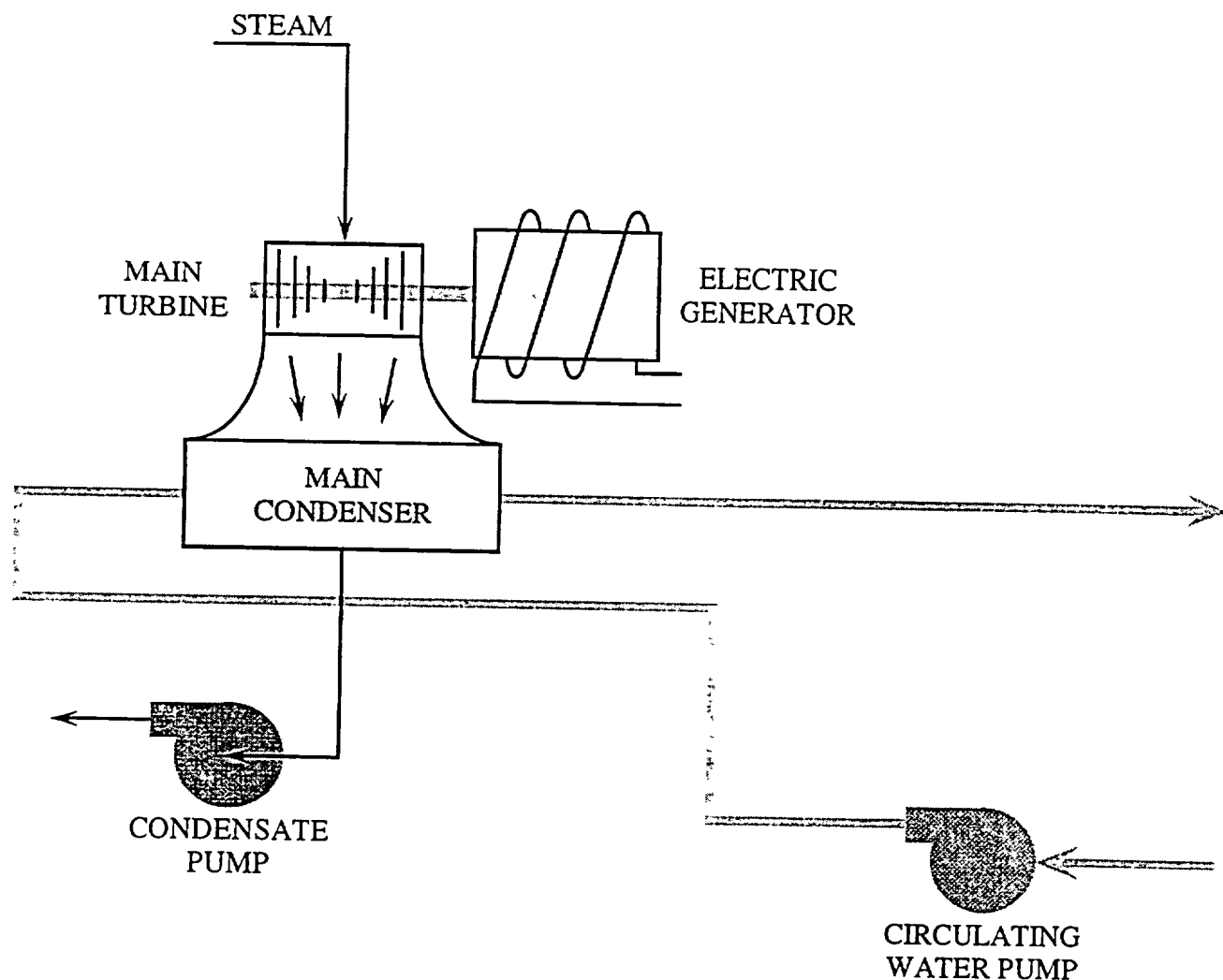
For comparison purposes, nuclear generation accounts for the following of the total electrical production in some other countries: 73% in France, 52% in Sweden, 28% in West Germany, and 24% in Japan.

The electricity produced in the United States from nuclear power is equivalent to 31% of the world's total nuclear generated electrical power. This compares with 16% for France, 10% for Japan, and 10% for the former USSR.

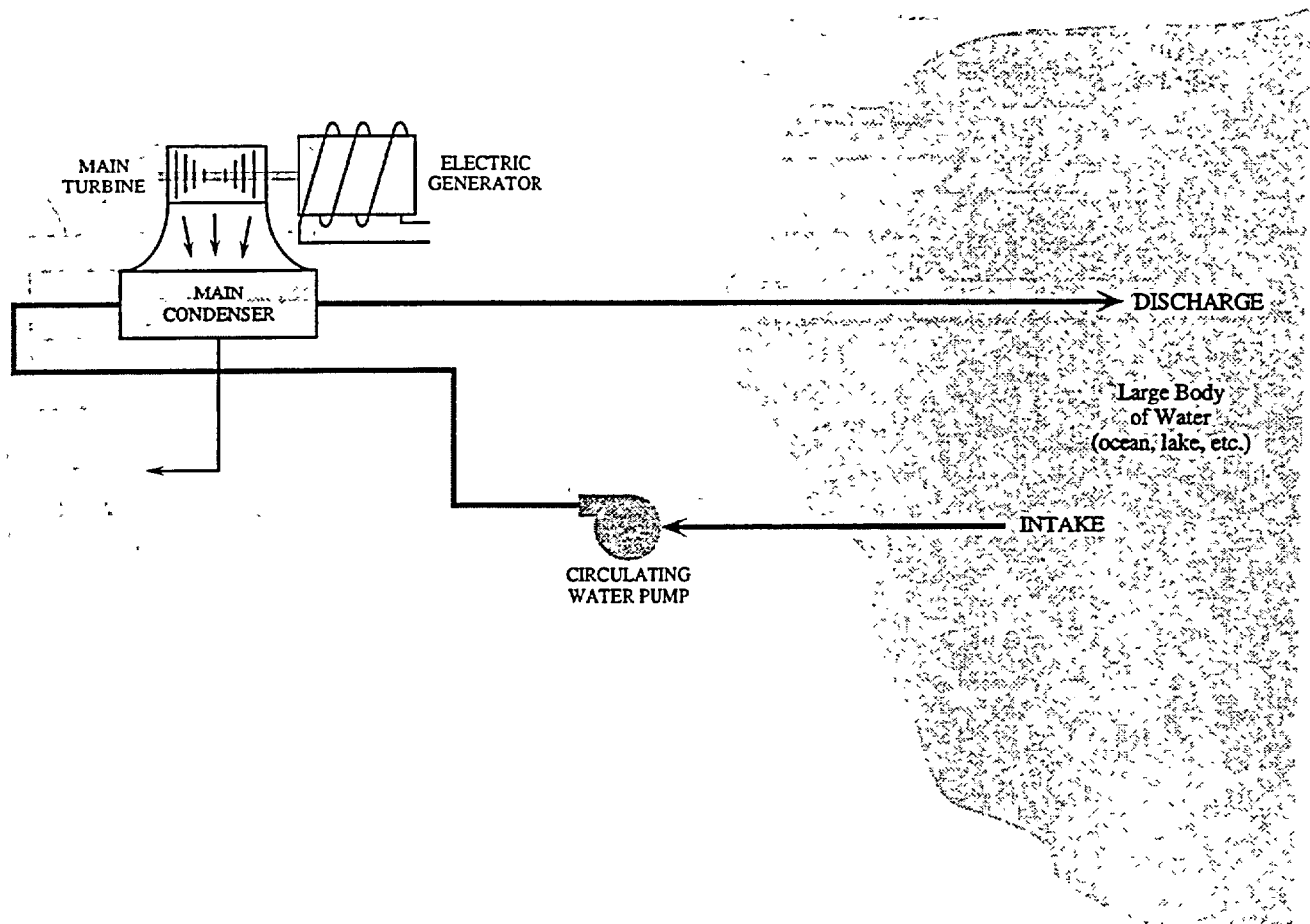


There are currently 104 licensed commercial nuclear power plants in the United States. Of the 104 plants, 48 were built by Westinghouse, 35 by General Electric, 14 by Combustion Engineering, and 7 by Babcock & Wilcox.

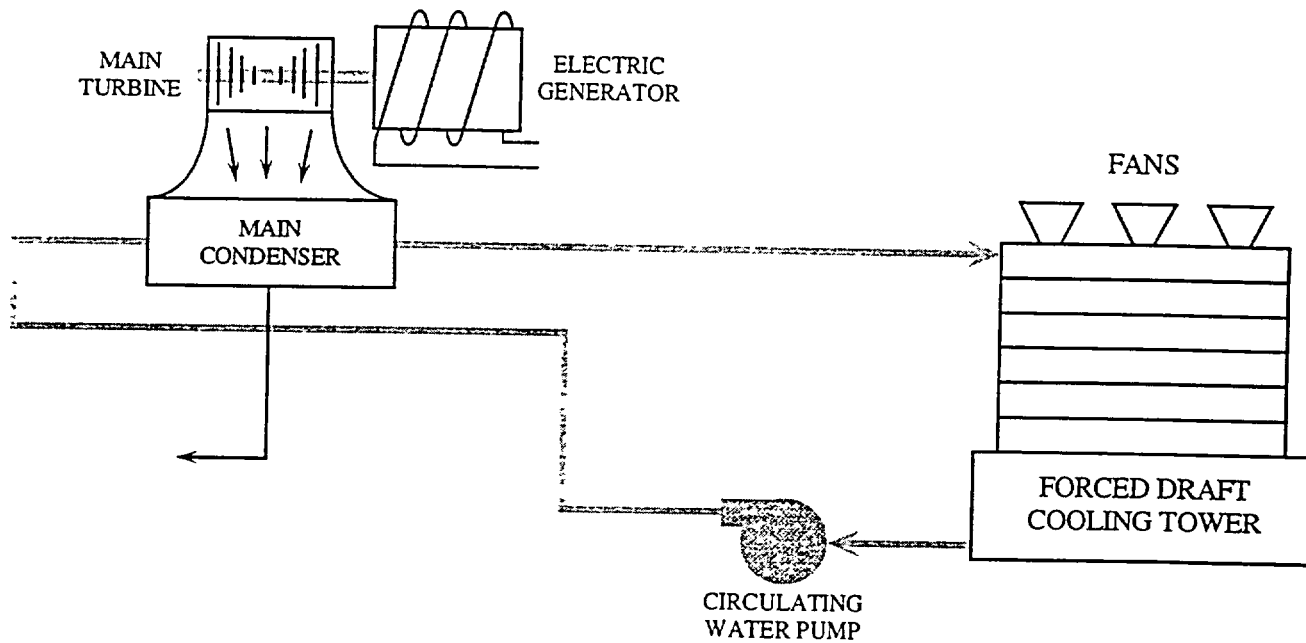
The illustration above shows the breakdown of the plants, by vendor, assigned to the four NRC Regions.



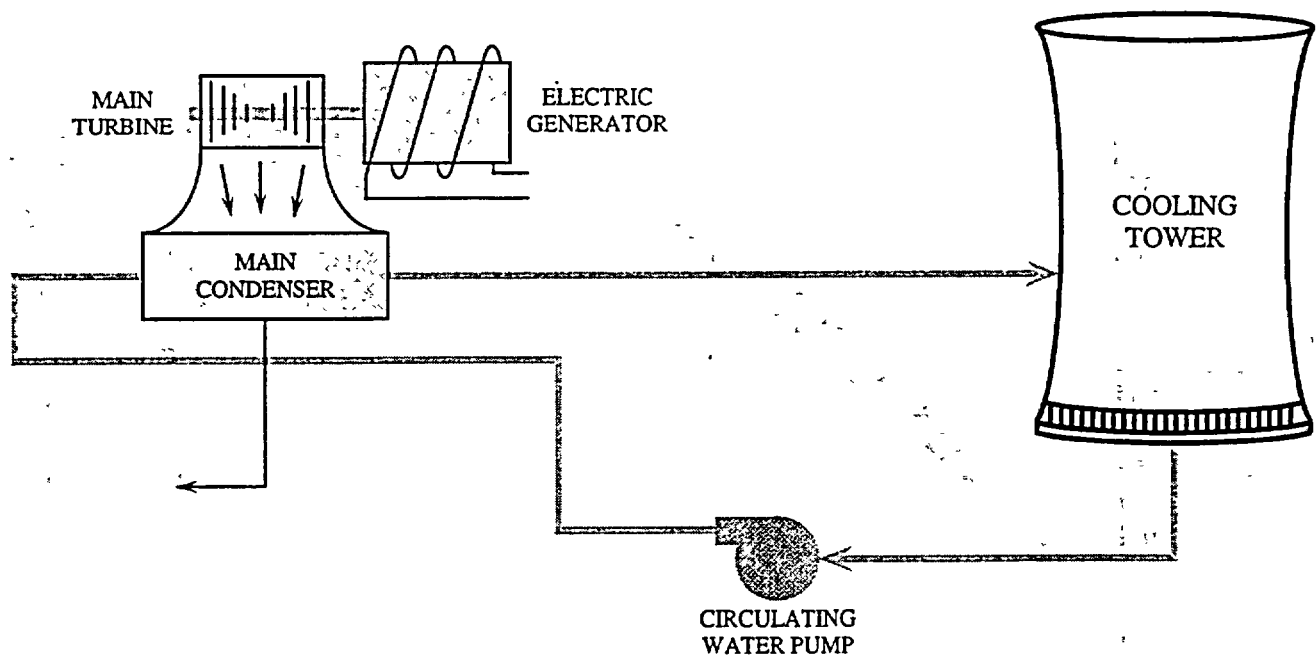
To operate properly, all steam plants, whether nuclear or fossil-fueled, need a circulating water system to remove excess heat from the steam system in order to condense the steam, and transfer that heat to the environment. The circulating water system pumps water (A) from the environment (river, lake, ocean) through thousands of metal tubes in the plant's condenser (B). Steam exiting the plant's turbine (C) 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.



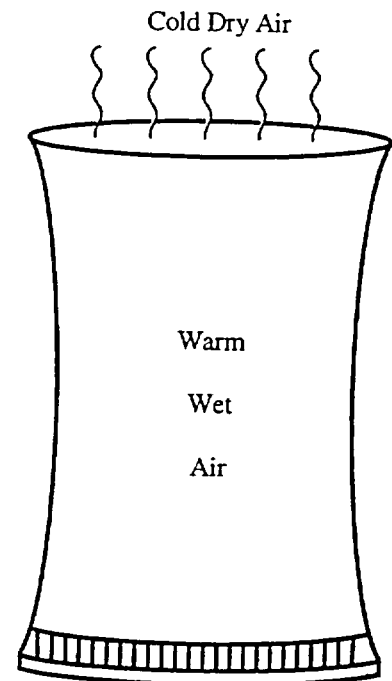
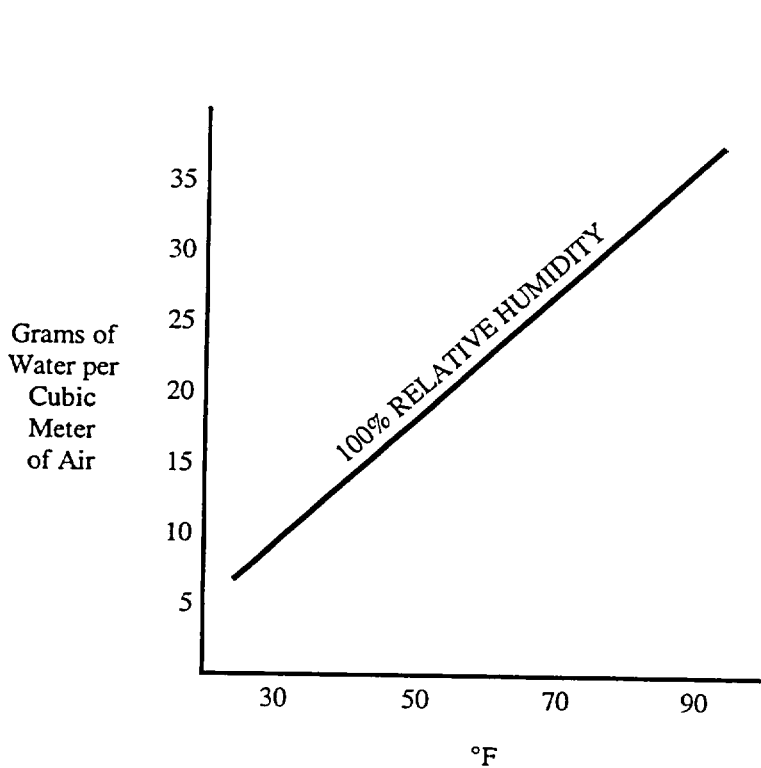
Power plants located on the ocean (or other large bodies of water) will often discharge their circulating water directly back to the ocean under strict environmental protection regulations. Water is taken from the ocean, pumped through the thousands of small tubes in the condenser to remove the excess 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.

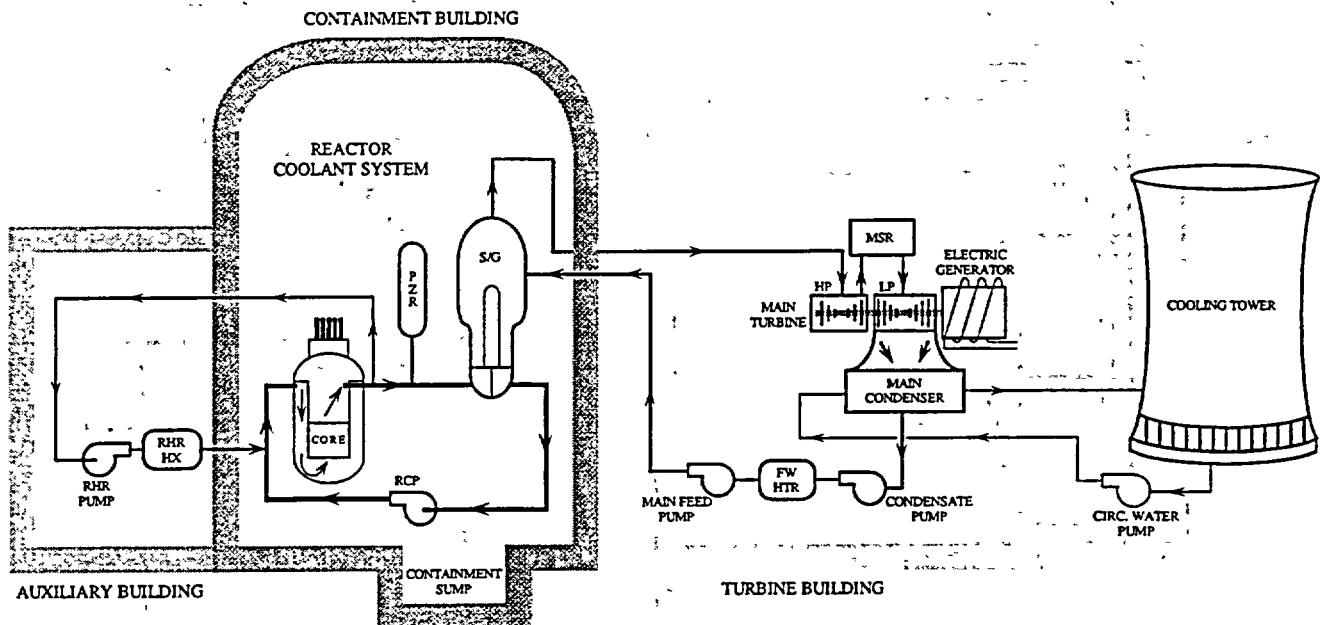


The taller hourglass shaped, natural convection cooling towers do not require fans to transfer the excess heat from the circulating water system into the air. Rather, the natural tendency of hot air to rise removes the excess heat as the circulating water splashes down inside the cooling tower.



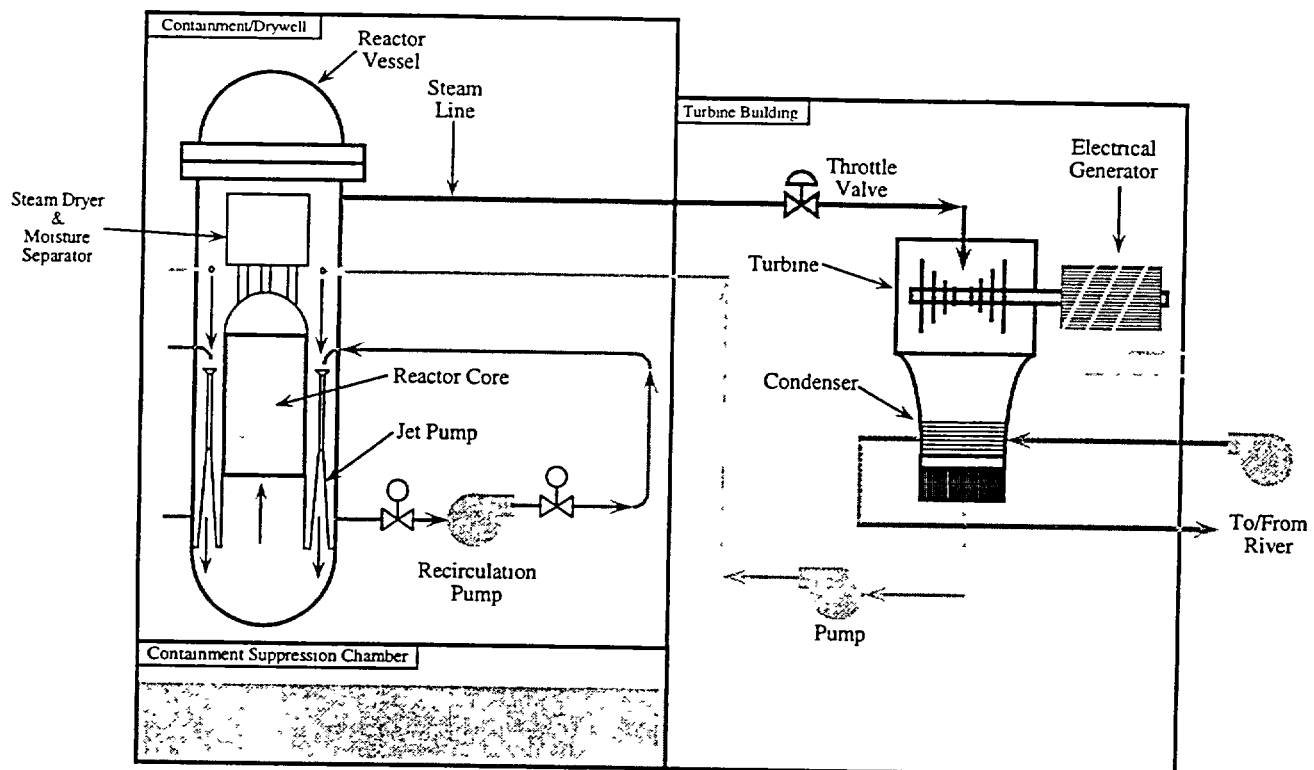
The "steam" vented from the top of a cooling tower is really lukewarm water vapor. IT IS NOT RADIOACTIVE. As the warm, wet air from inside the cooling tower contacts the cooler, dryer air above the cooling tower, the water vapor which cannot be held by the cooler air forms a visible cloud. This is because 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. The graph above shows air's ability to hold water as air temperature increases.

## PRESSURIZED WATER REACTOR PLANT LAYOUT



The major structures at a pressurized water reactor plant are the containment building, which houses the reactor and its high pressure steam generating equipment; the turbine building, which houses the steam turbines, condensers, and the electrical generator; the auxiliary building, which houses normal and emergency support systems (such as the residual heat removal (RHR) system, fuel handling and storage equipment, laboratories, maintenance areas, and the control room). Depending upon the plant location and environmental regulations, there may or may not be a cooling tower to remove the excess heat from the facility.

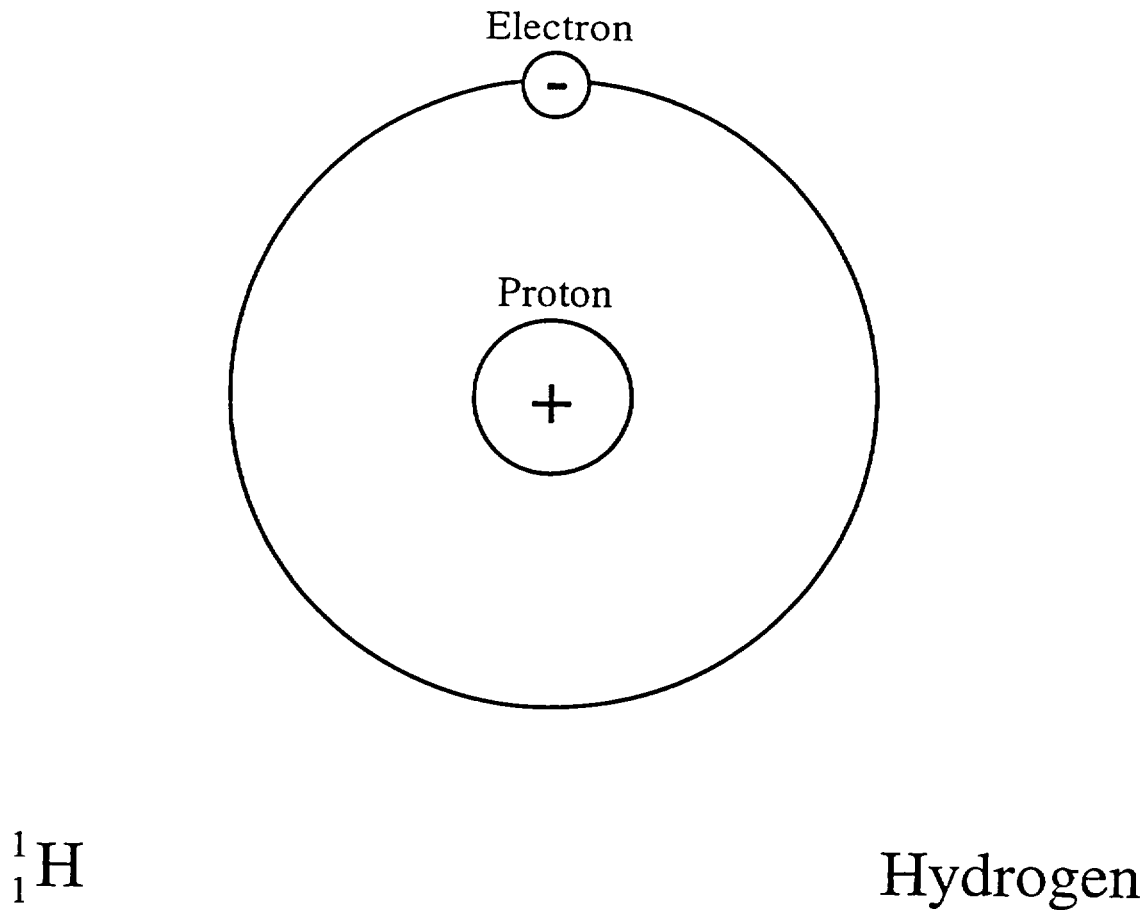




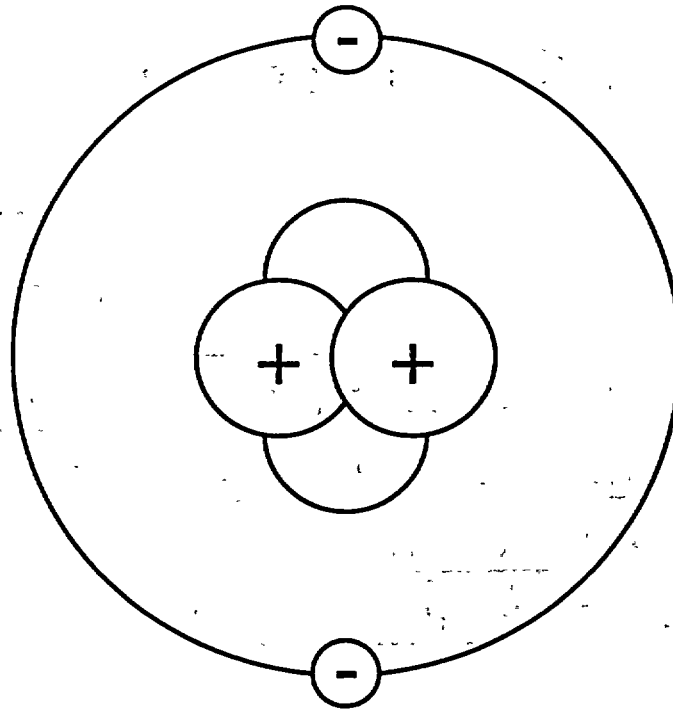
The major structures at a boiling water reactor plant are the primary containment, which includes the suppression chamber, and houses the reactor and recirculation pumps; the reactor building (secondary containment), which surrounds the primary containment and serves many of the same functions as a pressurized water reactor's auxiliary building; and the turbine building. Depending upon the plant location, there may or may not be a cooling tower to remove excess heat from the facility.

# The Fission Process and Heat Production

A nuclear power plant converts the energy contained within the nuclei of atoms into electrical energy. This section discusses the release of nuclear energy by the fission of uranium atoms and the methods used to control the rate at which energy is released and power is produced.



Atoms are composed of positively charged protons in the nucleus and negatively charged electrons orbiting the nucleus. The simplest atom is hydrogen, composed of one proton and one electron. Its atomic number, which is equal to the number of protons, is 1.

 ${}^4_2\text{He}$ 

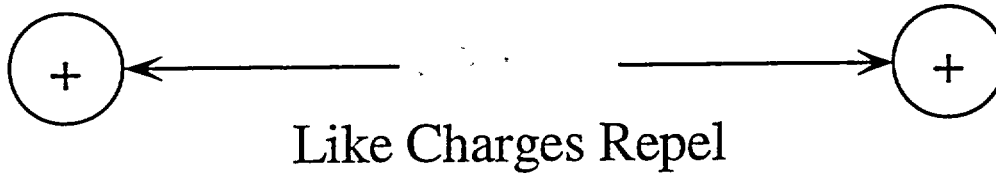
Helium

More complex atoms have more protons and electrons, but each unique combination of protons and electrons represents a different chemical element. Helium, for example, with two protons, two neutrons, and two electrons, has an atomic number of 2.

# Periodic Table of the Elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112		114		116		118
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Each element has a chemical symbol. Elements are listed by increasing atomic number and grouped by similar chemical characteristics in the Periodic Table of the Elements.

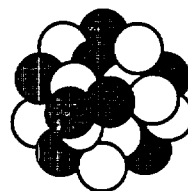


## Electrostatic Force

Since all protons are positively charged, and since like charges repel, electrostatic force tends to push protons away from each other.

## Neutrons

Provide  
Nuclear  
Attractive  
Force



Minimum  
Electrostatic  
Repulsion



## Hold Larger Atoms Together

Neutrons, with no electrical charge, provide the attractive nuclear force to offset the electrostatic repulsive forces and hold atoms together. All atoms found in nature, except the basic hydrogen atom, have one or more neutrons in their nuclei.

# Hydrogen Isotopes

## Deuterium



## Tritium



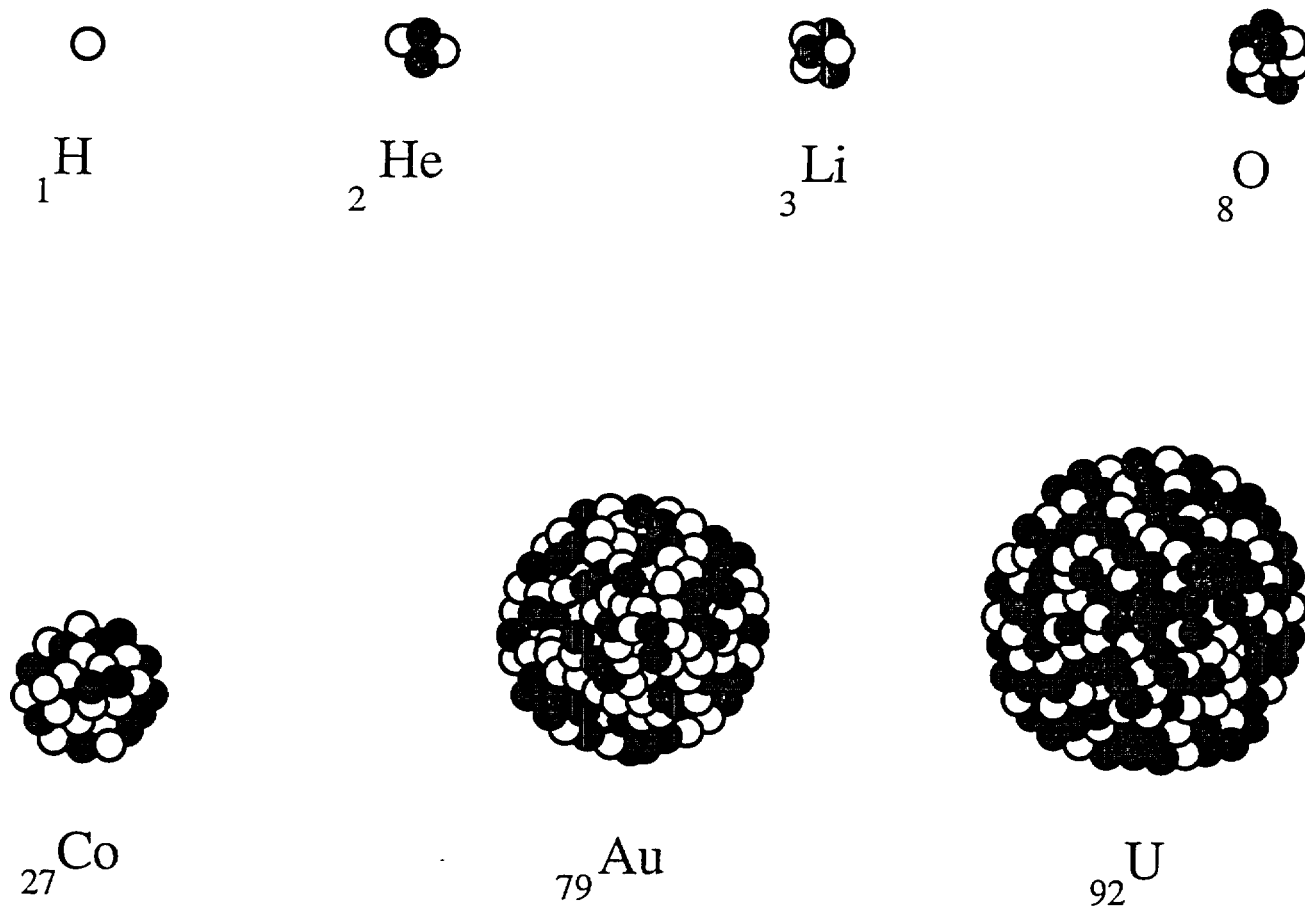
## Hydrogen



A chemical element can have several different combinations of protons and neutrons in its nuclei. Hydrogen, above, has three naturally occurring combinations (known as "isotopes"):

- 1) Basic hydrogen (one proton, one electron, and no neutrons),
- 2) Deuterium (one proton, one electron, and one neutron), and
- 3) Tritium (one proton, one electron, and two neutrons).

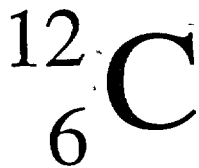




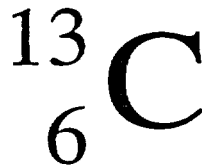
The number of protons an element has (atomic number) determines its chemical characteristics. Atomic numbers are always related to the same element (hydrogen-1, cobalt-27, uranium-92).

When used in technical literature, the atomic number is usually written to the lower left of the chemical symbol (as shown above). Often, the atomic number for an element will be omitted from technical writing since this number will never change for the element under discussion.

## Naturally Occurring Carbon



6 Protons  
6 Neutrons



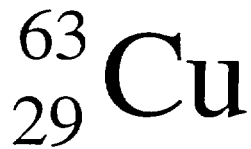
6 Protons  
7 Neutrons



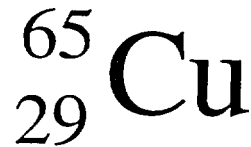
6 Protons  
8 Neutrons

Since chemical elements can have different numbers of neutrons, the use of isotopic numbers (or mass numbers) is necessary to distinguish one isotope from another. Naturally occurring isotopes of the element carbon are shown above. The isotopic number (shown to the upper left hand of the chemical symbol) is the sum of the number of protons and the number of neutrons in the nucleus of an atom.

# Naturally Occurring Copper



29 Protons  
34 Neutrons



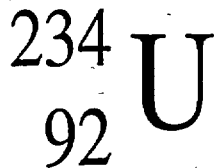
29 Protons  
36 Neutrons

The commonly found isotopes of copper are shown above. Although the placement of the isotopic number in the upper left is technically correct, many variations are encountered. For example:

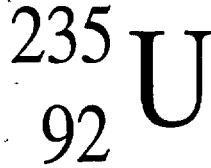


All of these variations refer to the same isotope of copper.

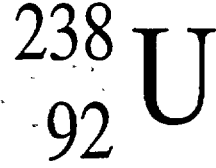
## Naturally Occurring Uranium



92 Protons  
142 Neutrons



92 Protons  
143 Neutrons

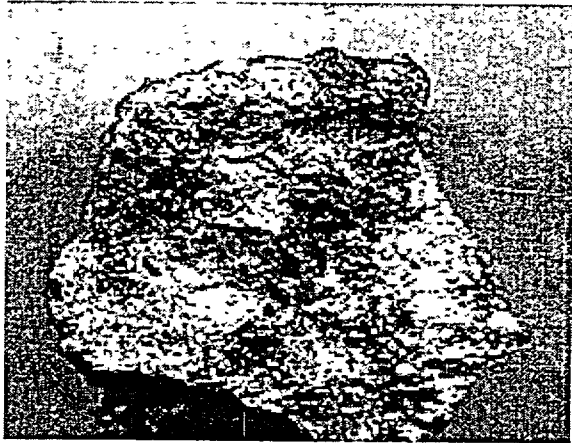


92 Protons  
146 Neutrons

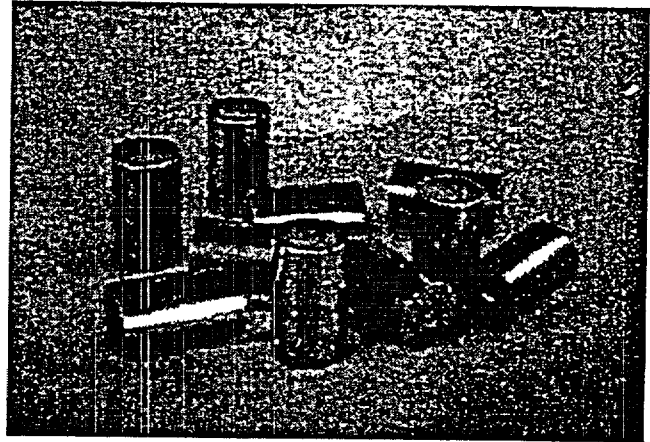
Power reactors in the United States use uranium as fuel. The naturally occurring isotopes of uranium are shown above. About 99.3% of all uranium atoms are the isotope U-238, and the remaining 0.7% are U-235. Trace amounts (far less than 1%) of U-234 can be found. Another isotope, U-233, does not exist naturally, but it can be manufactured and used to fuel some types of reactors.

# ENRICHMENT

## (% U-235)

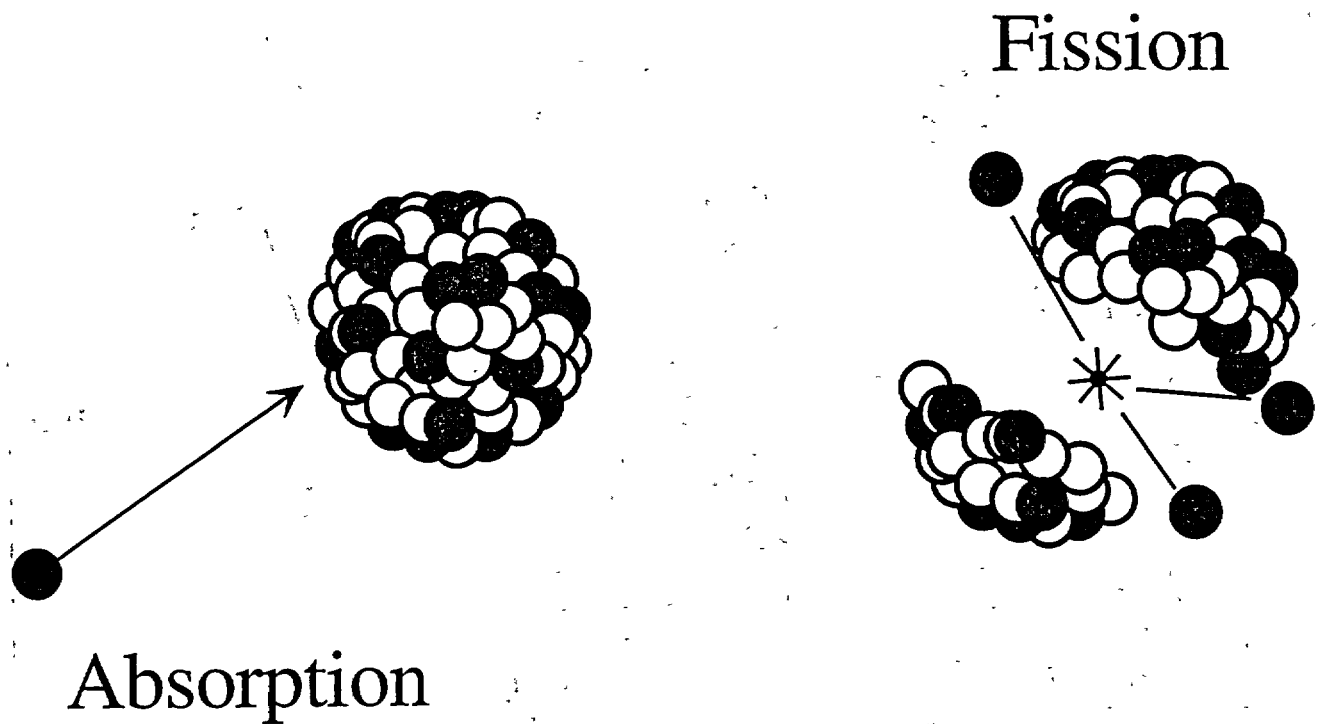


Uranium Ore (0.7%)



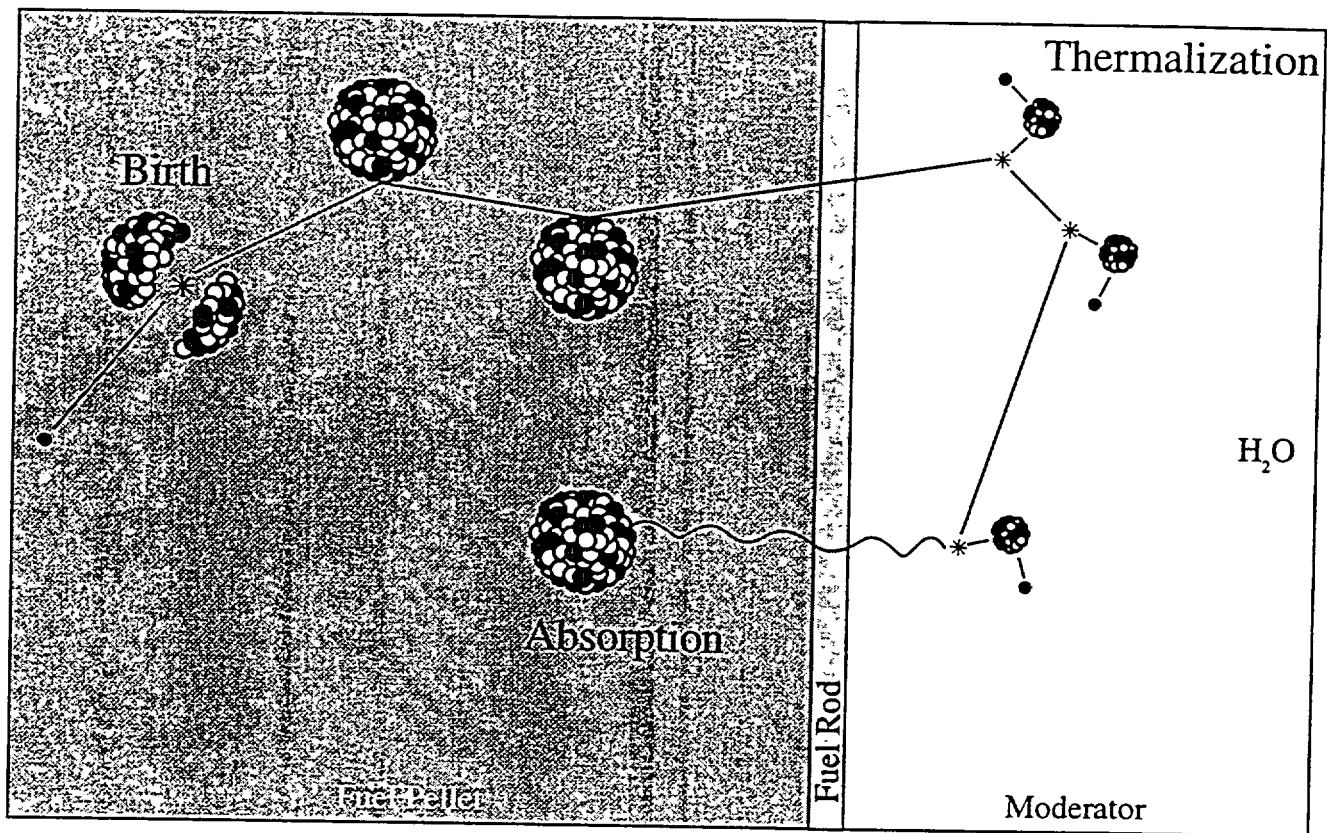
Fuel Pellet (3.5%)

Uranium-235 (enriched from 0.7% abundance to about 3.5%) is the fuel for most power reactors in the United States.



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."



## Neutron Life Cycle

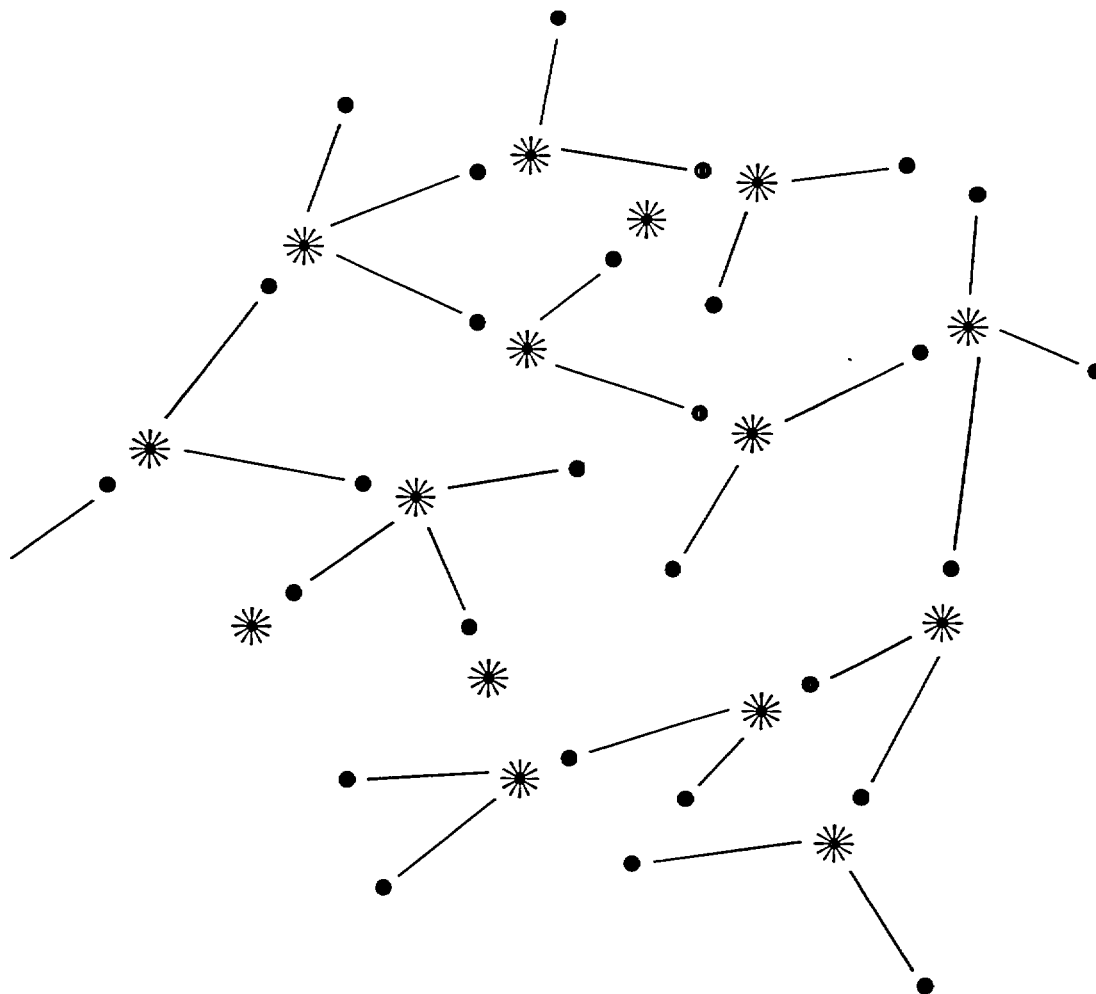
U-235 does have a high probability of absorbing a neutron. However, the probability increases even more if the neutron is moving slower. Therefore, in the reactor, it is desired to slow the neutrons down and then let the U-235 absorb them. This slowing down process is accomplished by the same water that 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."

## *Fissions $\Rightarrow$ Heat*

Controlling Fission Rate  $\Rightarrow$  Controlling Heat Production Rate

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 electrical power. The rate at which the uranium atoms are fissioned determines the rate at which heat (and power) are produced.

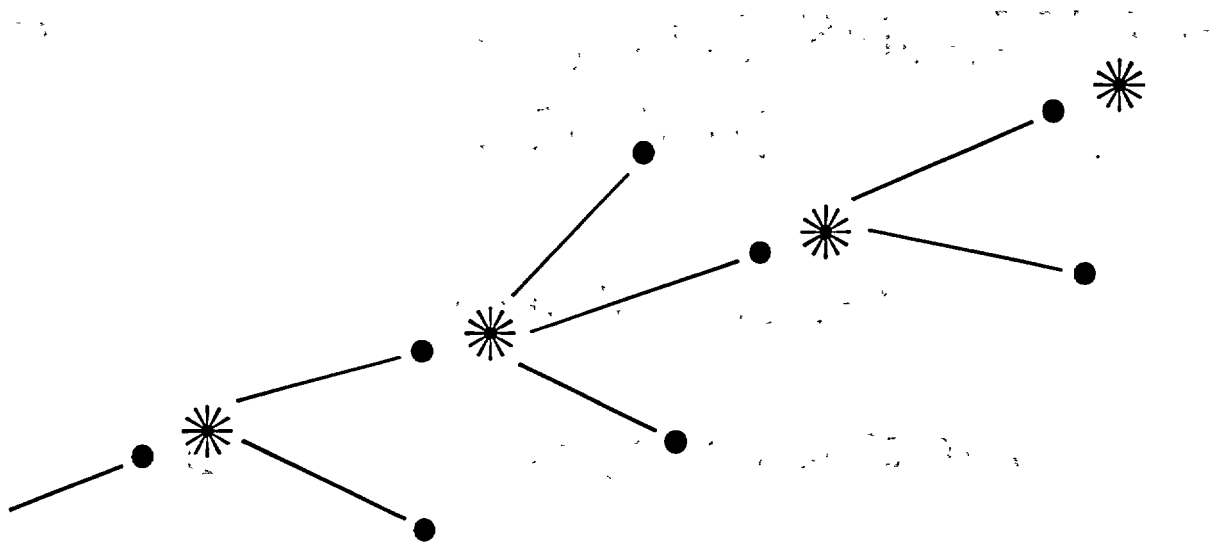




## Fission Chain Reaction

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.

# Criticality



## Steady Rate of Power Generation

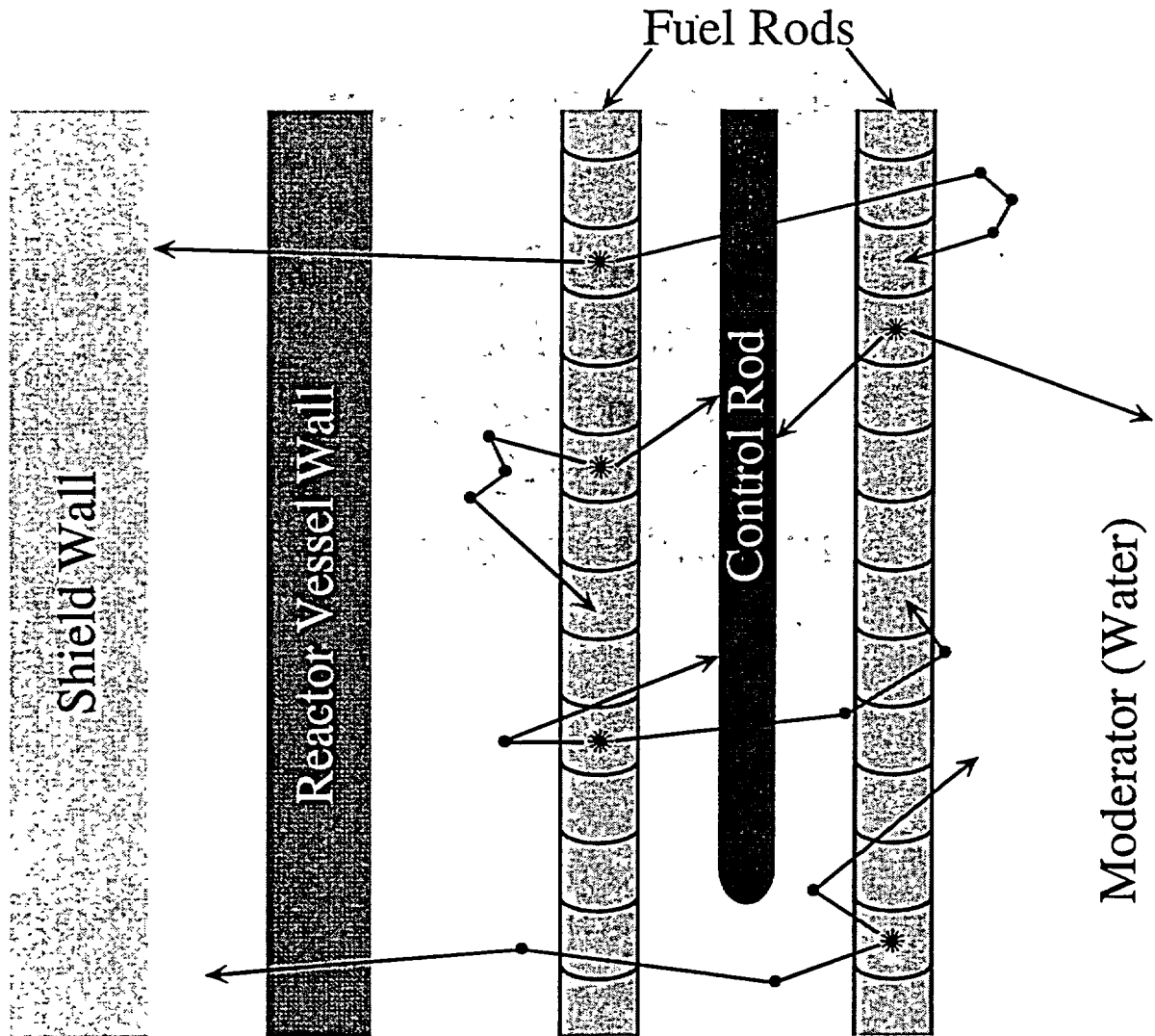
If the conditions in the core allow, the chain reaction will reach a state of being self-sustaining. At this point, for every fission event that occurs, a second event occurs. This point of equilibrium is known as "criticality." This just means that the number of neutrons produced by the fission events 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.

# NEUTRONS THAT DO NOT CAUSE FISSIONS:

Leak out of the core, or

Are absorbed by neutron poisons

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. These neutron absorbers are called "neutron poisons."



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.).

# Neutron Poisons:

Control Rods  
Soluble Boron  
Fission Products  
Uranium-238  
Structural Components

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. 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.

# Control Rods

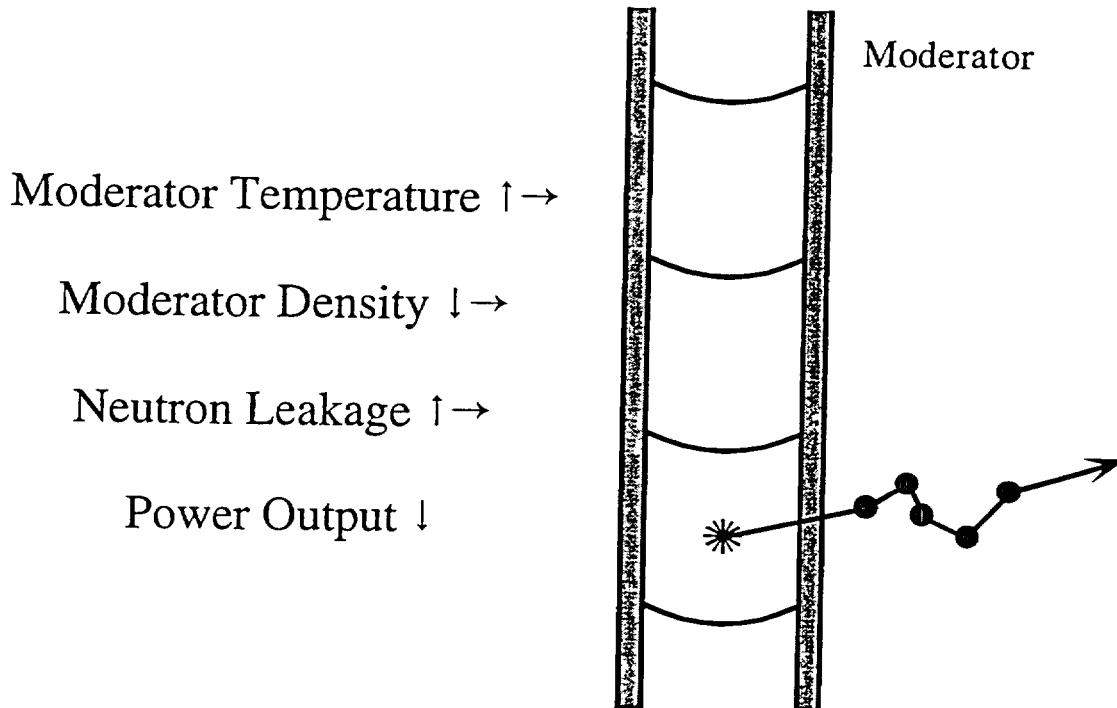
IN  $\Rightarrow$  Fewer Neutrons  $\Rightarrow$  Power Down

OUT  $\Rightarrow$  More Neutrons  $\Rightarrow$  Power Up

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.

## Temperature/Density Relationship of Water



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 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.

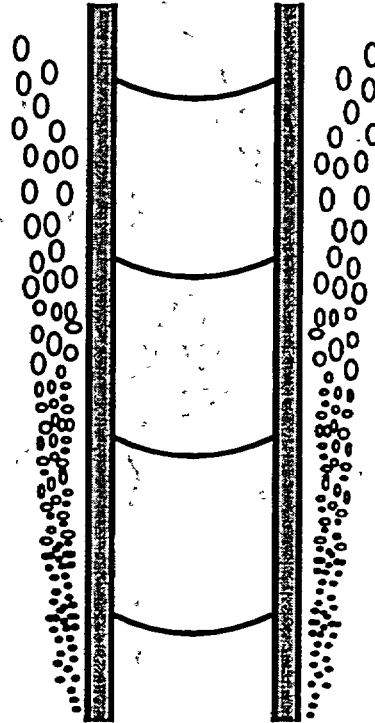
## Voids (Steam Bubbles)

Moderator Void Content  $\uparrow \rightarrow$

Moderator Density  $\downarrow \rightarrow$

Neutron Leakage  $\uparrow \rightarrow$

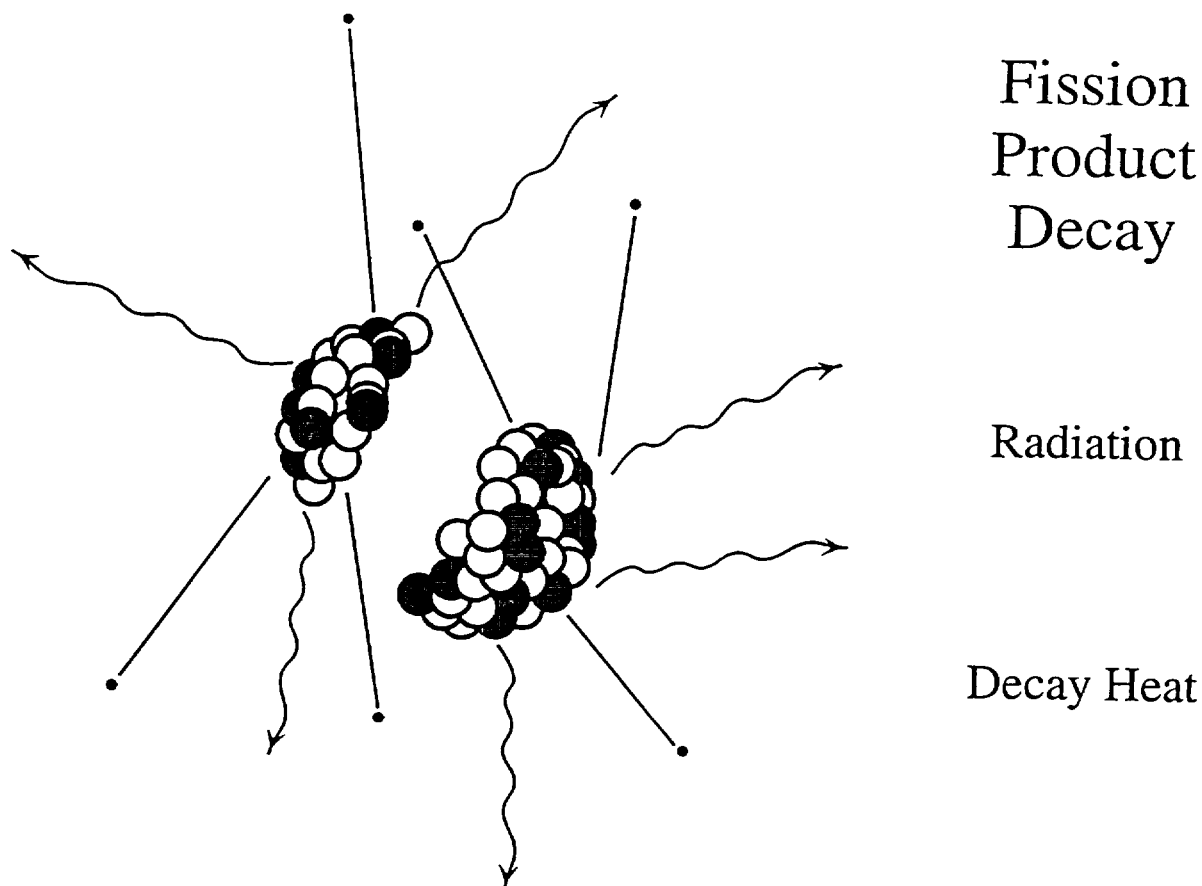
Power Output  $\downarrow$



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.

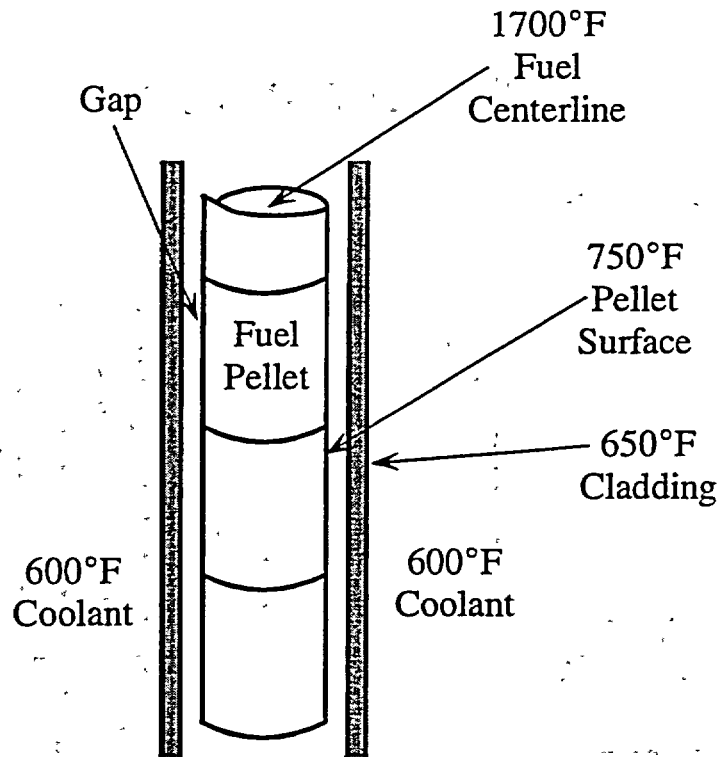
In a boiling water reactor, the conversion of water into steam produces a dramatic change in the density of the water from the bottom to the top of the core. Water at the bottom of the core is far more dense than the water-steam mixture at the top. Therefore, neutron moderation is much better towards 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.

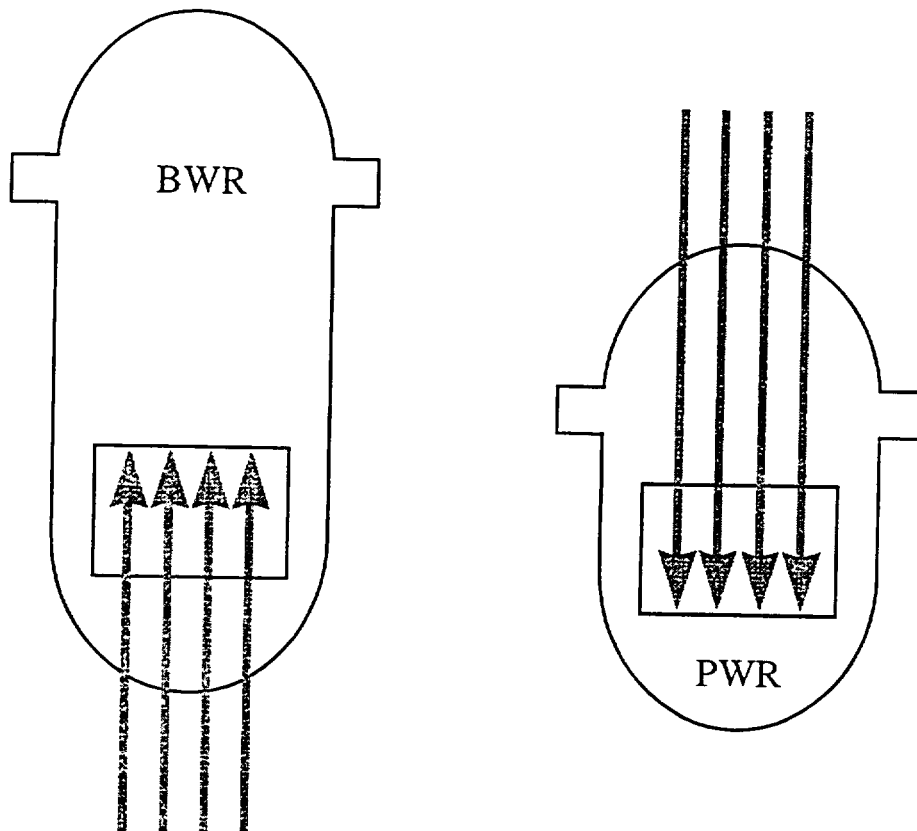
Another problem with the fission products is the generation of decay heat. When an atom decays, it gives off energy or particles to become more stable. The energy or particles then interact with the surroundings to generate heat. This heat will be collected inside the fuel pellet area. If this heat (decay 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). Radiation, decay heat, and fission product barriers will all be discussed in subsequent sections of this manual.



## 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°F. The melting temperature of the ceramic fuel is approximately 5200°F. The fuel cladding can be damaged by temperatures in excess of 1800°F. Significant fuel damage can be expected at sustained temperatures above 2200°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.

## Reactor Scram (Trip)



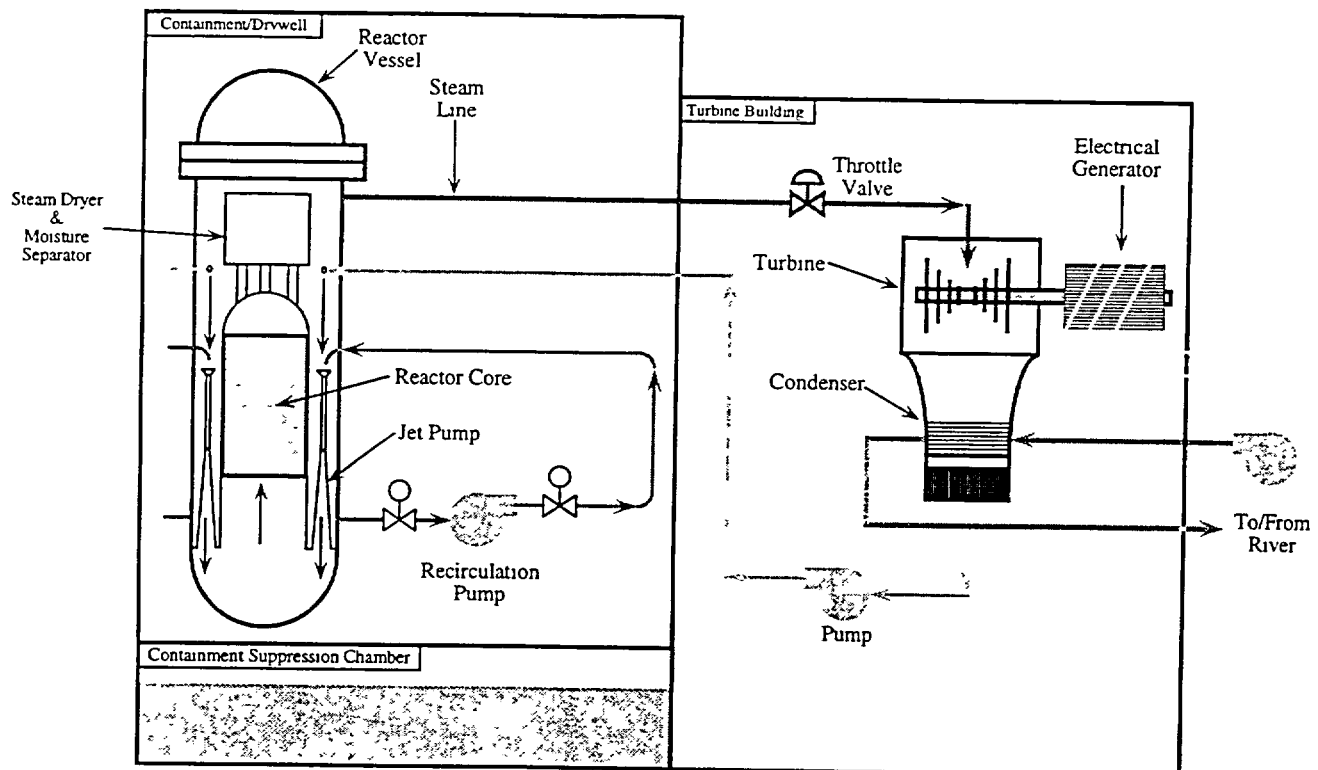
### Rapid Insertion of Control Rods to Shutdown the Fission Chain Reaction

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.

# Boiling Water Reactor (BWR) Systems

This chapter will discuss the purposes of some of the major systems and components associated with a boiling water reactor (BWR) in the generation of electrical power.



## Boiling Water Reactor Plant

Inside the boiling water reactor (BWR) vessel, a steam water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat. The major difference in the operation of a BWR from other nuclear systems is the steam void formation in the core. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation, where water droplets are removed before the steam is allowed to enter the steam line. The steam line, in turn, directs the steam to the main turbine causing it to turn the turbine and the attached electrical generator. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps and back to the reactor vessel. The recirculation pumps and jet pumps allow the operator to vary coolant flow through the core and change reactor power.

## BWR Reactor Vessel Assembly

The reactor vessel assembly, shown on page 3-5, consists of the reactor vessel and its internal components, including the core support structures, core shroud, moisture removal equipment, and jet pump assemblies. The purposes of the reactor vessel assembly are to:

- House the reactor core,
- Serve as part of the reactor coolant pressure boundary,
- Support and align the fuel and control rods,
- Provide a flow path for circulation of coolant past the fuel,
- Remove moisture from the steam exiting the core, and
- Provide a refloodable volume for a loss of coolant accident.

The reactor vessel is vertically mounted within the drywell and consists of a cylindrical shell with an integral rounded bottom head. The top head is also rounded in shape but is removable via the stud and nut arrangement to facilitate refueling operations. The vessel assembly is supported by the vessel support skirt (20) which is mounted to the reactor vessel support pedestal.

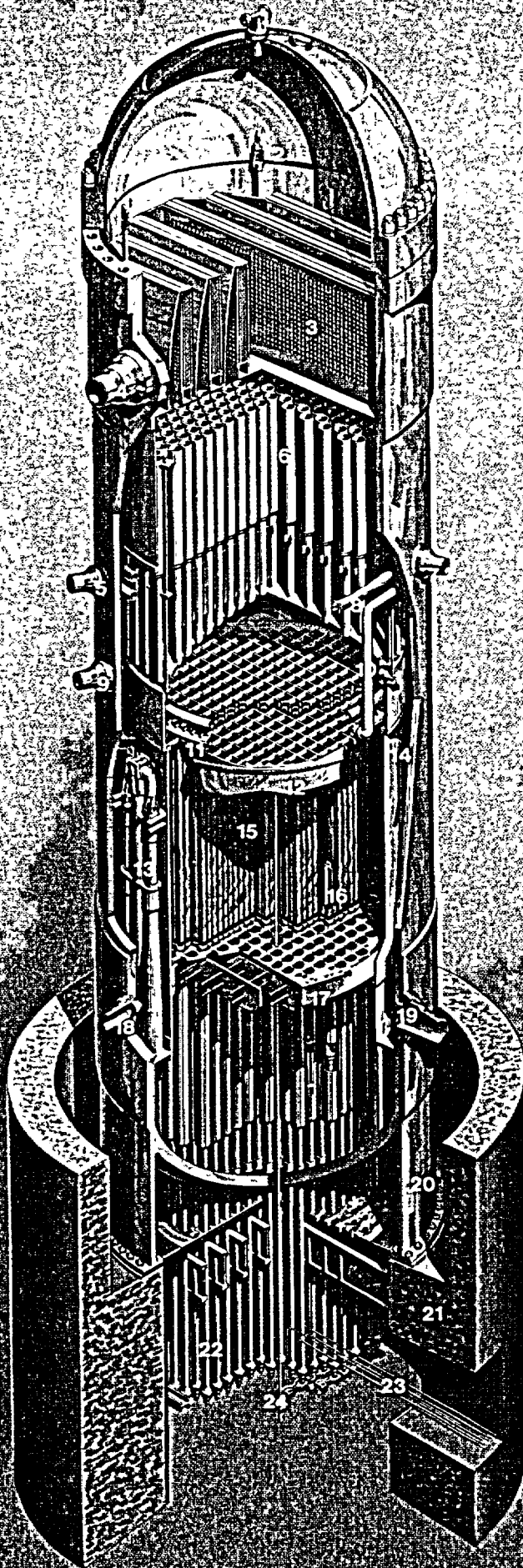
The internal components of the reactor vessel are supported from the bottom head and/or vessel wall. The reactor core is made up of fuel assemblies (15), control rods (16), and neutron monitoring instruments (24). The structure surrounding the active core consists of a core shroud (14), core plate (17), and top guide (12). The components making up the remainder of the reactor vessel internals are the jet pump assemblies (13), steam separators (6), steam dryers (3), feedwater spargers (8), and core spray spargers (11). The jet pump assemblies are located in the region between the core shroud and the vessel wall, submerged in water. The jet pump assemblies are arranged in two semicircular groups of ten, with each group being supplied by a separate recirculation pump.

The emergency core cooling systems, penetrations number 5 and 9, and the reactor vessel designs are compatible to ensure that the core can be adequately cooled following a loss of reactor coolant. The worst case loss of coolant accident, with respect to core cooling, is a recirculation line break (penetrations number 18 and 19). In this event, reactor water level decreases rapidly, uncovering the core. However, several emergency core cooling systems automatically provide makeup water to the nuclear core within the shroud, providing core cooling.

The control cell assembly (page 3-7) is representative for boiling water reactor 1 through 6. Each control cell consists of a control rod (7) and four fuel assemblies that surround it. Unlike the pressurized water reactor fuel assemblies, the boiling water reactor fuel bundle is enclosed in a fuel channel (6) to direct coolant up through the fuel assembly and act as a bearing surface for the control rod. In addition, the fuel channel protects the fuel during refueling operations. The power of the core is regulated by movement of bottom entry control rods.

# BWR/6

## REACTOR ASSEMBLY



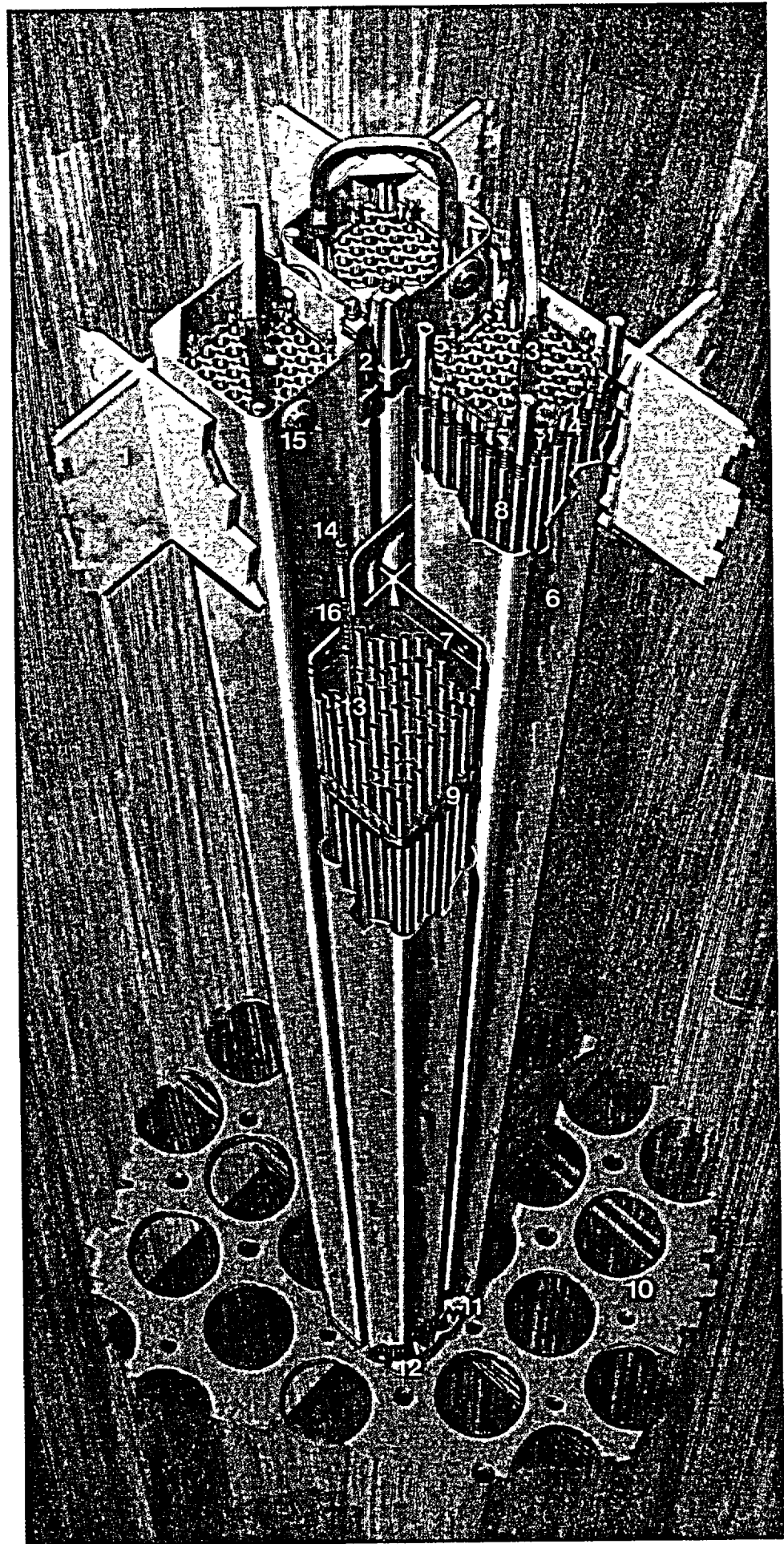
1. VENT AND HEAD SPRAY
2. STEAM DRYER LIFTING LUG
3. STEAM DRYER ASSEMBLY
4. STEAM OUTLET
5. CORE SPRAY INLET
6. STEAM SEPARATOR ASSEMBLY
7. FEEDWATER INLET
8. FEEDWATER SPARGER
9. LOW PRESSURE COOLANT INJECTION INLET
10. CORE SPRAY LINE
11. CORE SPRAY SPARGER
12. TOP GUIDE
13. JET PUMP ASSEMBLY
14. CORE SHROUD
15. FUEL ASSEMBLIES
16. CONTROL BLADE
17. CORE PLATE
18. JET PUMP / RECIRCULATION WATER INLET
19. RECIRCULATION WATER OUTLET
20. VESSEL SUPPORT SKIRT
21. SHIELD WALL
22. CONTROL ROD DRIVES
23. CONTROL ROD DRIVE HYDRAULIC LINES
24. IN-CORE FLUX MONITOR

GENERAL  ELECTRIC

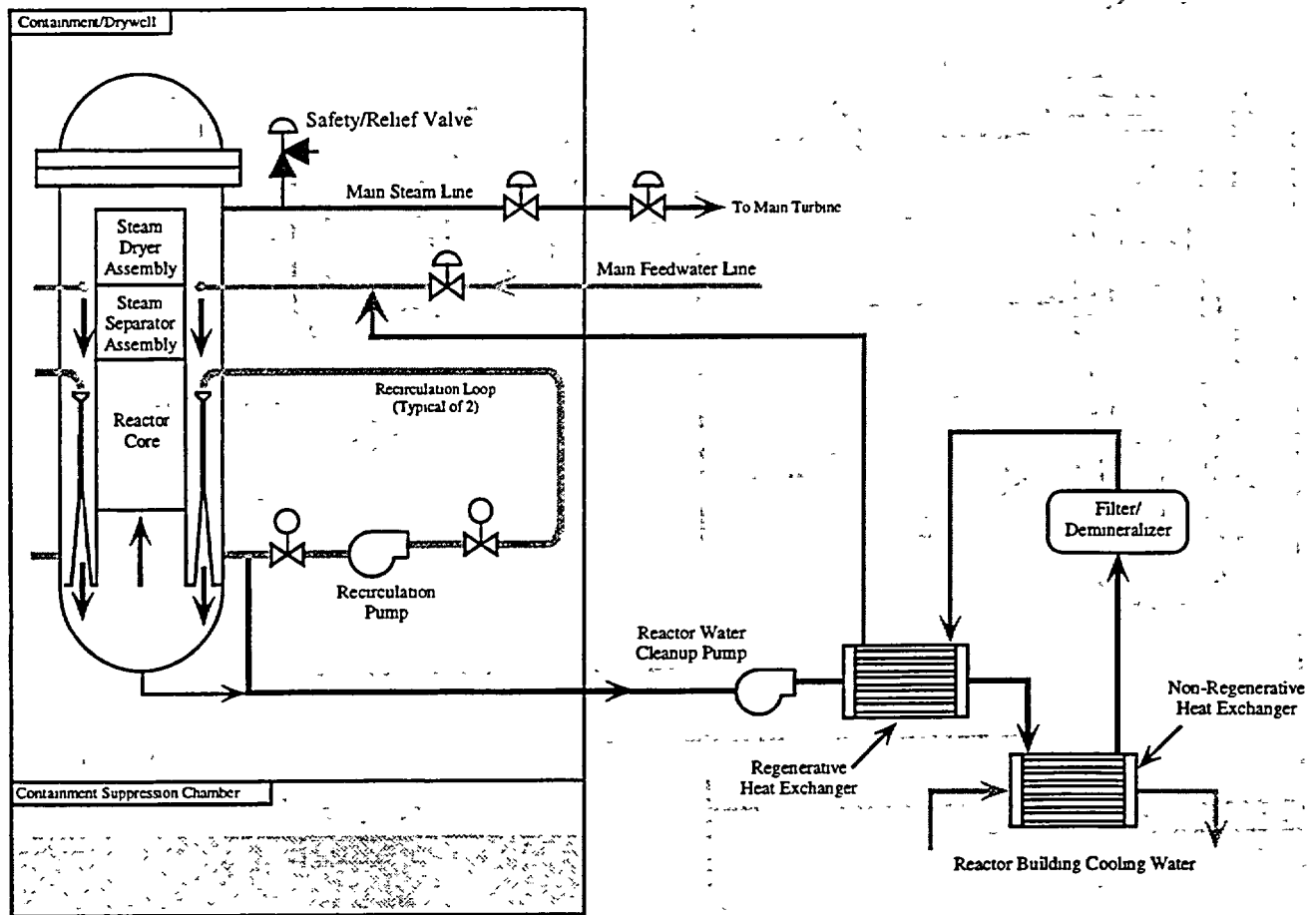
# BWR/6 FUEL ASSEMBLIES & CONTROL ROD MODULE

- 1.TOP FUEL GUIDE
- 2.CHANNEL  
FASTENER
- 3.UPPER TIE  
PLATE
- 4.EXPANSION  
SPRING
- 5.LOCKING TAB
- 6.CHANNEL
- 7.CONTROL ROD
- 8.FUEL ROD
- 9.SPACER
- 10.CORE PLATE  
ASSEMBLY
- 11.LOWER  
TIE PLATE
- 12.FUEL SUPPORT  
PIECE
- 13.FUEL PELLETS
- 14.END PLUG
- 15.CHANNEL  
SPACER
- 16.PLENUM  
SPRING

GENERAL  ELECTRIC

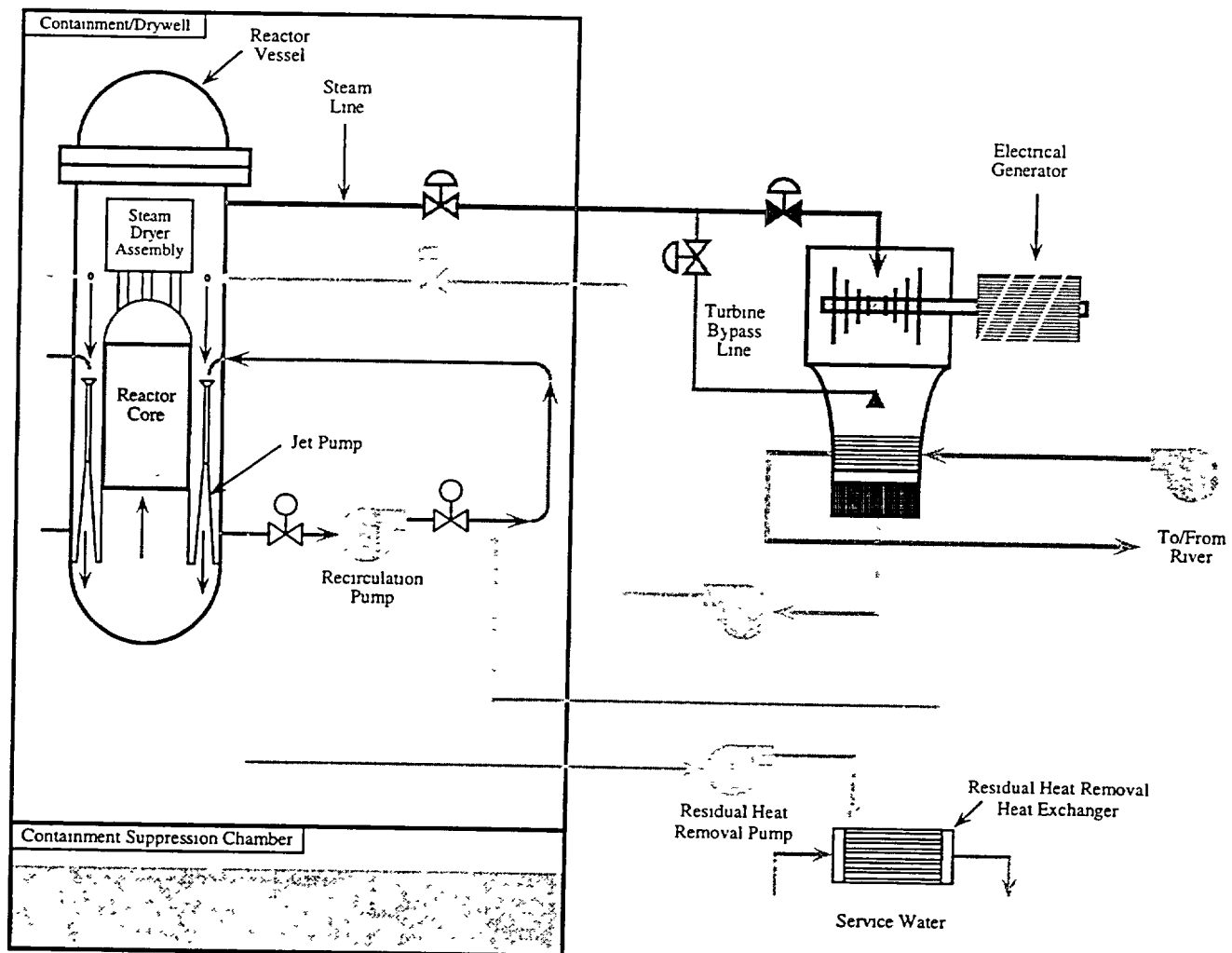






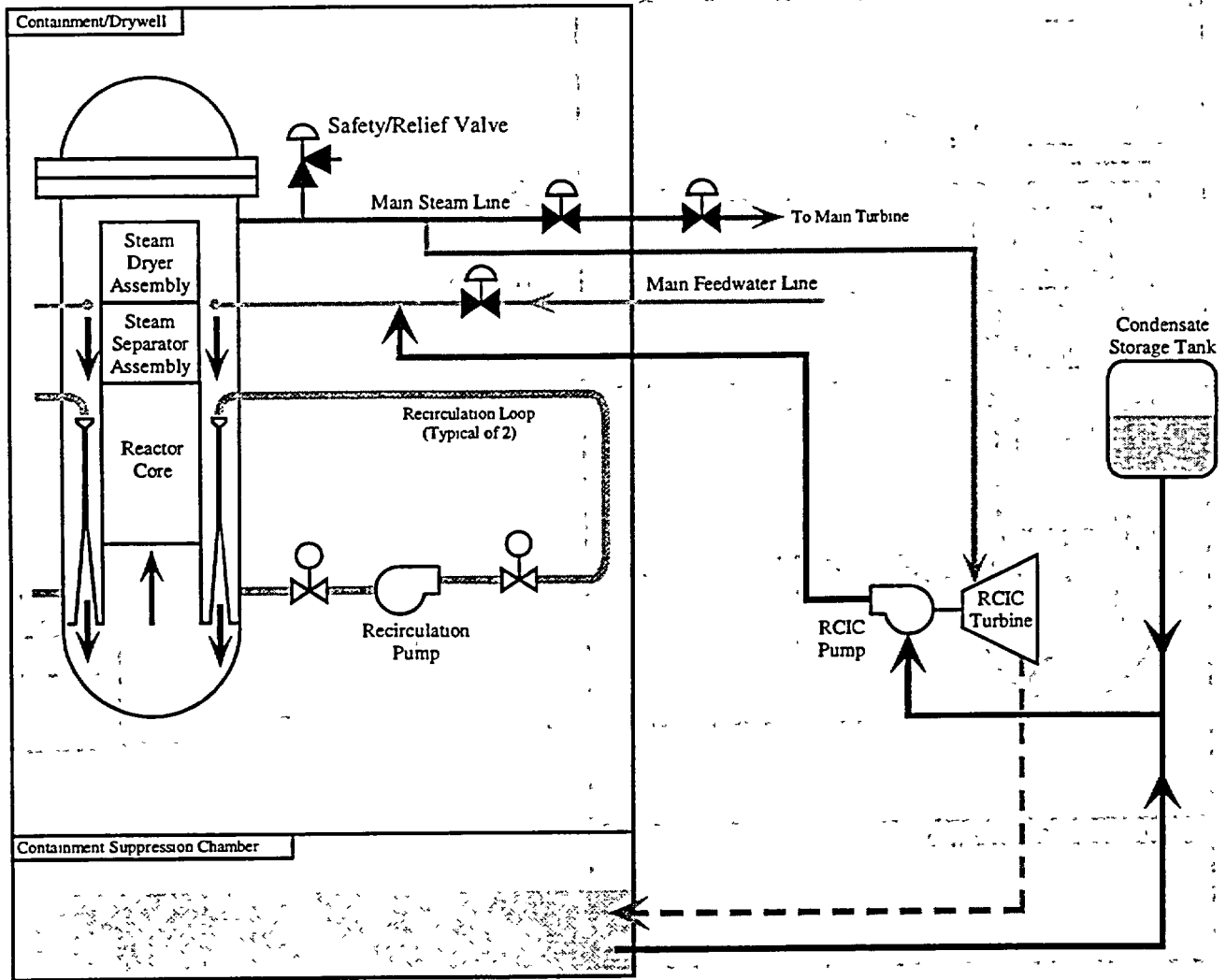
## Reactor Water Cleanup System

The purpose of the reactor water cleanup system (RWCU) is to maintain a high reactor water quality by removing fission products, corrosion products, and other soluble and insoluble impurities. The reactor water cleanup pump takes water from the recirculation system and the vessel bottom head and pumps the water through heat exchangers to cool the flow. The water is then sent through filter/demineralizers for cleanup. After cleanup, the water is returned to the reactor vessel via the feedwater piping.



## Decay Heat Removal

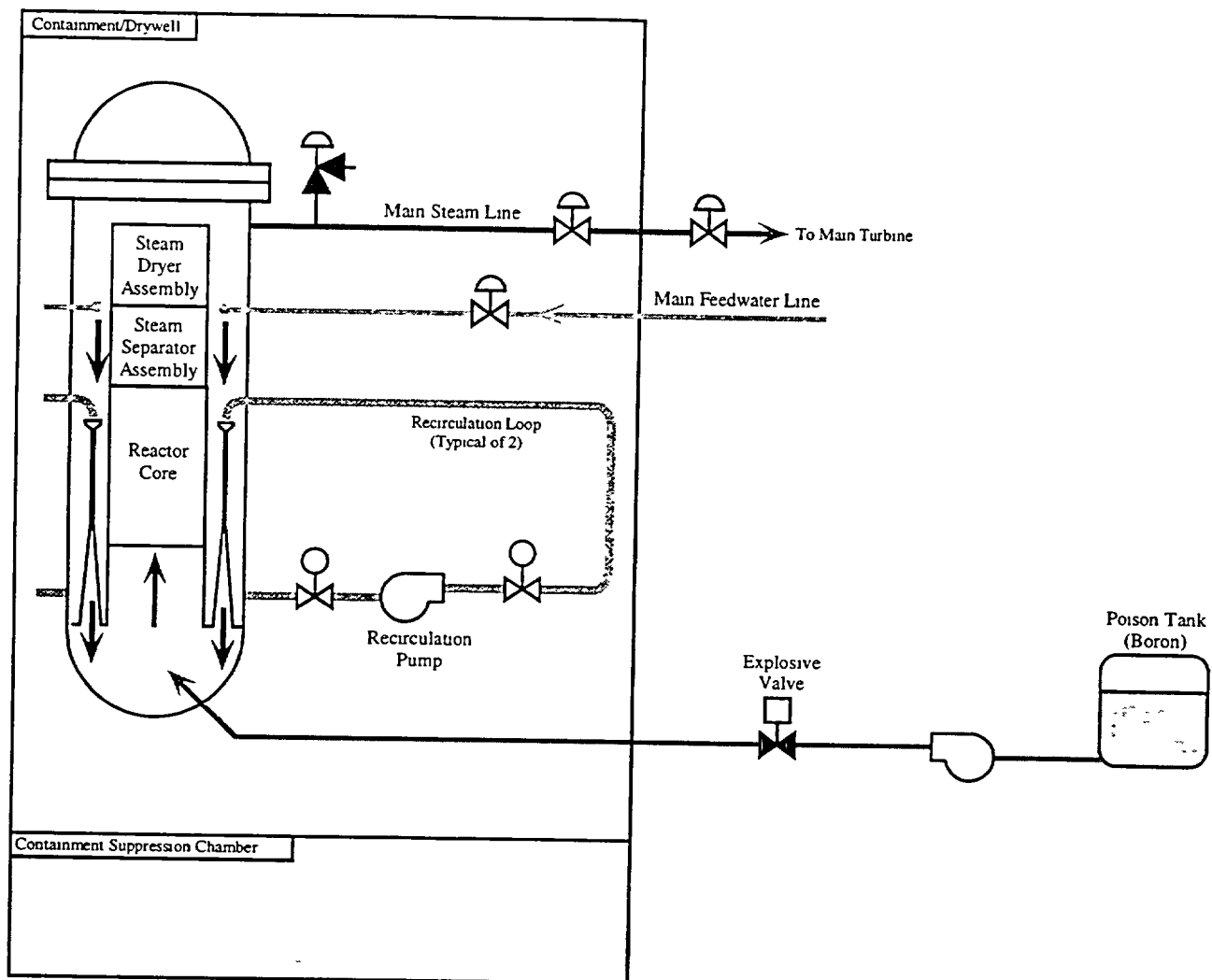
Heat is removed during normal power operation by generating steam in the reactor vessel and then using that steam to generate electrical energy. When the reactor is shutdown, the core will still continue to generate decay heat. The heat is removed by bypassing the turbine and dumping the steam directly to the condenser. The shutdown cooling mode of the residual heat removal (RHR) system is used to complete the cooldown process when pressure decreases to approximately 50 psig. Water is pumped from the reactor recirculation loop through a heat exchanger and back to the reactor via the recirculation loop. The recirculation loop is used to limit the number of penetrations into the reactor vessel.



## Reactor Core Isolation Cooling

The reactor core isolation cooling (RCIC) system provides makeup water to the reactor vessel for core cooling when the main steam lines are isolated and the normal supply of water to the reactor vessel is lost. The RCIC system consists of a turbine-driven pump, piping, and valves necessary to deliver water to the reactor vessel at operating conditions.

The turbine is driven by steam supplied by the main steam lines. The turbine exhaust is routed to the suppression pool. The turbine-driven pump supplies makeup water from the condensate storage tank, with an alternate supply from the suppression pool, to the reactor vessel via the feedwater piping. The system flow rate is approximately equal to the steaming rate 15 minutes after shutdown with design maximum decay heat. Initiation of the system is accomplished automatically on low water level in the reactor vessel or manually by the operator.



## Standby Liquid Control System

The standby liquid control system injects a neutron poison (boron) into the reactor vessel to shutdown the chain reaction, independent of the control rods, and maintains the reactor shutdown as the plant is cooled to maintenance temperatures.

The standby liquid control system consists of a heated storage tank, two positive displacement pumps, two explosive valves, and the piping necessary to inject the neutron absorbing solution into the reactor vessel. The standby liquid control system is manually initiated and provides the operator with a relatively slow method of achieving reactor shutdown conditions.

## Emergency Core Cooling Systems

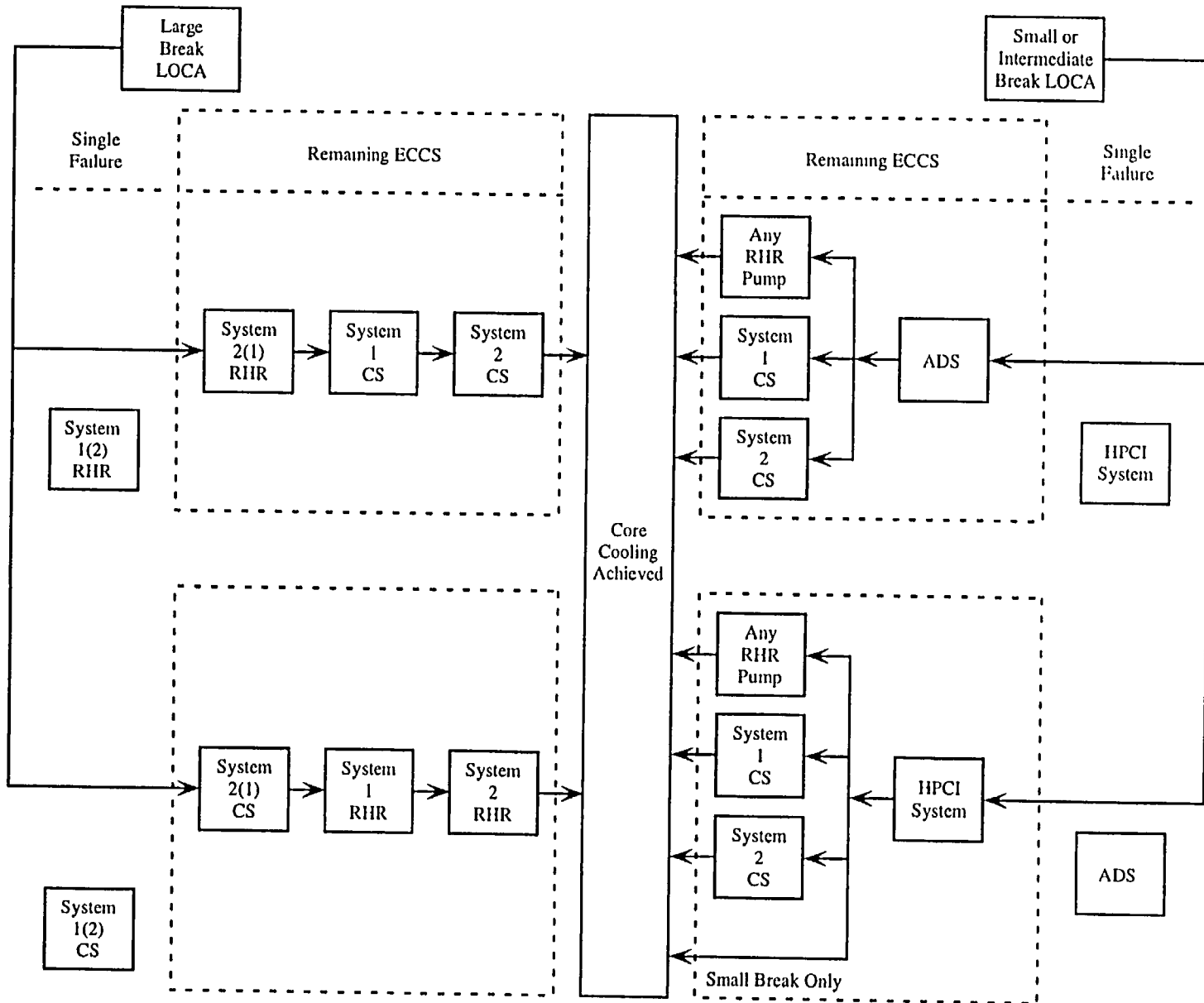
The emergency core cooling systems (ECCS) provide core cooling under loss of coolant accident conditions to limit fuel-cladding damage. The emergency core cooling systems consist of two high pressure and two low pressure systems. The high pressure systems are the high pressure coolant injection (HPCI) system and the automatic depressurization system (ADS). The low pressure systems are the low pressure coolant injection (LPCI) mode of the residual heat removal system and the core spray (CS) system.

The manner in which the emergency core cooling systems operate to protect the core is a function of the rate at which reactor coolant inventory is lost from the break in the nuclear system process barrier. The high pressure coolant injection system is designed to operate while the nuclear system is at high pressure. The core spray system and low pressure coolant injection mode of the residual heat removal system are designed for operation at low pressures. If the break in the nuclear system process barrier is of such a size that the loss of coolant exceeds the capability of the high pressure coolant injection system, reactor pressure decreases at a rate fast enough for the low pressure emergency core cooling systems to commence coolant injection into the reactor vessel in time to cool the core.

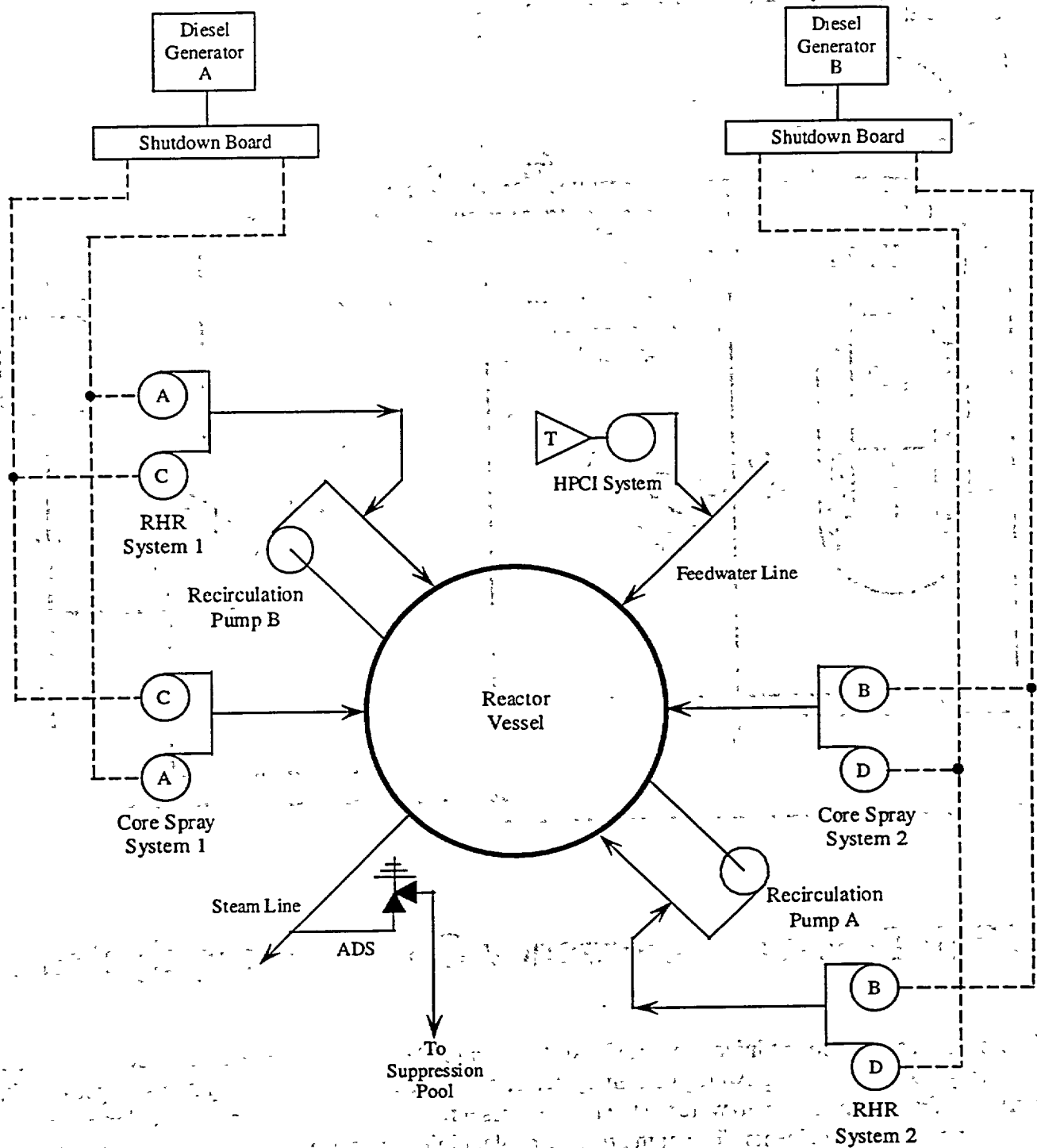
Automatic depressurization is provided to automatically reduce reactor pressure if a break has occurred and the high pressure coolant injection system is inoperable. Rapid depressurization of the reactor is desirable to permit flow from the low pressure emergency core cooling systems so that the temperature rise in the core is limited to less than regulatory requirements.

If, for a given break size, the high pressure coolant injection system has the capacity to make up for all of the coolant loss, flow from the low pressure emergency core cooling systems is not required for core cooling protection until reactor pressure has decreased below approximately 100 psig.

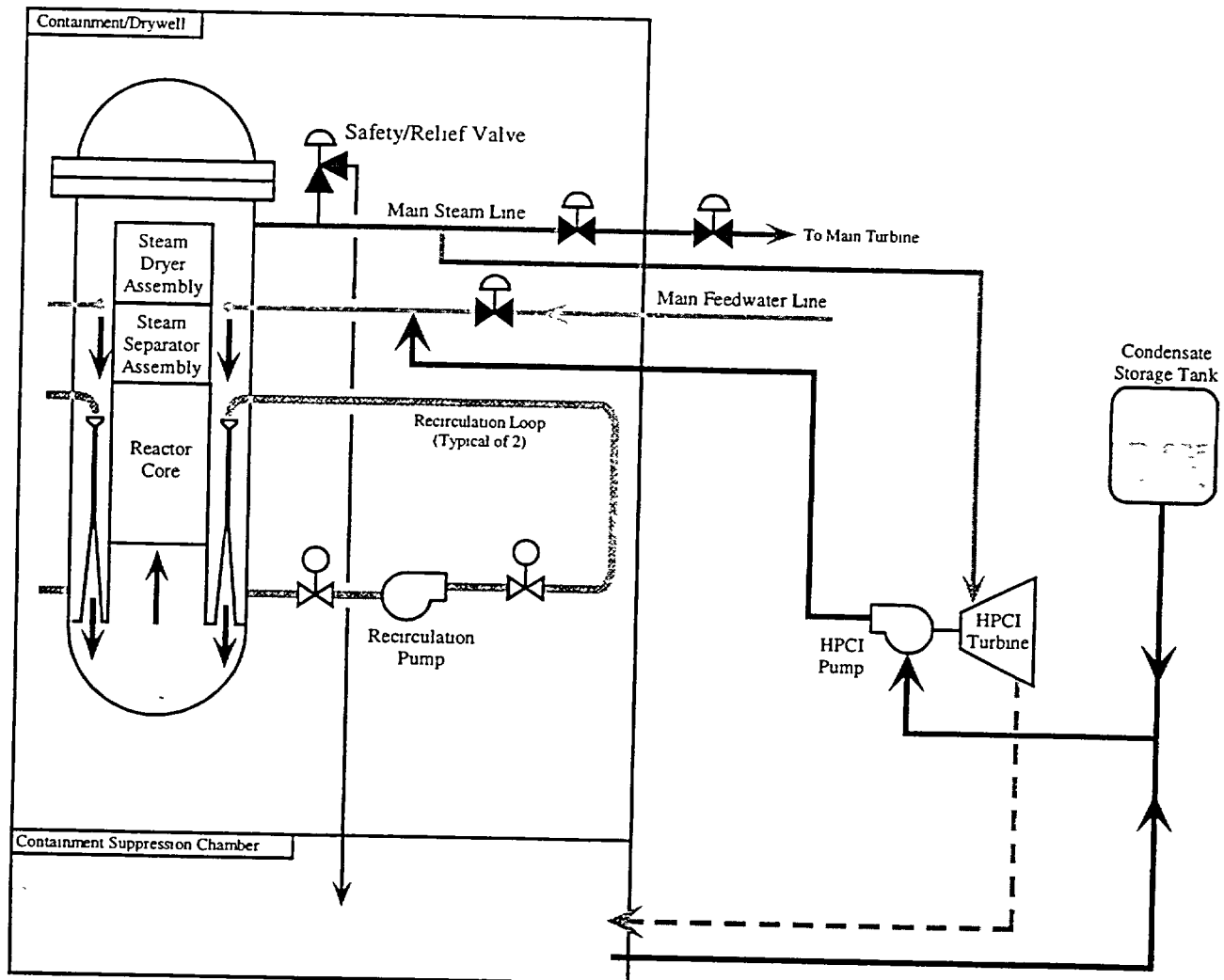
The performance of the emergency core cooling systems as an integrated package can be evaluated by determining what is left after the postulated break and a single failure of one of the emergency core cooling systems. The remaining emergency core cooling systems and components must meet the 10 CFR requirements over the entire spectrum of break locations and sizes. The integrated performance for small, intermediate, and large sized breaks is shown on pages 3-14 and 3-15.



ECCS Integrated Performance



Emergency Core Cooling System Network

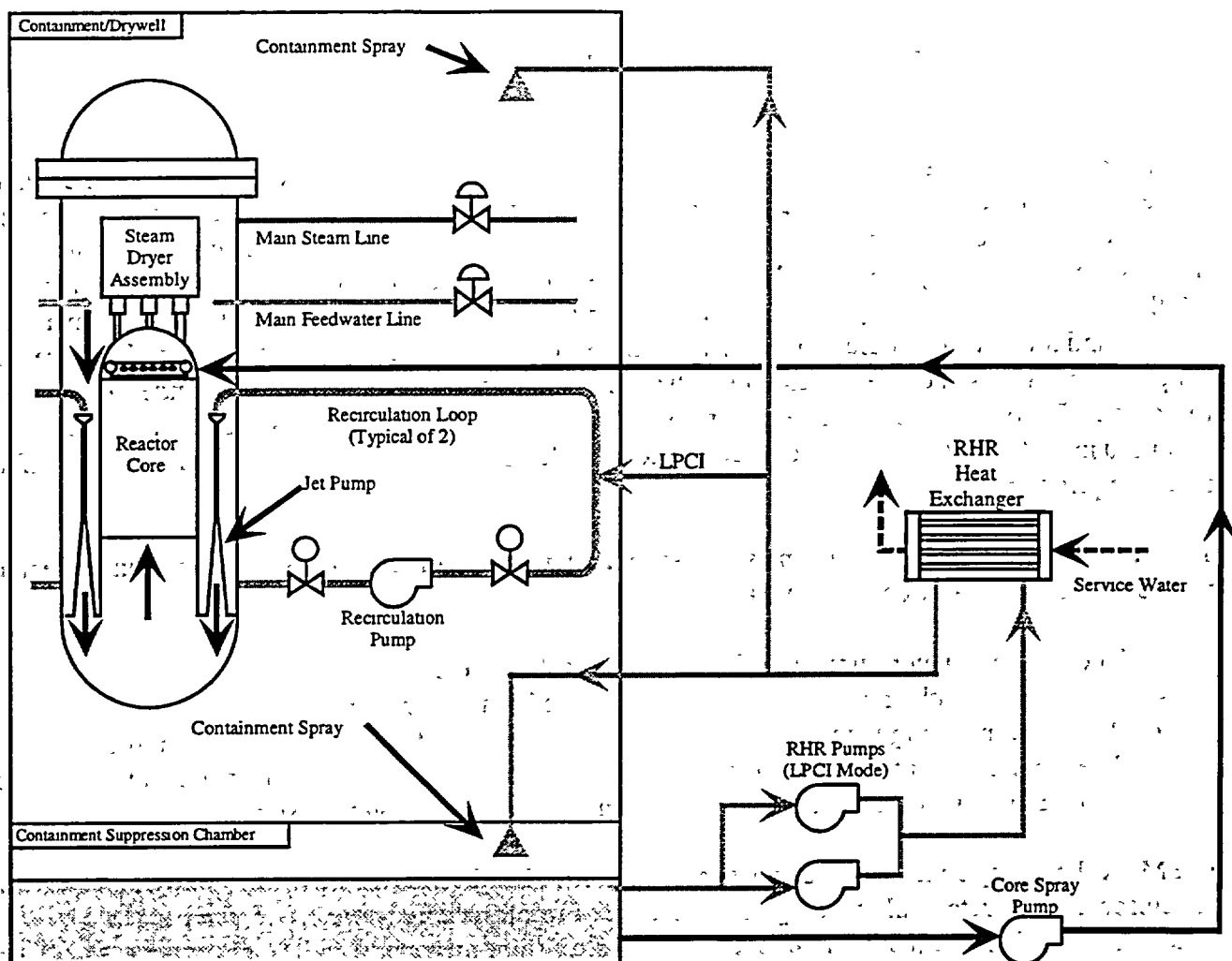


## High Pressure Emergency Core Cooling Systems

The high pressure coolant injection (HPCI) system is an independent emergency core cooling system requiring no auxiliary ac power, plant air systems, or external cooling water systems to perform its purpose of providing make up water to the reactor vessel for core cooling under small and intermediate size loss of coolant accidents. The high pressure coolant injection system can supply make up water to the reactor vessel from above rated reactor pressure to a reactor pressure below that at which the low pressure emergency core cooling systems can inject.

The automatic depressurization system (ADS) consists of redundant logics capable of opening selected safety relief valves, when required, to provide reactor depressurization for events involving small or intermediate size loss of coolant accidents if the high pressure coolant injection system is not available or cannot recover reactor vessel water level.





## Low Pressure Emergency Core Cooling Systems

The low pressure emergency core cooling systems consist of two separate and independent systems, the core spray system and the low pressure coolant injection (LPCI) mode of the residual heat removal system. The core spray system consists of two separate and independent pumping loops, each capable of pumping water from the suppression pool into the reactor vessel. Core cooling is accomplished by spraying water on top of the fuel assemblies.

The low pressure coolant injection mode of the residual heat removal system provides makeup water to the reactor vessel for core cooling under loss of coolant accident conditions. The residual heat removal system is a multipurpose system with several operational modes, each utilizing the same major pieces of equipment. The low pressure coolant injection mode is the dominant mode and normal valve lineup configuration of the residual heat removal system. The low pressure coolant injection mode operates automatically to restore and, if necessary, maintain the reactor vessel coolant inventory to preclude fuel cladding temperatures in excess of 2200°F. During low pressure coolant injection operation, the residual heat removal pumps take water from the suppression pool and discharge to the reactor vessel.

## Boiling Water Reactor Containments

The primary containment package provided for a particular product line is dependent upon the vintage of the plant and the cost-benefit analysis performed prior to the plant being built. During the evolution of the boiling water reactors, three major types of containments were built. The major containment designs are the Mark I (page 3-19), Mark II (page 3-21), and the Mark III (page 3-23). Unlike the Mark III, that consists of a primary containment and a drywell, the Mark I and Mark II designs consist of a drywell and a wetwell (suppression pool). All three containment designs use the principle of pressure suppression for loss of coolant accidents. The primary containment is designed to condense steam and to contain fission products released from a loss of coolant accident so that offsite radiation doses specified in 10 CFR 100 are not exceeded and to provide a heat sink and water source for certain safety-related equipment.

The Mark I containment design consists of several major components, many of which can be seen on page 3-19. These major components include:

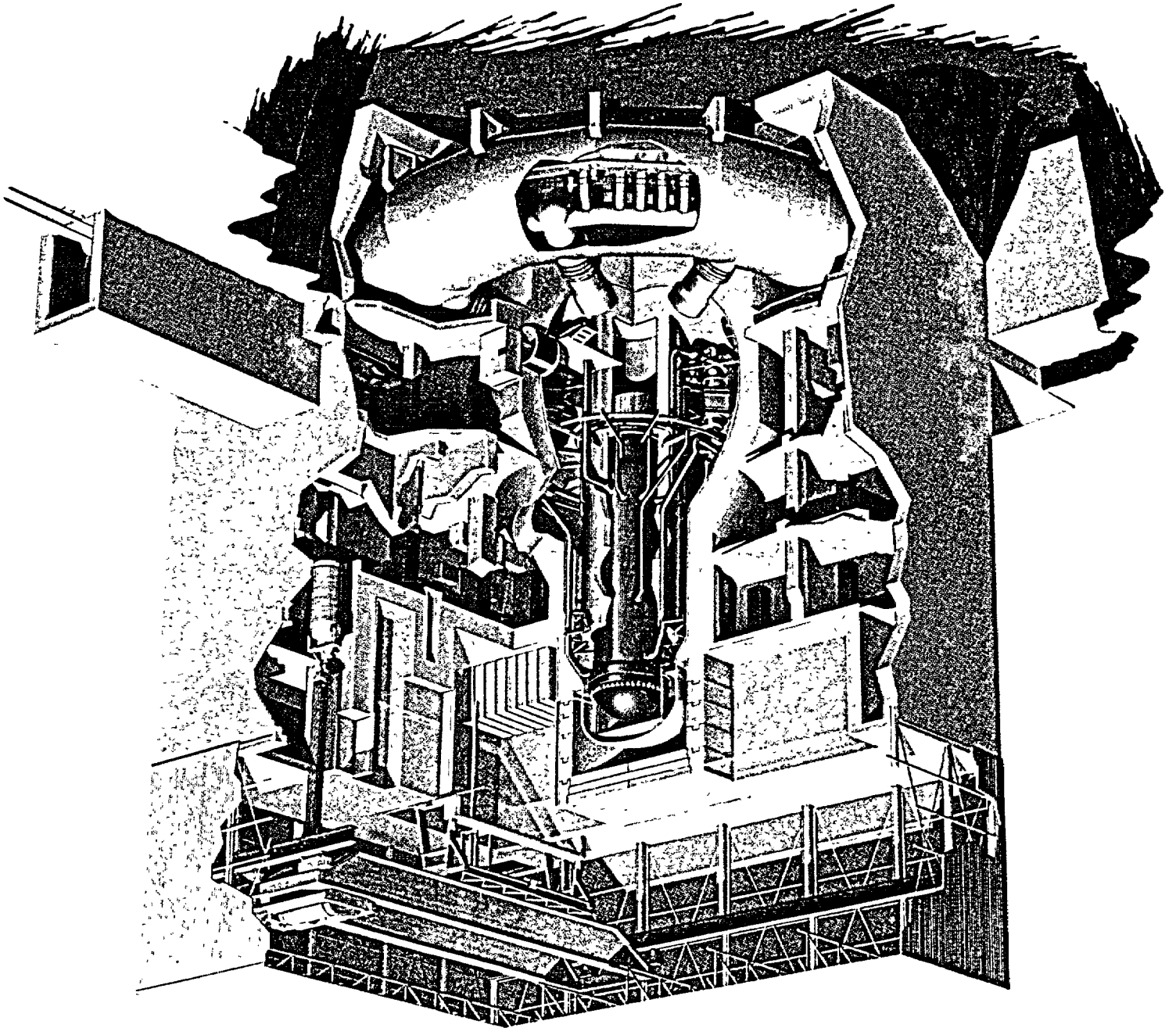
- The drywell, which surrounds the reactor vessel and recirculation loops,
- A suppression chamber, which stores a large body of water (suppression pool),
- An interconnecting vent network between the drywell and the suppression chamber, and
- The secondary containment, which surrounds the primary containment (drywell and suppression pool) and houses the spent fuel pool and emergency core cooling systems.

The Mark II primary containment consists of a steel dome head and either a post-tensioned concrete wall or reinforced concrete wall standing on a base mat of reinforced concrete. The inner surface of the containment is lined with a steel plate that acts as a leak-tight membrane. The containment wall also serves as a support for the floor slabs of the reactor building (secondary containment) and the refueling pools. The Mark II design is an over-under configuration. The drywell, in the form of a frustum of a cone or a truncated cone, is located directly above the suppression pool. The suppression chamber is cylindrical and separated from the drywell by a reinforced concrete slab. The drywell is topped by an elliptical steel dome called a drywell head. The drywell inerted atmosphere is vented into the suppression chamber through a series of downcomer pipes penetrating and supported by the drywell floor.

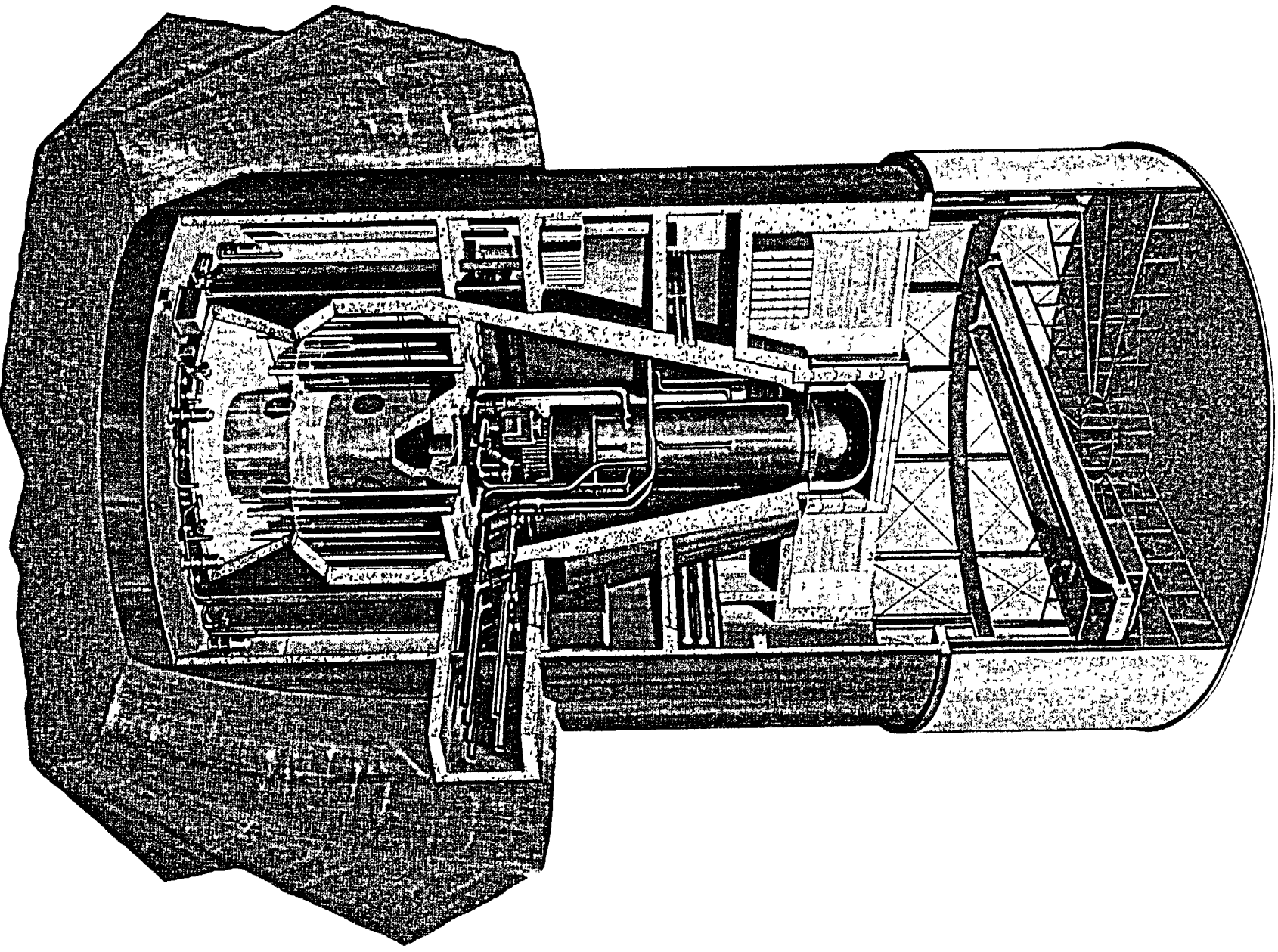
The Mark III primary containment consists of several major components, many of which can be seen on page 3-23. The drywell (13) is a cylindrical, reinforced concrete structure with a removable head. The drywell is designed to withstand and confine steam generated during a pipe rupture inside the containment and to channel the released steam into the suppression pool (10) via the weir wall (11) and the horizontal vents (12). The suppression pool contains a large volume of water for rapidly condensing steam directed to it. A leak tight, cylindrical, steel containment vessel (2) surround the drywell and the suppression pool to prevent gaseous and particulate fission products from escaping to the environment following a pipe break inside containment.

GENERAL ELECTRIC

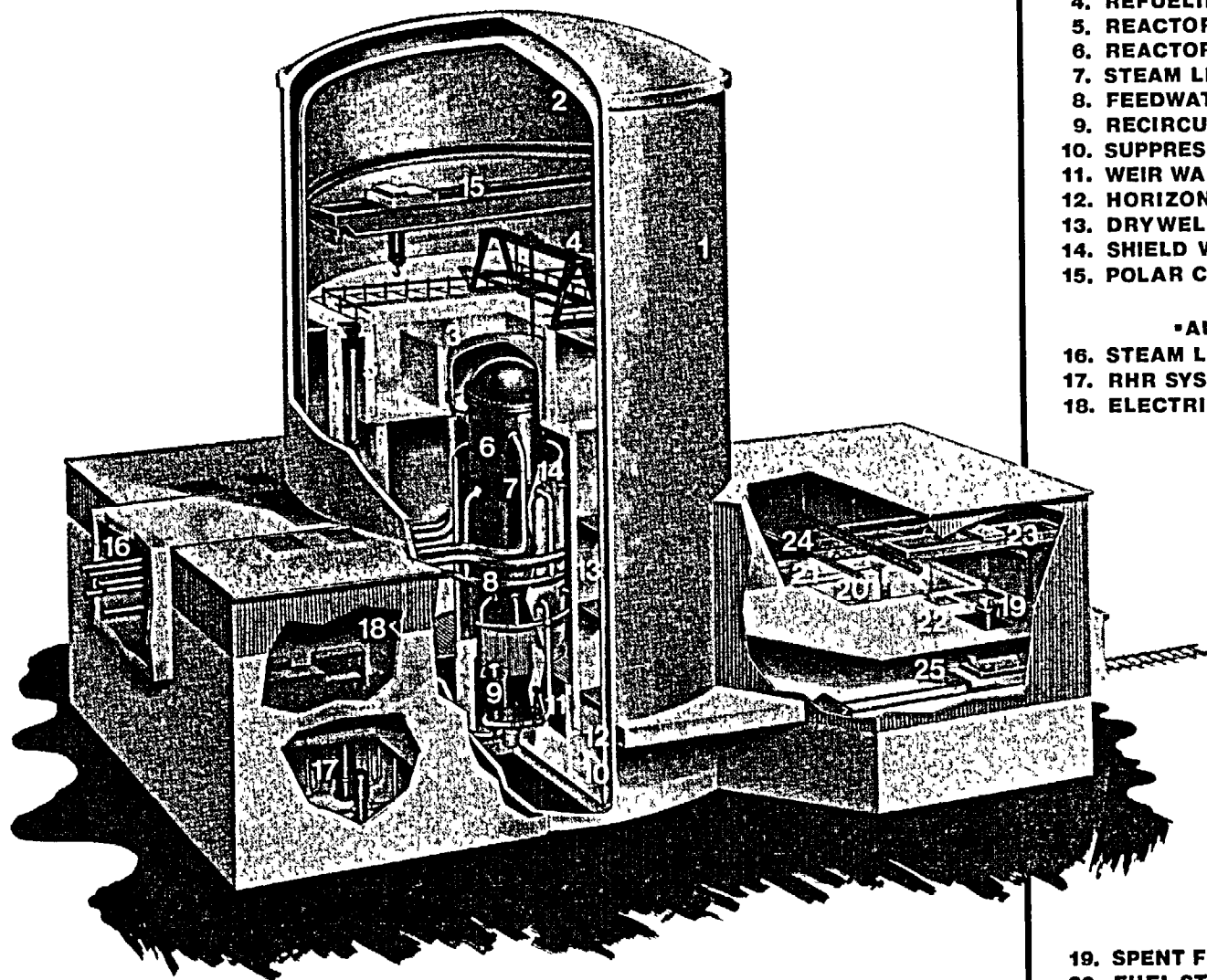
# DRYWELL TORUS



# BWR CONCRETE CONTAINMENT



# MARK III CONTAINMENT



## •REACTOR BUILDING•

1. SHIELD BUILDING
2. FREESTANDING STEEL CONTAINMENT
3. UPPER POOL
4. REFUELING PLATFORM
5. REACTOR WATER CLEANUP
6. REACTOR VESSEL
7. STEAM LINE
8. FEEDWATER LINE
9. RECIRCULATION LOOP
10. SUPPRESSION POOL
11. WEIR WALL
12. HORIZONTAL VENT
13. DRYWELL
14. SHIELD WALL
15. POLAR CRANE

## •AUXILIARY BUILDING•

16. STEAM LINE TUNNEL
17. RHR SYSTEM
18. ELECTRICAL EQUIPMENT ROOM

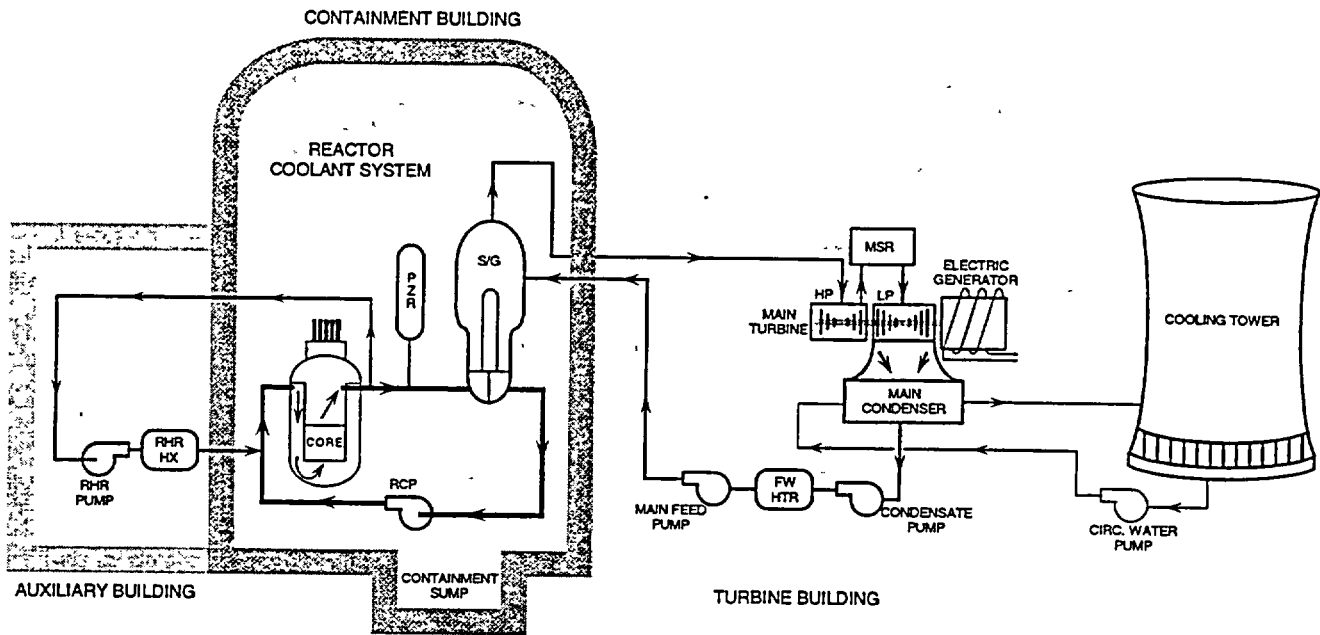
## •FUEL BUILDING•

19. SPENT FUEL SHIPPING CASK
20. FUEL STORAGE POOL
21. FUEL TRANSFER POOL
22. CASK LOADING POOL
23. CASK HANDLING CRANE
24. FUEL TRANSFER BRIDGE
25. FUEL CASK SKID ON RAILROAD CAR

GENERAL  ELECTRIC

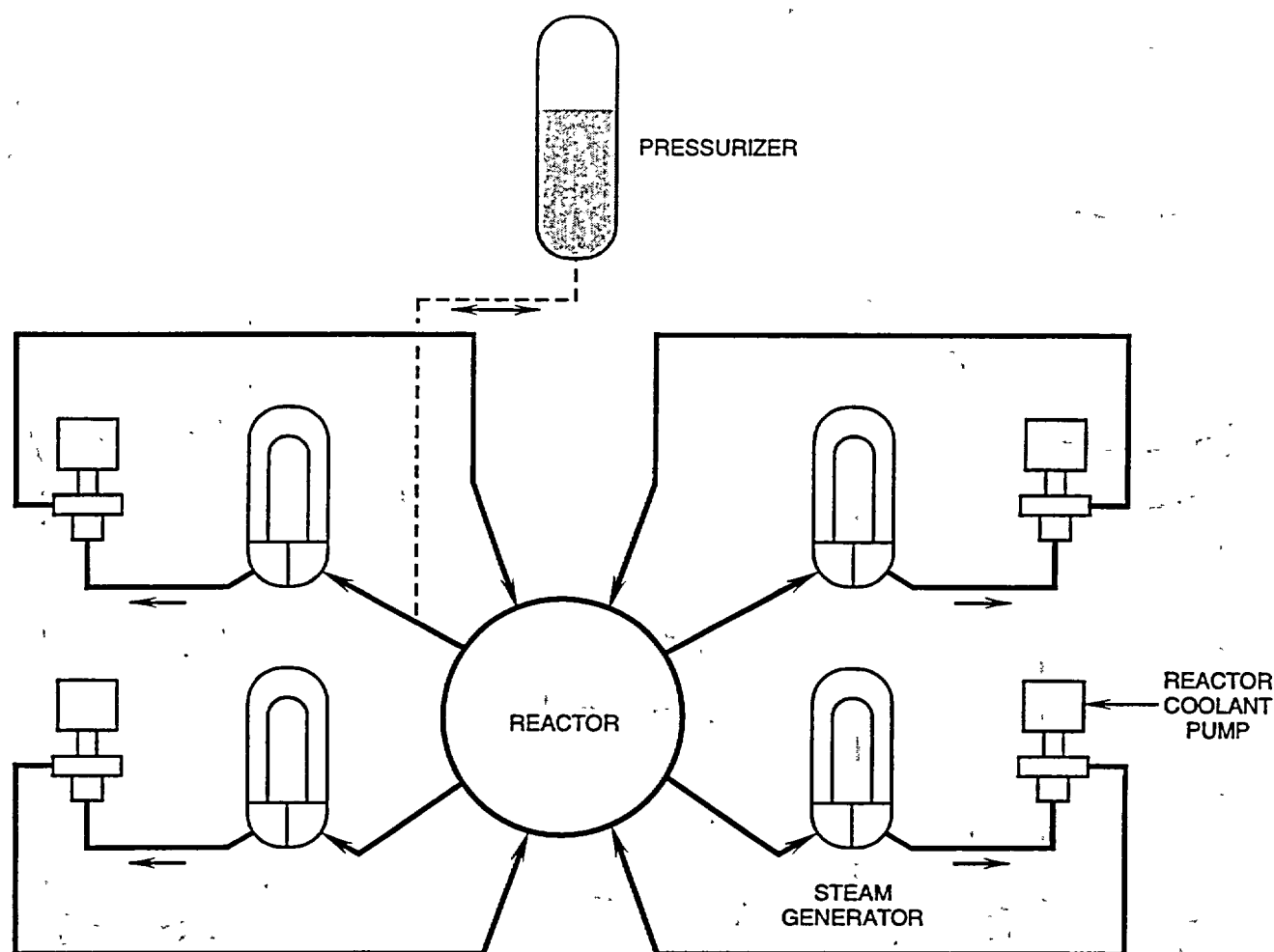
# Pressurized Water Reactor (PWR) Systems

For a nuclear power plant to perform the function of generating electricity, many different systems must perform their functions. These functions may range from the monitoring of a plant parameter to the controlling of the main turbine or the reactor. This chapter will discuss the purposes of some of the major systems and components associated with a pressurized water reactor.



There are two major systems utilized to convert the heat generated in the fuel into electrical power for industrial and residential use. The primary system transfers the heat from the fuel to the steam generator, where the secondary system begins. The steam formed in the steam generator is transferred by the secondary system to the main turbine generator, where it is converted into electricity. After passing through the low pressure turbine, the steam is routed to the main condenser. Cool water, flowing through the tubes in the condenser, removes excess heat from the steam, which allows the steam to condense. The water is then pumped back to the steam generator for reuse.

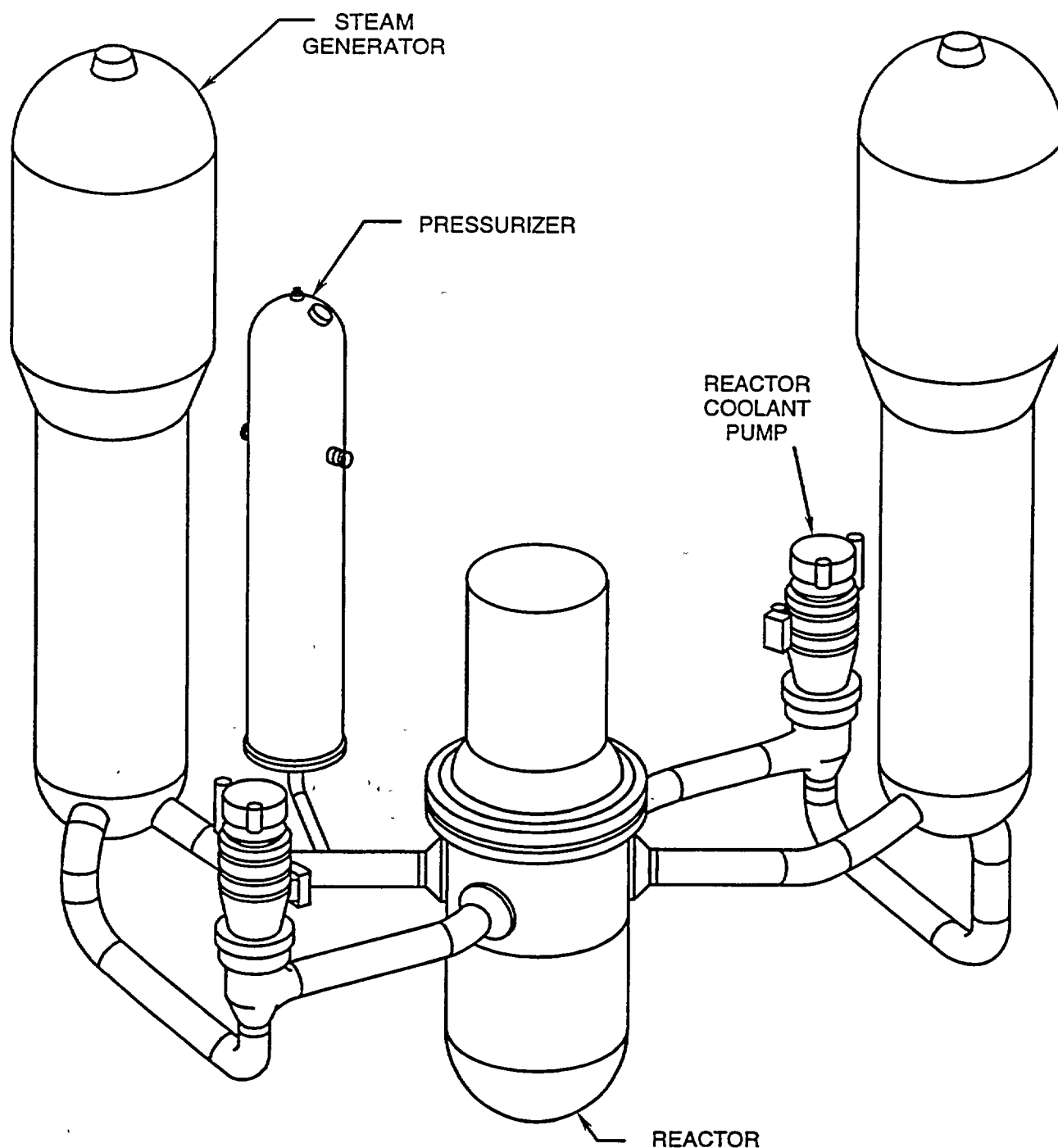
In order for the primary and secondary systems to perform their functions, there are approximately one hundred support systems. In addition, for emergencies, there are dedicated systems to mitigate the consequences of accidents.



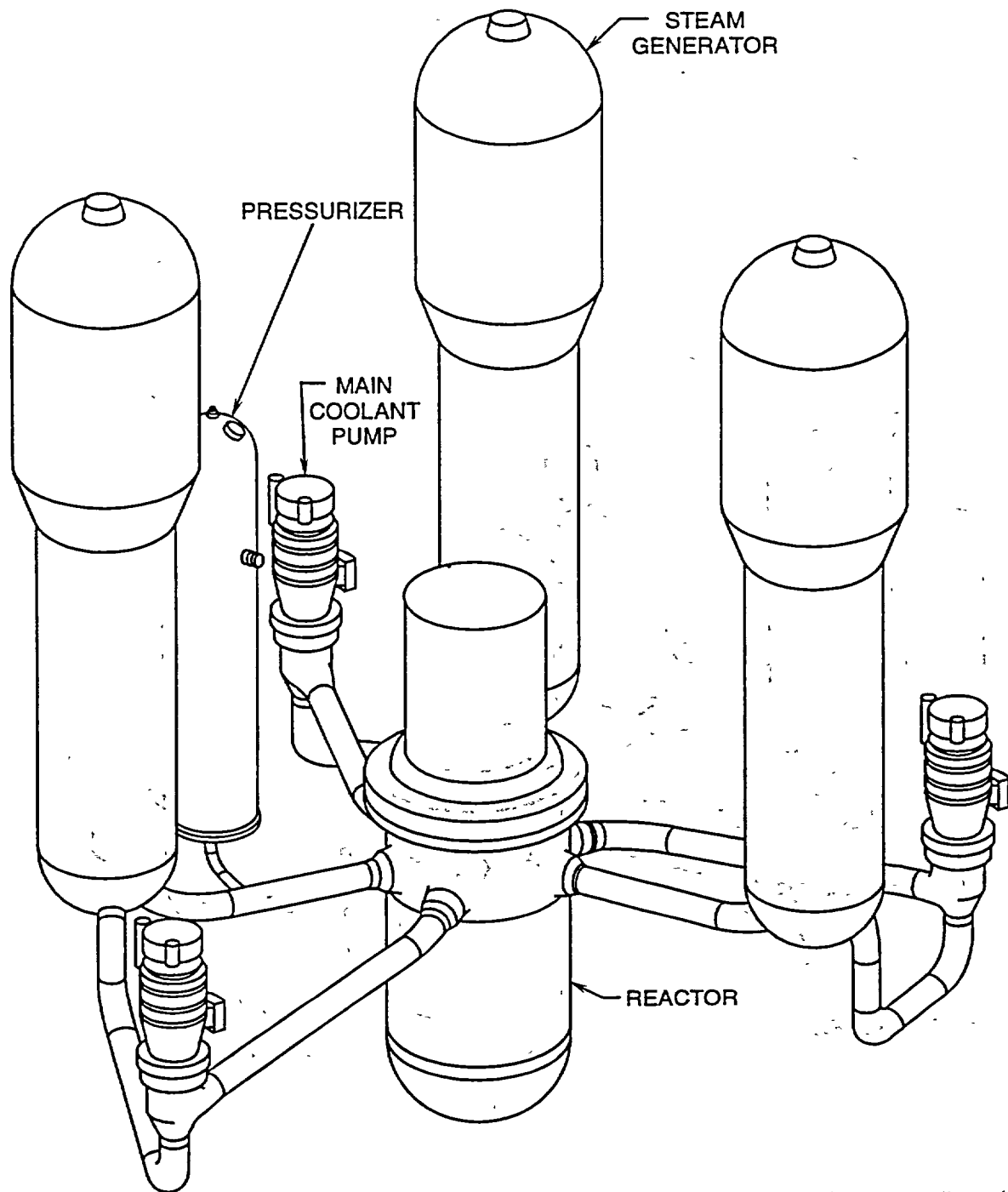
The primary system (also called the Reactor Coolant System) consists of the reactor vessel, the steam generators, the reactor coolant pumps, a pressurizer, and the connecting piping. A reactor coolant loop is a reactor coolant pump, a steam generator, and the piping that connects these components to the reactor vessel. The primary function of the reactor coolant system is to transfer the heat from the fuel to the steam generators. A second function is to contain any fission products that escape the fuel.

The following drawings show the layout of the reactor coolant systems for three pressurized water reactor vendors. All of the systems consist of the same major components, but they are arranged in slightly different ways. For example, Westinghouse has built plants with two, three, or four loops, depending upon the power output of the plant. The Combustion Engineering plants and the Babcock & Wilcox plants only have two steam generators, but they have four reactor coolant pumps.

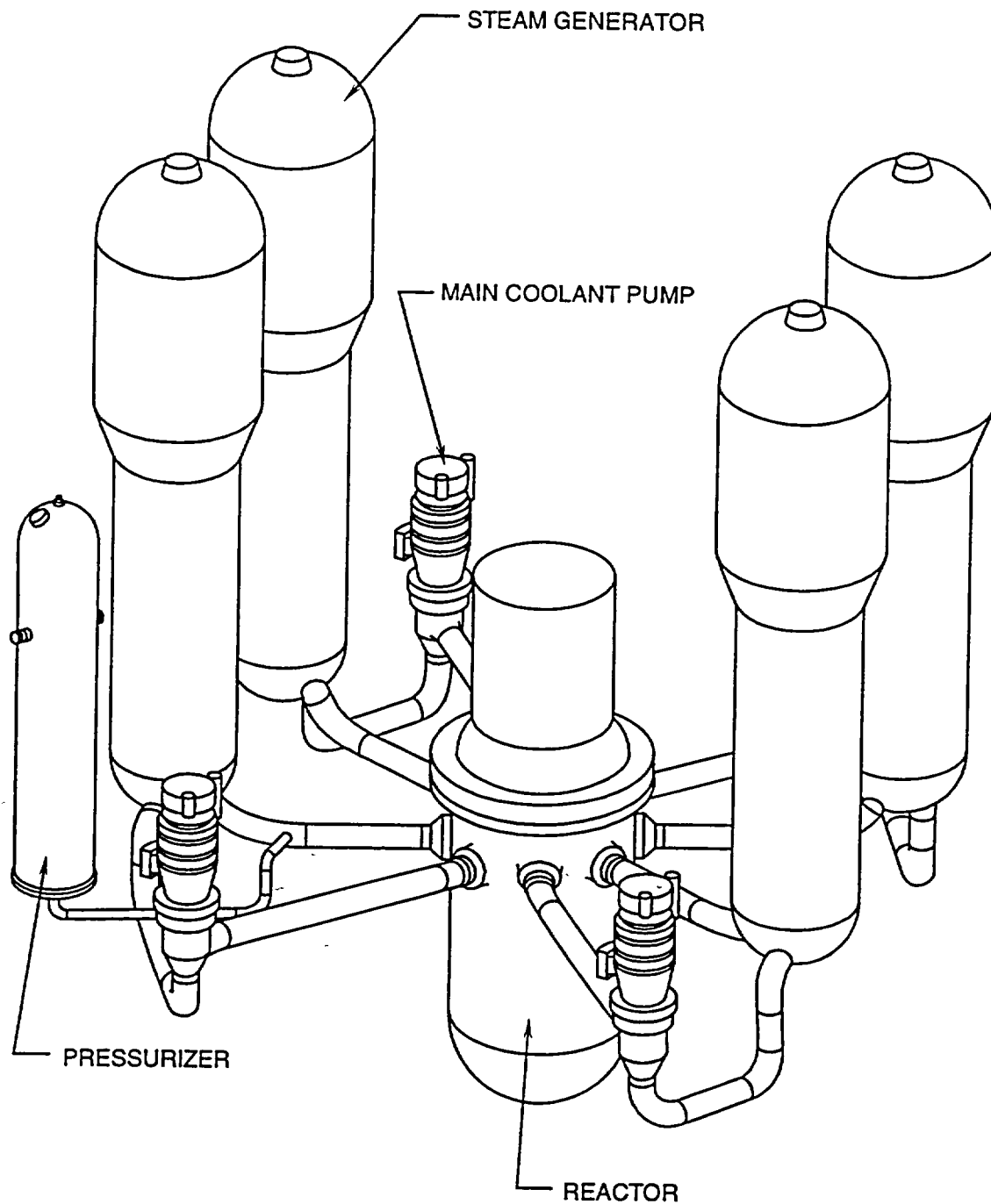




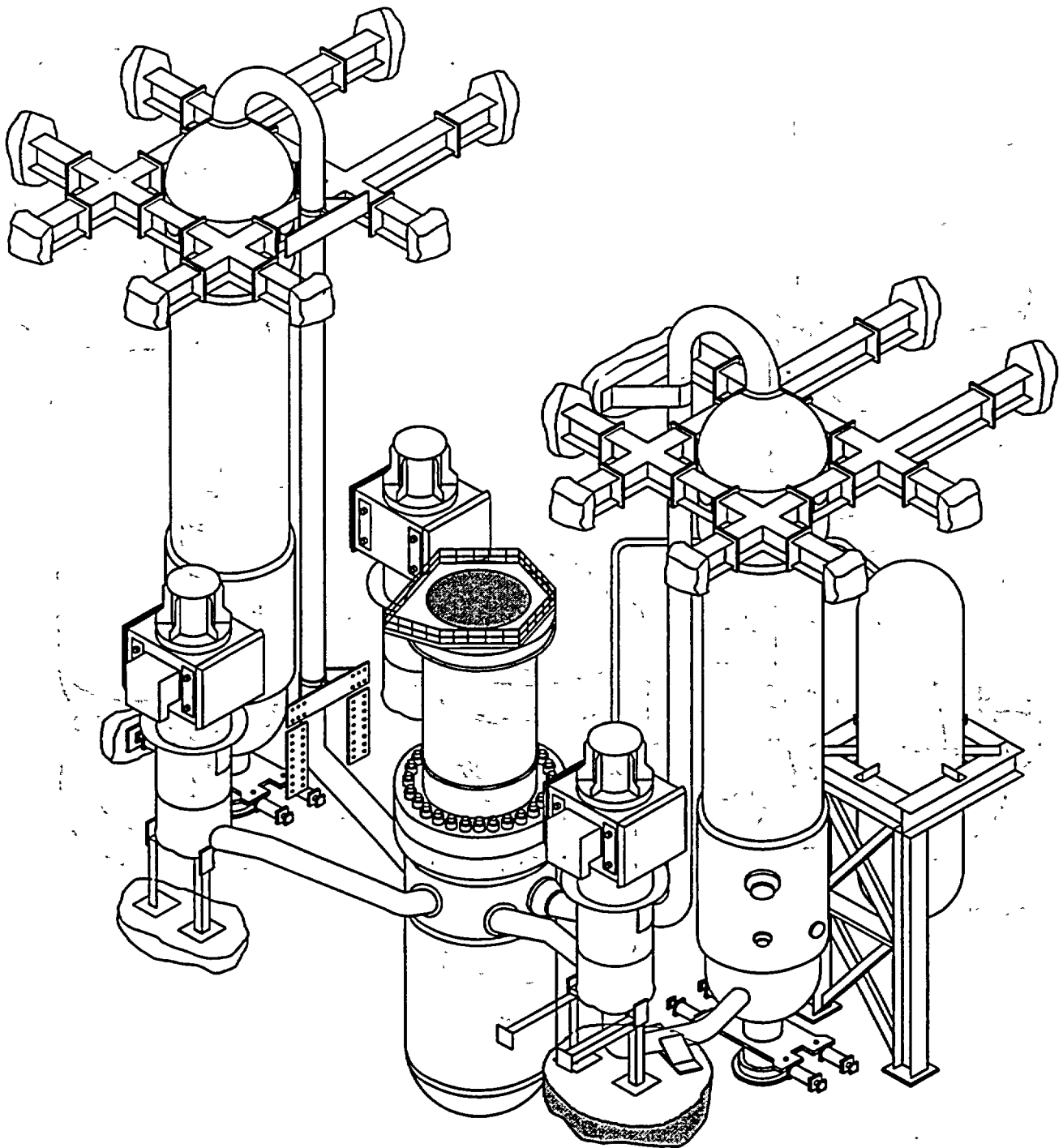
A two-loop Westinghouse plant has two steam generators, two reactor coolant pumps, and a pressurizer. The two-loop units in the United States are Ginna, Kewaunee, Point Beach 1 and 2, and Prairie Island 1 and 2. Each of these plants has 121, 14 x 14 fuel assemblies arranged inside a reactor vessel that has an internal diameter of 132 inches. The electrical output of these plants is approximately 500 megawatts.



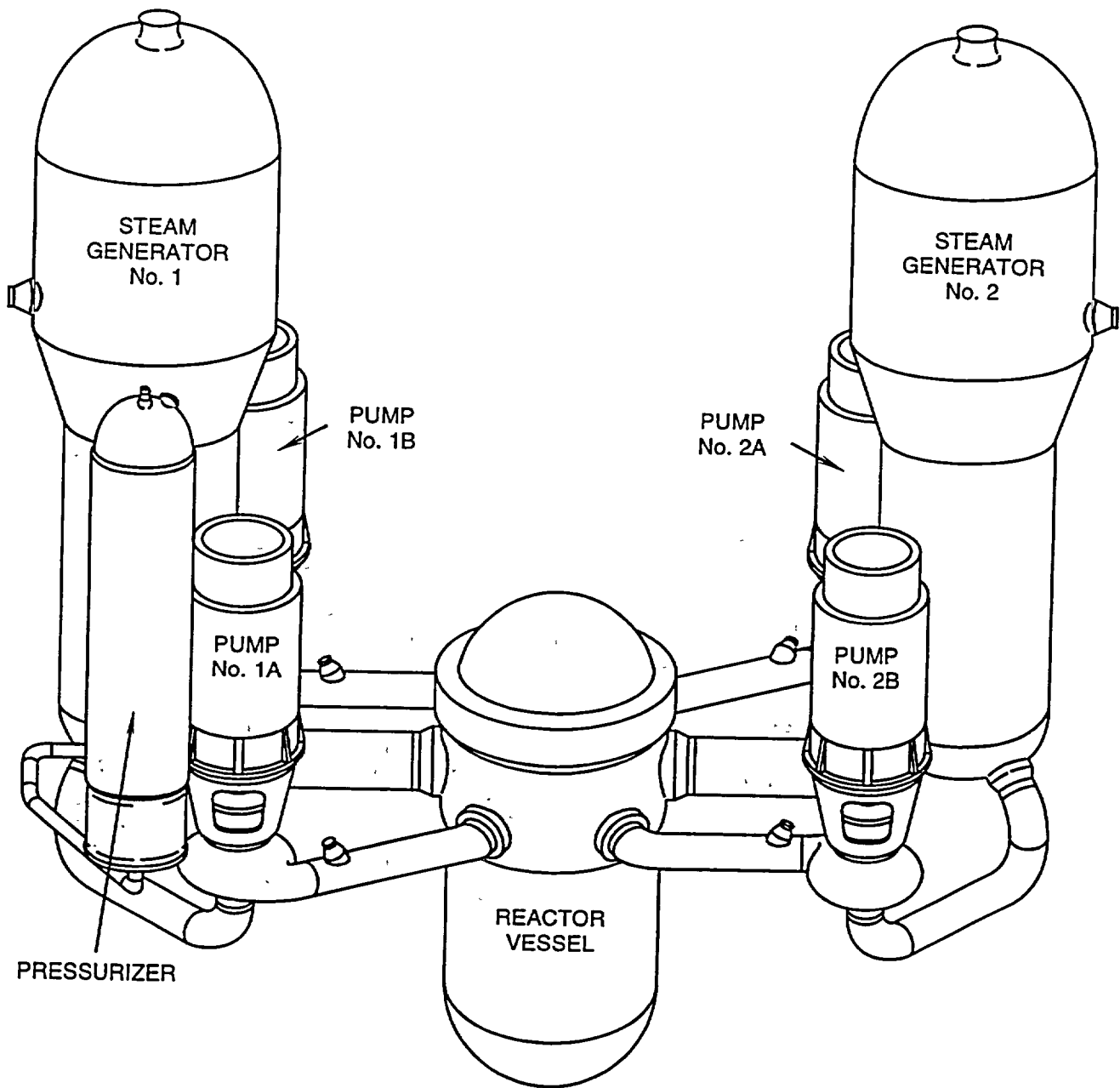
A three-loop Westinghouse plant has three steam generators, three reactor coolant pumps, and a pressurizer. The three-loop units in the United States are Beaver Valley 1 and 2, Farley 1 and 2, H. B. Robinson 2, North Anna 1 and 2, Shearon Harris 1, V. C. Summer, Surry 1 and 2, and Turkey Point 3 and 4. Each of these plants has 157 fuel assemblies. Some units use 15 x 15 fuel assemblies while others use 17 x 17 arrays. The reactor vessels have internal diameters of 156 to 159 inches, except Summer and Turkey Point, which have 172-inch reactor vessels. The electrical output of these plants varies from almost 700 to more than 900 megawatts.



A four-loop Westinghouse plant has four steam generators, four reactor coolant pumps, and a pressurizer. The four-loop units in the United States are Braidwood 1 and 2, Byron 1 and 2, Callaway, Catawba 1 and 2, Comanche Peak 1 and 2, D. C. Cook 1 and 2, Diablo Canyon 1 and 2, Indian Point 2 and 3, McGuire 1 and 2, Millstone 3, Salem 1 and 2, Seabrook, Sequoyah 1 and 2, South Texas Project 1 and 2, Vogtle 1 and 2, Watts Bar 1, and Wolf Creek. Each of these plants has 193 fuel assemblies arranged inside a reactor vessel that has an internal diameter of 173 inches (except South Texas has an internal diameter of 167 inches). The fuel assemblies are arranged in 17 x 17 array except for Cook and Indian Point, which have 15 x 15 fuel. The electrical output of these plants ranges from 950 to 1250 megawatts.



A Babcock & Wilcox plant has two once through steam generators, four reactor coolant pumps, and a pressurizer. The Babcock & Wilcox units in the United States are Arkansas 1, Crystal River 3, Davis Besse, Oconee 1, 2, and 3; and Three Mile Island 1. Each of these plants has 177 fuel assemblies. The electrical output of these plants is approximately 850 megawatts.



A Combustion Engineering plant has two steam generators, four reactor coolant pumps, and a pressurizer. The Combustion Engineering units in the United States are Arkansas 2, Calvert Cliffs 1 and 2, Fort Calhoun, Millstone 2, Palisades, Palo Verde 1, 2, and 3, San Onofre 2 and 3, Saint Lucie 1 and 2, and Waterford 3. The electrical output of these plants varies from less than 500 to more than 1200 megawatts.

## Reactor Vessel

The reactor core, and all associated support and alignment devices, are housed within the reactor vessel (cutaway view on page 4-10). The major components are the reactor vessel, the core barrel, the reactor core, and the upper internals package.

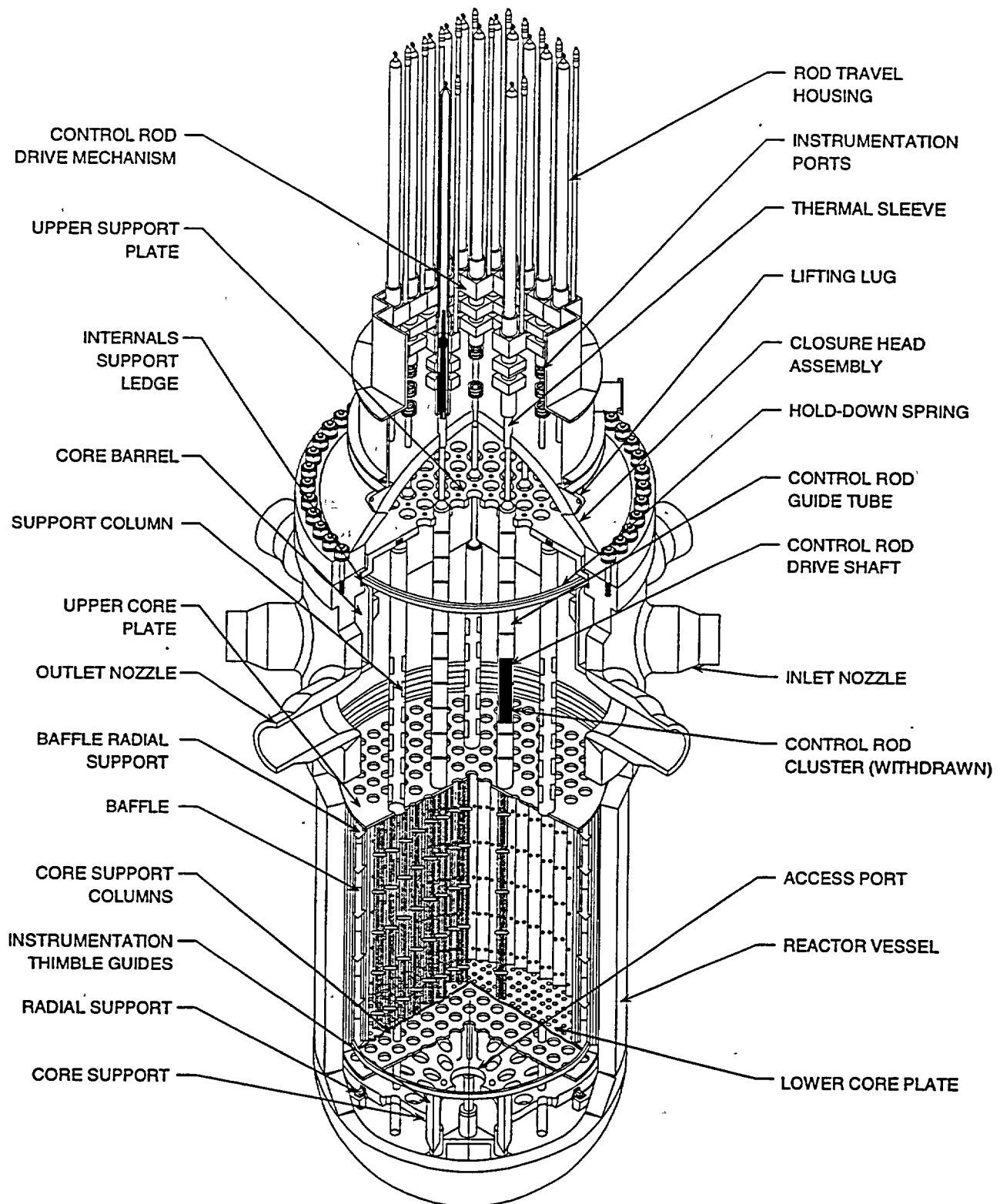
The reactor vessel is a cylindrical vessel with a hemispherical bottom head and a removable hemispherical top head. The top head is removable to allow for the refueling of the reactor. There will be one inlet (or cold leg) nozzle and one outlet (or hot leg) nozzle for each reactor coolant system loop. The reactor vessel is constructed of a manganese molybdenum steel, and all surfaces that come into contact with reactor coolant are clad with stainless steel to increase corrosion resistance.

The core barrel slides down inside of the reactor vessel and houses the fuel. Toward the bottom of the core barrel, there is a lower core support plate on which the fuel assemblies sit. The core barrel and all of the lower internals actually hang inside the reactor vessel from the internals support ledge. On the outside of the core barrel will be irradiation specimen holders in which samples of the material used to manufacture the vessel will be placed. At periodic time intervals, some of these samples will be removed and tested to see how the radiation from the fuel has affected the strength of the material.

The upper internals package sits on top of the fuel. It contains the guide columns to guide the control rods when they are pulled from the fuel. The upper internals package prevents the core from trying to move up during operation due to the force from the coolant flowing through the assemblies.

The flow path for the reactor coolant through the reactor vessel would be:

- The coolant enters the reactor vessel at the inlet nozzle and hits against the core barrel.
- The core barrel forces the water to flow downward in the space between the reactor vessel wall and the core barrel.
- After reaching the bottom of the reactor vessel, the flow is turned upward to pass through the fuel assemblies.
- The coolant flows all around and through the fuel assemblies, removing the heat produced by the fission process.
- The now hotter water enters the upper internals region, where it is routed out the outlet nozzle and goes on to the steam generator.



**Cutaway View of Reactor Vessel**

## Steam Generators

The reactor coolant flows from the reactor to the steam generator. Inside of the steam generator, the hot reactor coolant flows inside of the many tubes. The secondary coolant, or feedwater, flows around the outside of the tubes, where it picks up heat from the primary coolant. When the feedwater absorbs sufficient heat, it starts to boil and form steam. At this point, the steam generators used by the three Pressurized Water Reactor vendors differ slightly in their designs and operations.

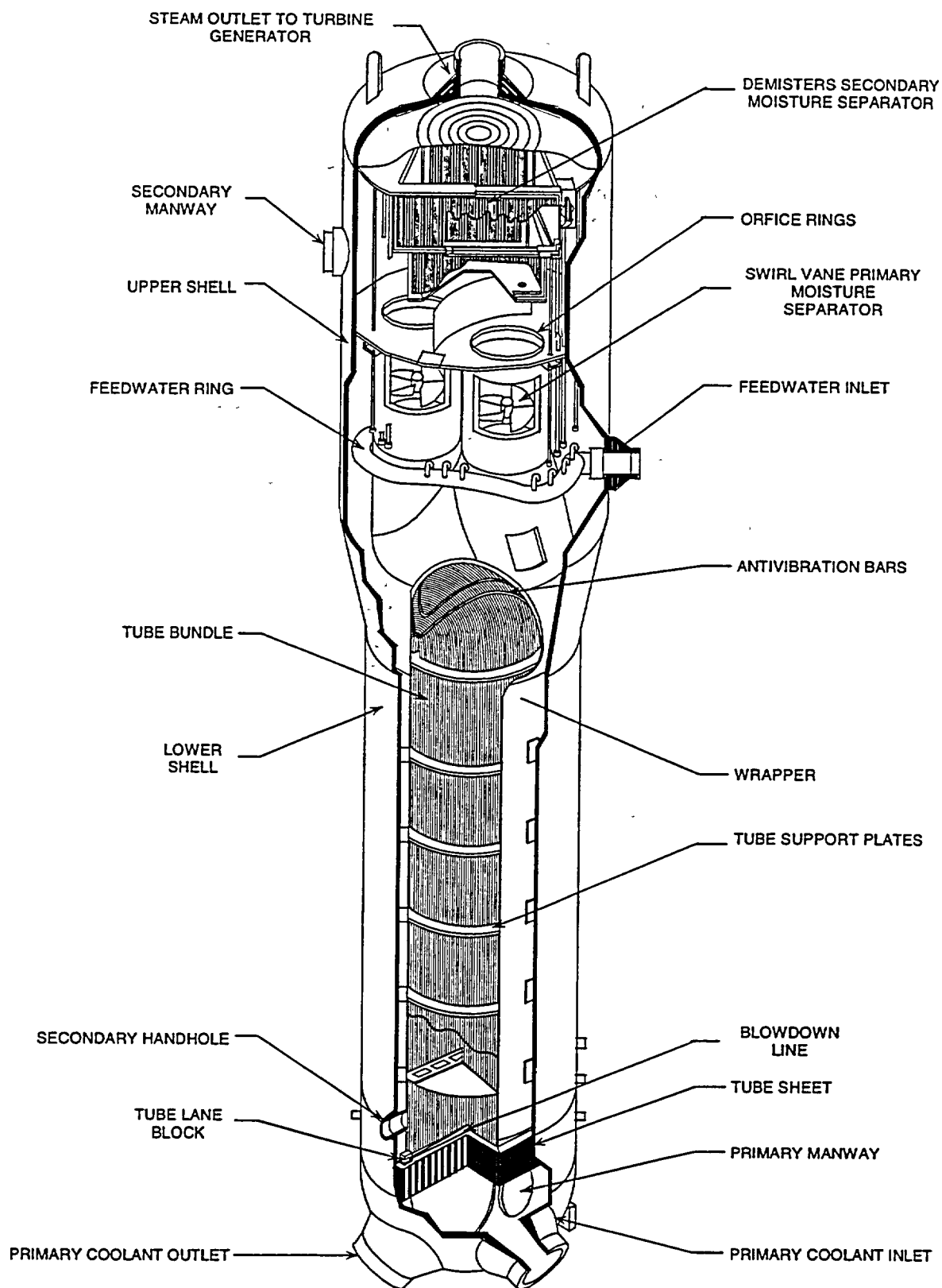
In the Westinghouse (page 4-12) and Combustion Engineering (page 4-13) designs, the steam/water mixture passes through multiple stages of moisture separation. One stage causes the mixture to spin, which slings the water to the outside. The water is then drained back to be used to make more steam. The drier steam is routed to the second stage of separation. In this stage, the mixture is forced to make rapid changes in direction. Because of the steam's ability to change direction and the water's inability to change, the steam exits the steam generator, and the water is drained back for reuse. The two stage process of moisture removal is so efficient at removing the water that for every 100 pounds of steam that exits the steam generator, the water content is less than 0.25 pounds. It is important to maintain the moisture content of the steam as low as possible to prevent damage to the turbine blading.

The Babcock & Wilcox design uses a once through steam generator (OTSG, page 4-14). In this design, the flow of primary coolant is from the top of the steam generator to the bottom, instead of through U-shaped tubes as in the Westinghouse and Combustion Engineering designs. Because of the heat transfer achieved by this design, the steam that exits the once through steam generator contains no moisture. This is done by heating the steam above the boiling point, or superheating.

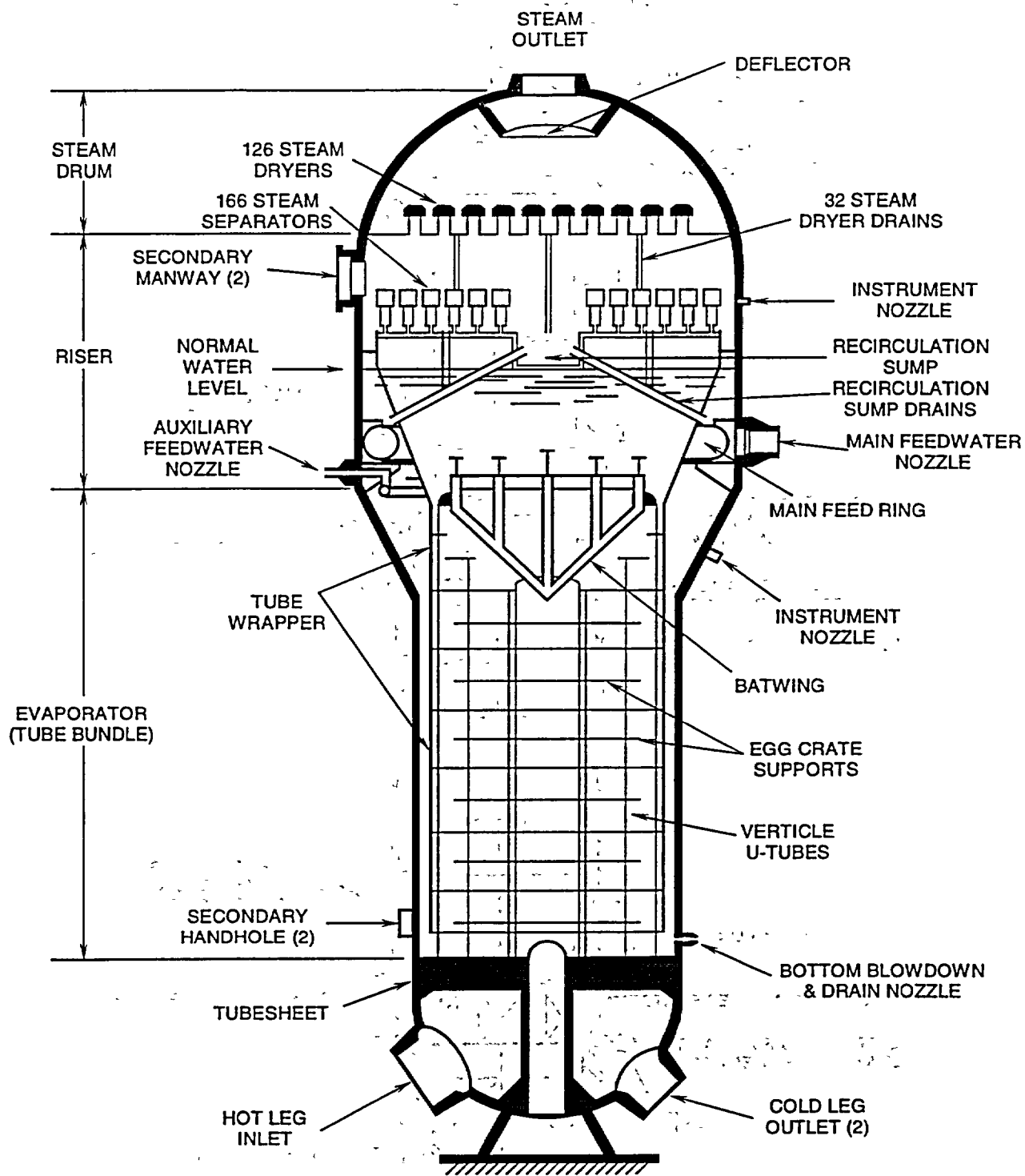
Other differences in design include the ways in which the steam and the cooler primary coolant exit the steam generators. In a Westinghouse steam generator, there is a single outlet for the steam and a single outlet for the primary coolant. For both the Babcock & Wilcox design and the Combustion Engineering design there are two steam outlets and two primary coolant outlets.

For all of the steam generator designs, the steam is piped to the main turbine, and the coolant is routed to the suction of the reactor coolant pumps.

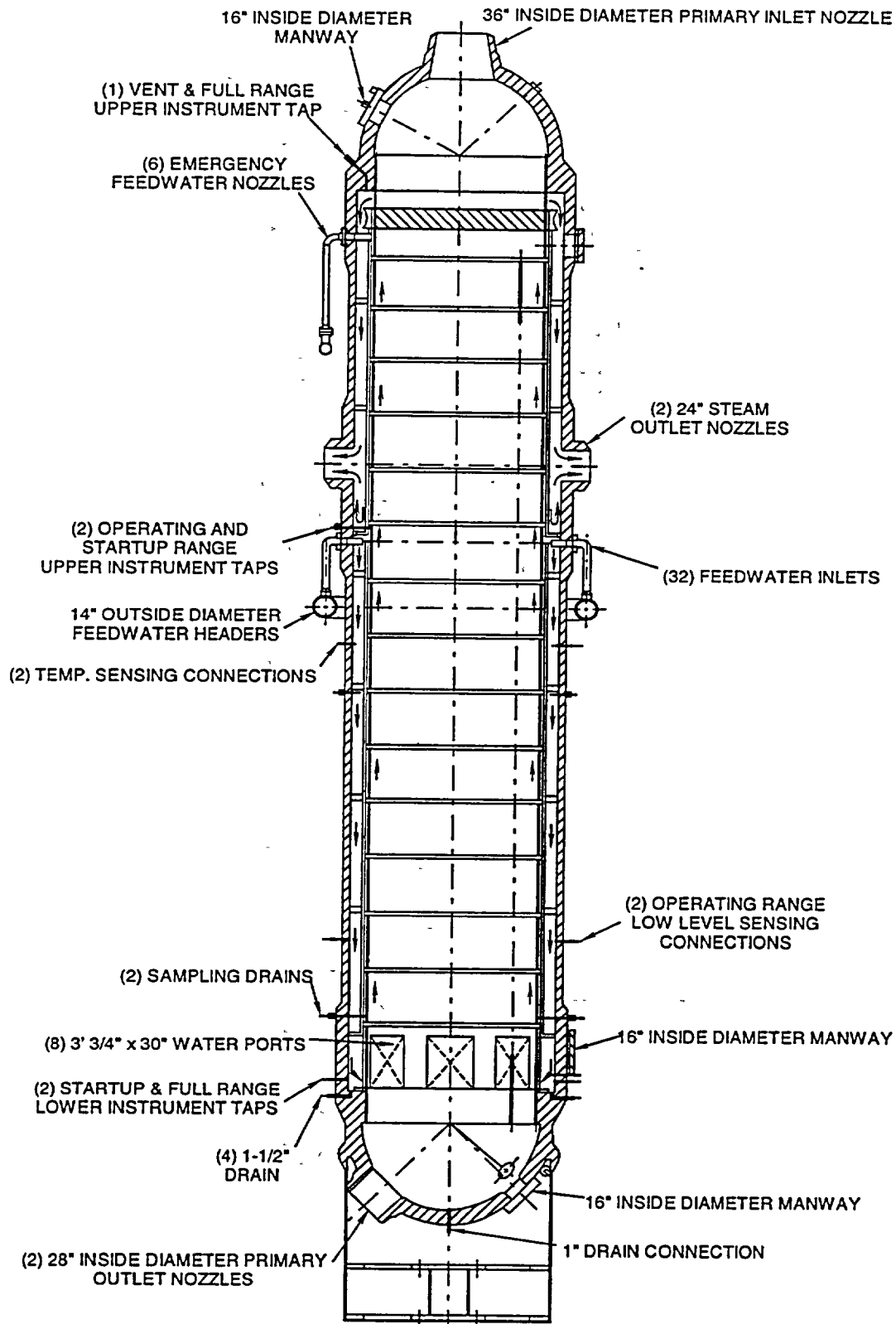




**Cutaway View of A Westinghouse Steam Generator**



**Cutaway View of a Combustion Engineering Steam Generator**



**Cutaway View of a Babcock & Wilcox Once Through Steam Generator**

## Reactor Coolant Pump

The purpose of the reactor coolant pump is to provide forced primary coolant flow to remove the amount of heat being generated by the fission process. Even without a pump, there would be natural circulation flow through the reactor. However, this flow is not sufficient to remove the heat being generated when the reactor is at power. Natural circulation flow is sufficient for heat removal when the plant is shutdown (not critical).

The reactor coolant enters the suction side of the pump from the outlet of the steam generator. The water is increased in velocity by the pump impeller. This increase in velocity is converted to pressure in the discharge volute. At the discharge of the reactor coolant pump, the reactor coolant pressure will be approximately 90 psi higher than the inlet pressure.

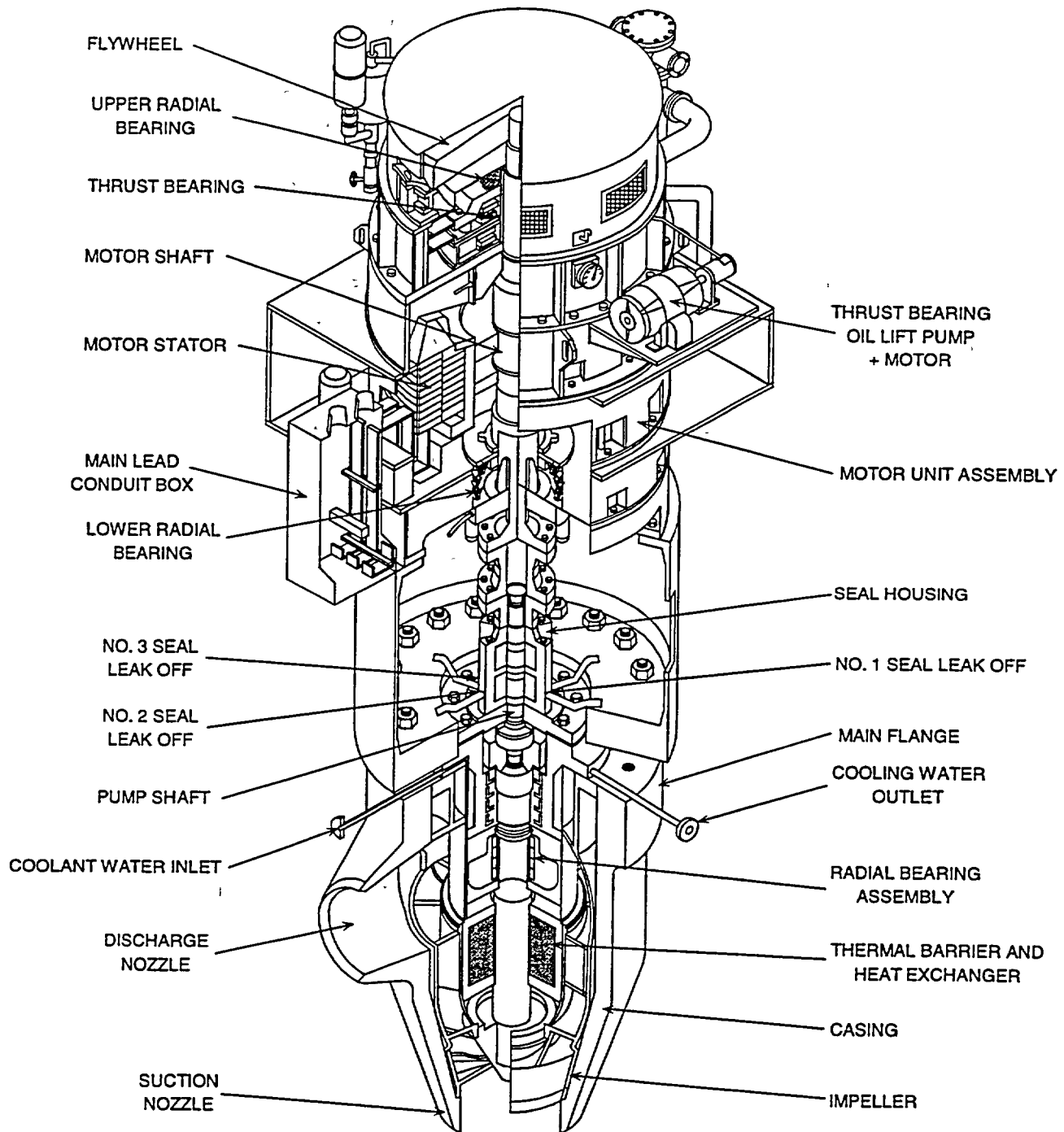
After the coolant leaves the discharge side of the pump, it will enter the inlet or cold leg side of the reactor vessel. The coolant will then pass through the fuel to collect more heat and is sent back to the steam generators.

The major components of a reactor coolant pump (page 4-16) are the motor, the hydraulic section, and the seal package.

The motor is a large, air cooled, electric motor. The horsepower rating of the motor will be from 6,000 to 10,000 horsepower. This large amount of power is needed in order to provide the necessary flow of coolant for heat removal (approximately 100,000 gallons per minute per pump).

The hydraulic section of the pump is the impeller and the discharge volute. The impeller of the pump is attached to the motor by a long shaft.

The seal package is located between the motor and the hydraulic section and prevents any water from leaking up the shaft into the containment atmosphere. Any water that does leak up the shaft is collected and routed to the seal leakoff system for collection in various systems.



**Cutaway View of a Reactor Coolant Pump**

## Pressurizer

The pressurizer (page 4-18) is the component in the reactor coolant system which provides a means of controlling the system pressure. Pressure is controlled by the use of electrical heaters, pressurizer spray, power operated relief valves, and safety valves.

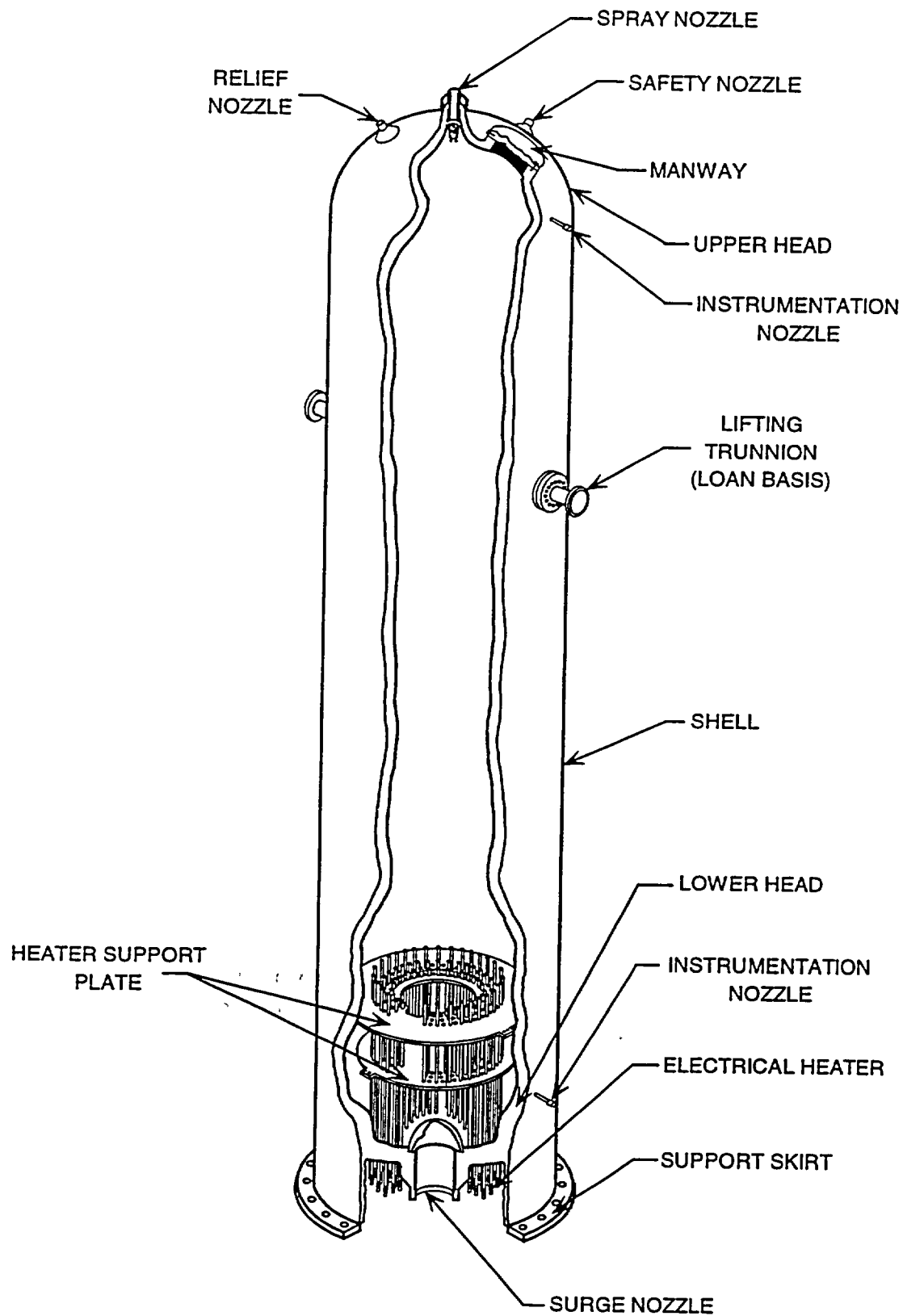
The pressurizer operates with a mixture of steam and water in equilibrium. If pressure starts to deviate from the desired value, the various components will actuate to bring pressure back to the normal operating point. The cause of the pressure deviation is normally associated with a change in the temperature of the reactor coolant system. If reactor coolant system temperature starts to increase, the density of the reactor coolant will decrease, and the water will take up more space. Since the pressurizer is connected to the reactor coolant system via the surge line, the water will expand up into the pressurizer. This will cause the steam in the top of the pressurizer to be compressed, and therefore, the pressure to increase.

The opposite effect will occur if the reactor coolant system temperature decreases. The water will become more dense, and will occupy less space. The level in the pressurizer will decrease, which will cause a pressure decrease. For a pressure increase or decrease, the pressurizer will operate to bring pressure back to normal.

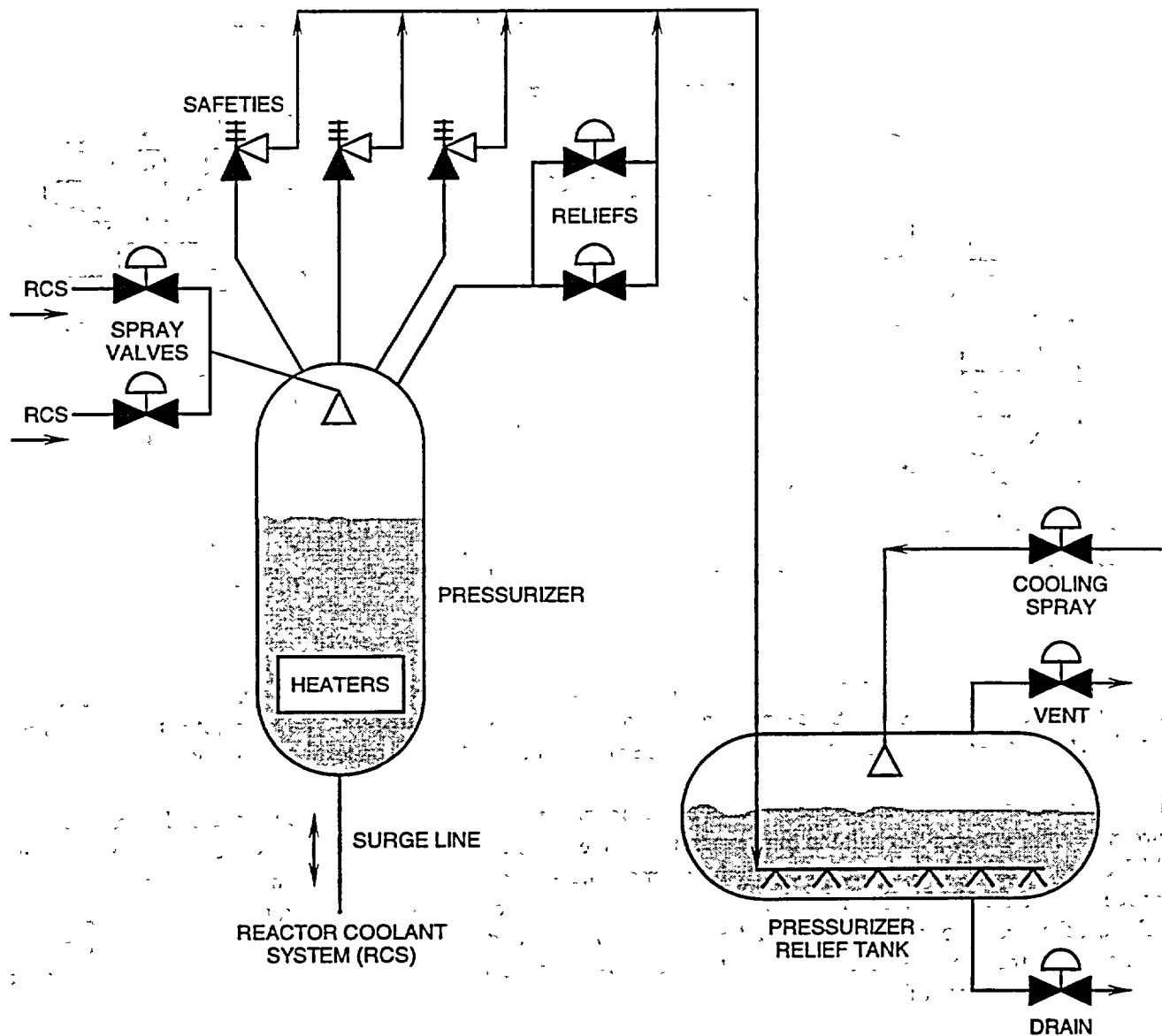
For example, if pressure starts to increase above the desired setpoint, the spray line will allow relatively cold water from the discharge of the reactor coolant pump to be sprayed into the steam space. The cold water will condense the steam into water, which will reduce pressure (due to the fact that steam takes up about six times more space than the same mass of water). If pressure continues to increase, the pressurizer relief valves will open and dump steam to the pressurizer relief tank. If this does not relieve pressure, the safety valves will lift, also discharging to the pressurizer relief tank.

If pressure starts to decrease, the electrical heaters will be energized to boil more water into steam, and therefore increase pressure. If pressure continues to decrease, and reaches a predetermined setpoint, the reactor protection system will trip the reactor.

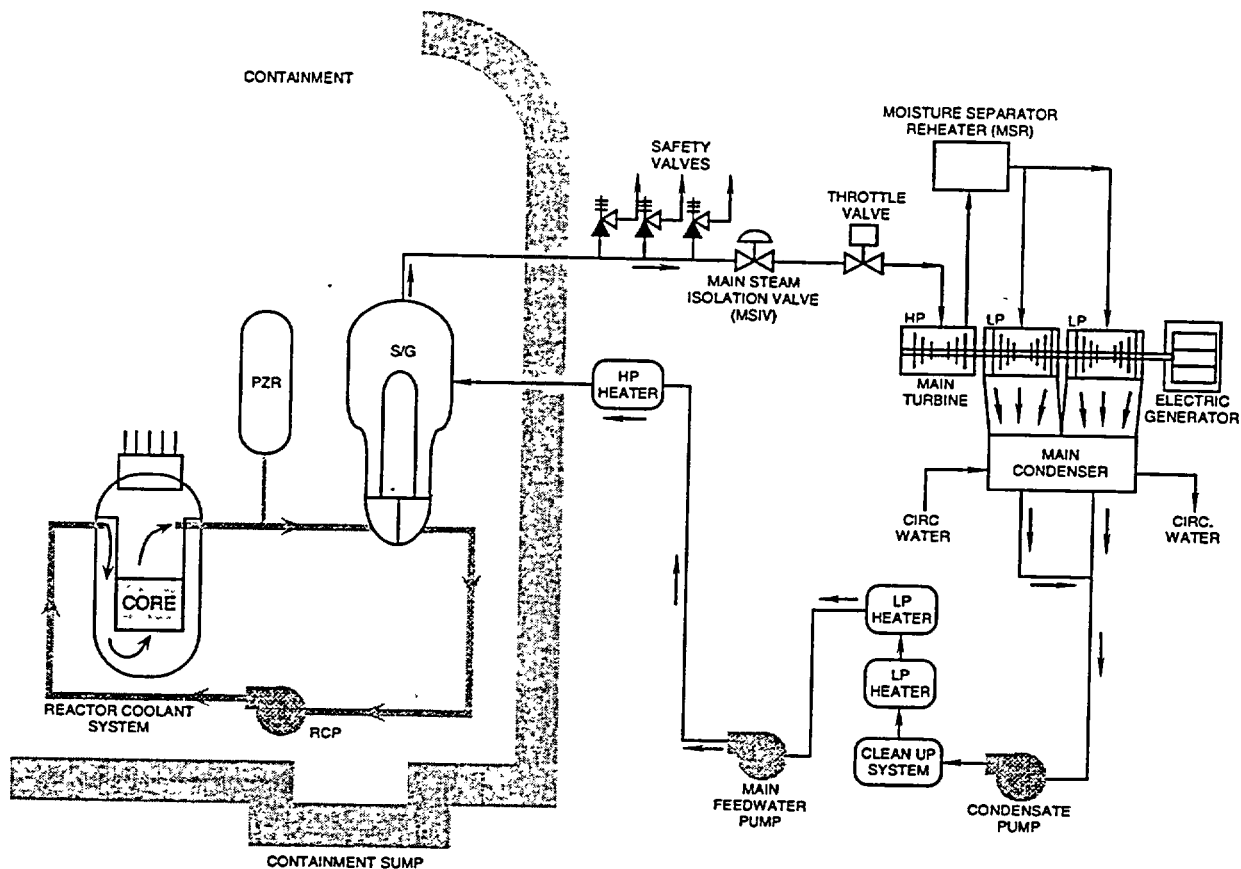
The pressurizer relief tank (page 4-19) is a large tank containing water with a nitrogen atmosphere. The water is there to condense any steam discharged by the safety or relief valves. Since the reactor coolant system contains hydrogen, the nitrogen atmosphere is used to prevent the hydrogen from existing in a potentially explosive environment.



**Cutaway View of a Pressurizer**

**Pressurizer and Pressurizer Relief Tank**

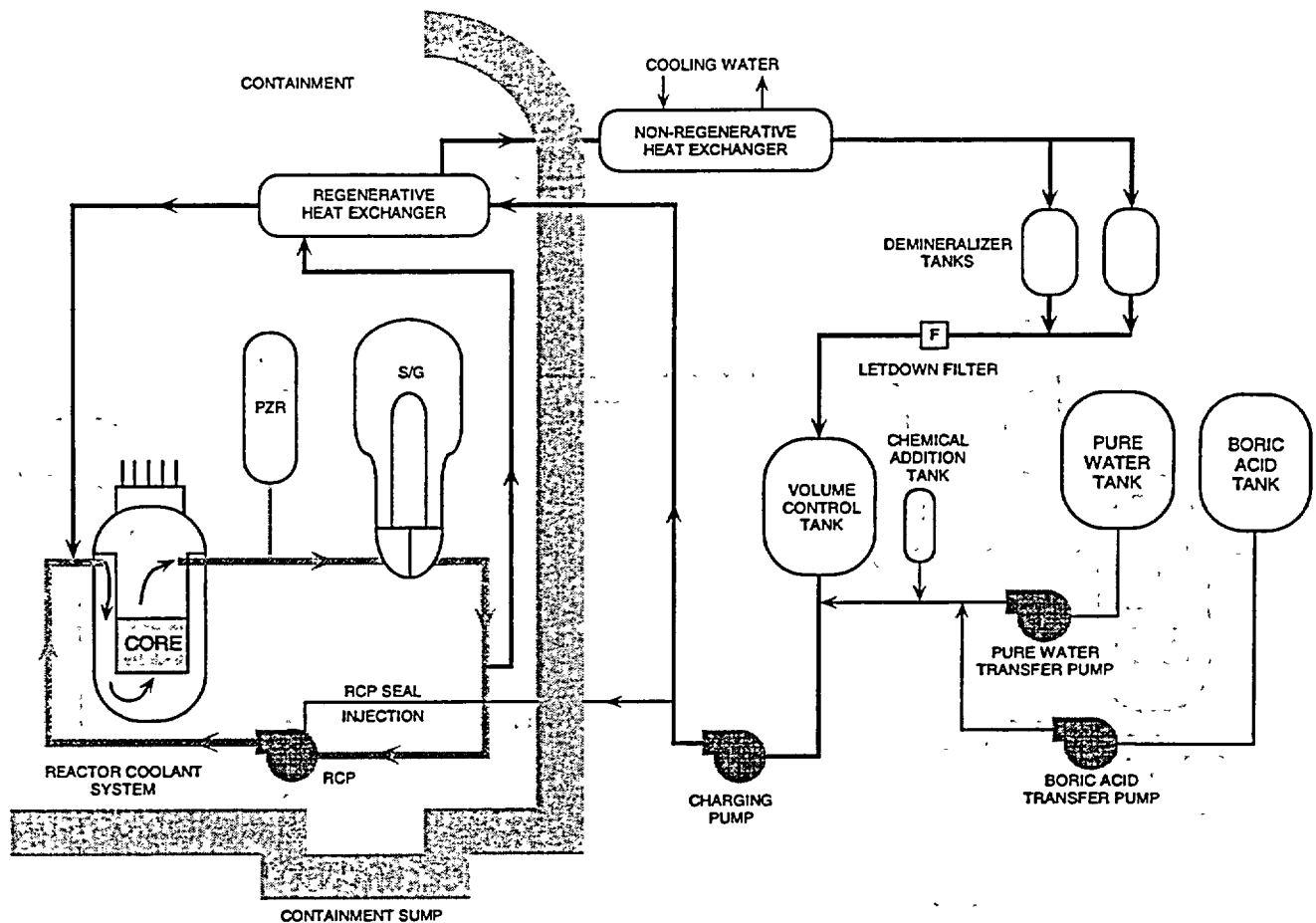




The major secondary systems of a pressurized water reactor are the main steam system and the condensate/feedwater system. Since the primary and secondary systems are physically separated from each other (by the steam generator tubes), the secondary system will contain little or no radioactive material.

The main steam system starts at the outlet of the steam generator. The steam is routed to the high pressure main turbine. After passing through the high pressure turbine, the steam is piped to the moisture separator/reheaters (MSRs). In the MSRs, the steam is dried with moisture separators and reheated using other steam as a heat source. From the MSRs, the steam goes to the low pressure turbines. After passing through the low pressure turbines, the steam goes to the main condenser, which is operated at a vacuum to allow for the greatest removal of energy by the low pressure turbines. The steam is condensed into water by the flow of circulating water through the condenser tubes.

At this point, the condensate/feedwater system starts. The condensed steam collects in the hotwell area of the main condenser. The condensate pumps take a suction on the hotwell to increase the pressure of the water. The condensate then passes through a cleanup system to remove any impurities in the water. This is necessary because the steam generator acts as a concentrator. If the impurities are not removed, they will be left in the steam generator after the steam forming process, and this could reduce the heat transfer capability of the steam generator and/or damage the steam generator tubes. The condensate then passes through some low pressure feedwater heaters. The temperature of the condensate is increased in the heaters by using steam from the low pressure turbine (extraction steam). The condensate flow then enters the suction of the main feedwater pumps, which increases the pressure of the water high enough to enter the steam generator. The feedwater now passes through a set of high pressure feedwater heaters, which are heated by extraction steam from the high pressure turbine (heating the feedwater helps to increase the efficiency of the plant). The flow rate of the feedwater is controlled as it enters the steam generators.



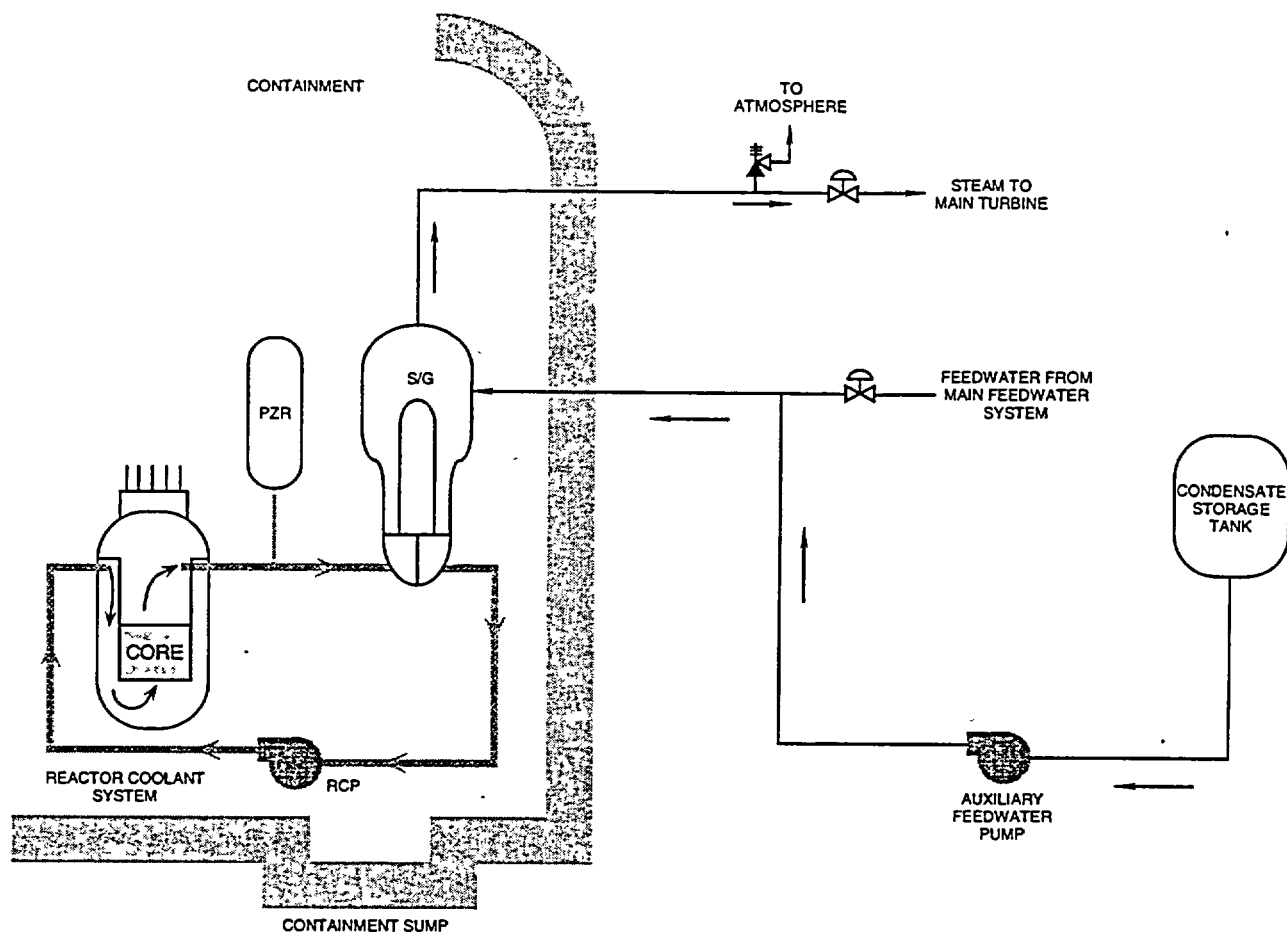
The chemical and volume control system (CVCS) is a major support system for the reactor coolant system. Some of the functions of the system are to:

- Purify the reactor coolant system using filters and demineralizers,
- Add and remove boron as necessary, and
- Maintain the level of the pressurizer at the desired setpoint.

A small amount of water (about 75 gpm) is continuously routed through the chemical and volume control system (called letdown). This provides a continuous cleanup of the reactor coolant system which maintains the purity of the coolant and helps to minimize the amount of radioactive material in the coolant.

The reactor coolant pump seals prevent the leakage of primary coolant to the containment atmosphere. The chemical and volume control system provides seal injection to keep the seals cool and provide lubrication for the seals. This water has been cooled by the heat exchangers and cleaned by the filters and demineralizers.

There is also a path (not shown) to route the letdown flow to the radioactive waste system for processing and/or disposal.



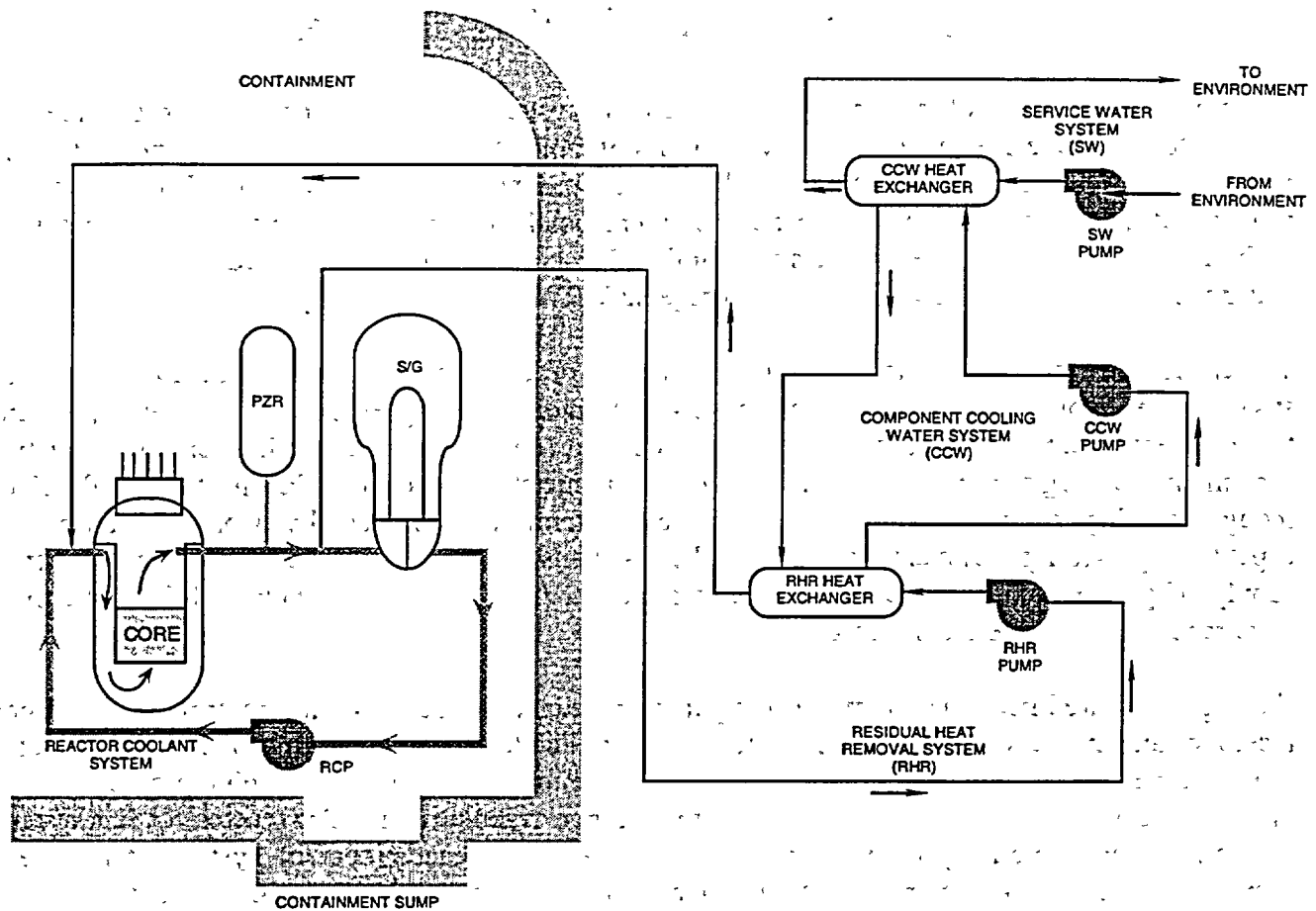
During normal operation, the heat produced by the fission process is removed by the reactor coolant and transferred to the secondary coolant in the steam generators. Here, the secondary coolant is boiled into steam and sent to the main turbine.

Even after the reactor has been shutdown, there is a significant amount of heat produced by the decay of fission products (decay heat). The amount of heat produced by decay heat is sufficient to cause fuel damage if not removed. Therefore, systems must be designed and installed in the plant to remove the decay from the core and transfer that heat to the environment, even in a shutdown plant condition. Also, if it is desired to perform maintenance on reactor coolant system components, the temperature and pressure of the reactor coolant system must be reduced low enough to allow personnel access to the equipment.

The auxiliary feedwater system and the steam dump system (turbine bypass valves) work together to allow the operators to remove the decay heat from the reactor. The auxiliary feedwater system pumps water from the condensate storage tank to the steam generators. This water is allowed to boil to make steam. The steam can then be dumped to the main condenser through the steam dump valves. The circulating water will then condense the steam and take the heat to the environment.

If the steam dump system is not available (for example, no circulating water for the main condenser), the steam can be dumped directly to the atmosphere through the atmospheric relief valves.

By using either method of steam removal, the heat is being removed from the reactor coolant system, and the temperature of the reactor coolant system can be reduced to the desired level.



At some point, the decay heat being produced will not be sufficient to generate enough steam in the steam generators to continue the cooldown. When the reactor coolant system pressure and temperature have been reduced to within the operational limits, the residual heat removal system (RHR) will be used to continue the cooldown by removing heat from the core and transferring it to the environment.

This is accomplished by routing some of the reactor coolant through the residual heat removal system heat exchanger, which is cooled by the component cooling water system (CCW). The heat removed by the component cooling water system is then transferred to the service water system in the component cooling water heat exchanger. The heat picked up by the service water system will be transferred directly to the environment from the service water system.

The residual heat removal system can be used to cool the plant down to a low enough temperature that personnel can perform any maintenance functions, including refueling.

## Emergency Core Cooling Systems

There are two purposes of the emergency core cooling systems (ECCS). The first is to provide core cooling to minimize fuel damage following a loss of coolant accident. This is accomplished by the injection of large amounts of cool, borated water into the reactor coolant system. The second is to provide extra neutron poisons to ensure the reactor remains shutdown following the cooldown associated with a main steam line rupture, which is accomplished by the use of the same borated water source. This water source is called the refueling water storage tank (RWST).

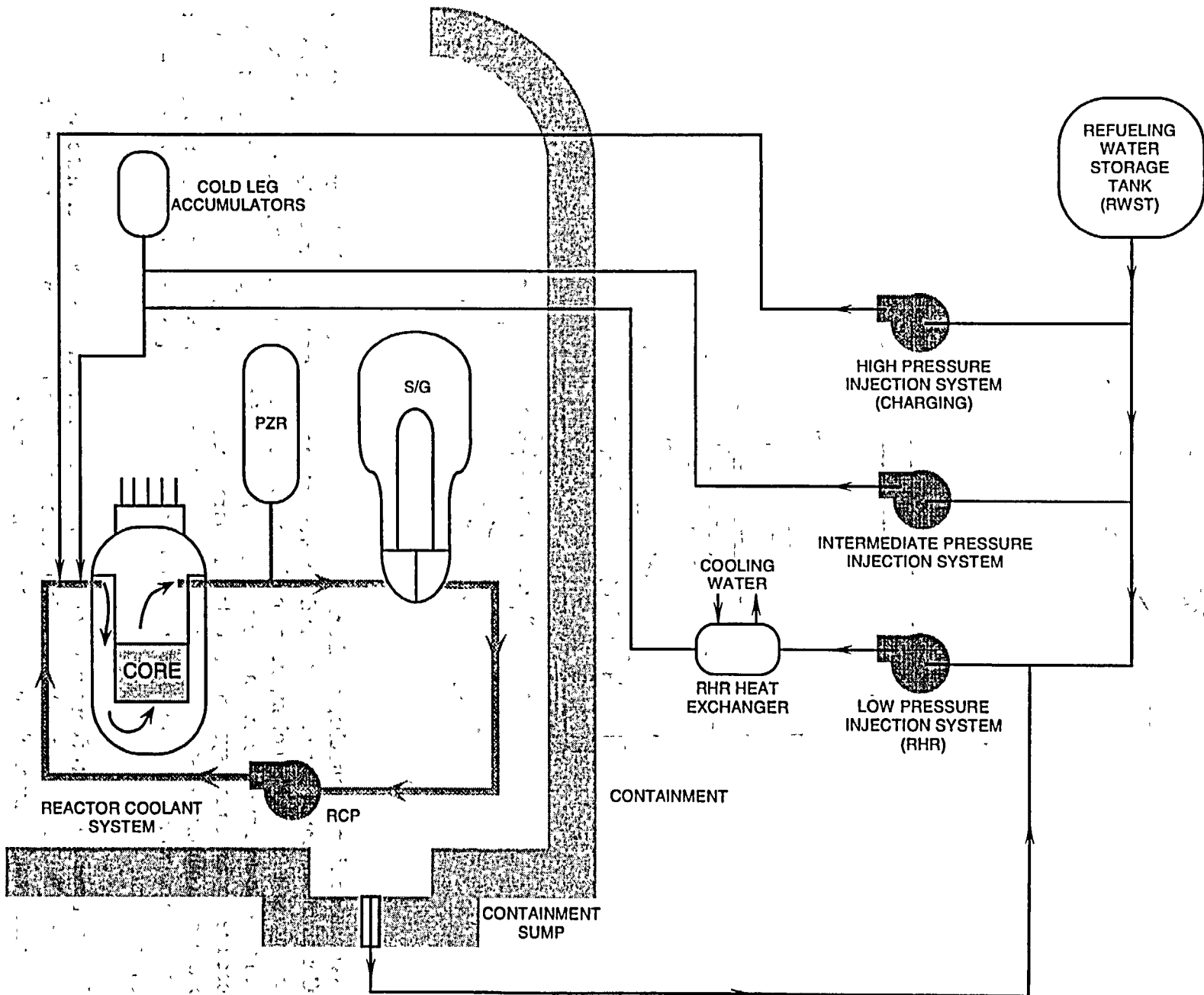
To perform this function of injection of large quantities of borated water, the emergency core cooling systems consist of four separate systems (page 4-25). In order of highest pressure to lowest pressure, these systems are: the high pressure injection (or charging) system, the intermediate pressure injection system, the cold leg accumulators, and the low pressure injection system (residual heat removal). Even though the diagram shows only one pump in each system, there are actually two, each of which is capable of providing sufficient flow. Also, these systems must be able to operate when the normal supply of power is lost to the plant. For this reason, these systems are powered from the plant emergency (diesel generators) power system.

The high pressure injection system uses the pumps in the chemical and volume control system. Upon receipt of an emergency actuation signal, the system will automatically realign to take water from the refueling water storage tank and pump it into the reactor coolant system. The high pressure injection system is designed to provide water to the core during emergencies in which reactor coolant system pressure remains relatively high (such as small break in the reactor coolant system, steam break accidents, and leaks of reactor coolant through a steam generator tube to the secondary side).

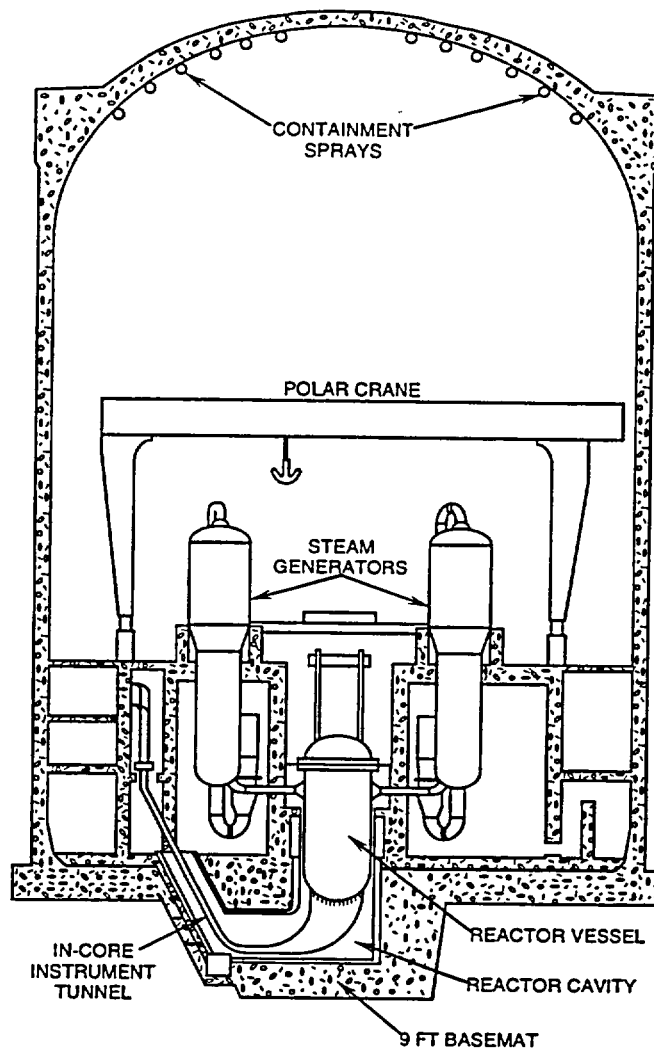
The intermediate pressure injection system is also designed for emergencies in which the primary pressure stays relatively high, such as small to intermediate size primary breaks. Upon an emergency start signal, the pumps will take water from the refueling water storage tank and pump it into the reactor coolant system.

The cold leg accumulators do not require electrical power to operate. These tanks contain large amounts of borated water with a pressurized nitrogen gas bubble in the top. If the pressure of the primary system drops below low enough, the nitrogen will force the borated water out of the tank and into the reactor coolant system. These tanks are designed to provide water to the reactor coolant system during emergencies in which the pressure of the primary drops very rapidly, such as large primary breaks.

The low pressure injection system (residual heat removal) is designed to inject water from the refueling water storage tank into the reactor coolant system during large breaks, which would cause a very low reactor coolant system pressure. In addition, the residual heat removal system has a feature that allows it to take water from the containment sump, pump it through the residual heat removal system heat exchanger for cooling, and then send the cooled water back to the reactor for core cooling. This is the method of cooling that will be used when the refueling water storage tank goes empty after a large primary system break. This is called the long term core cooling or recirculation mode.



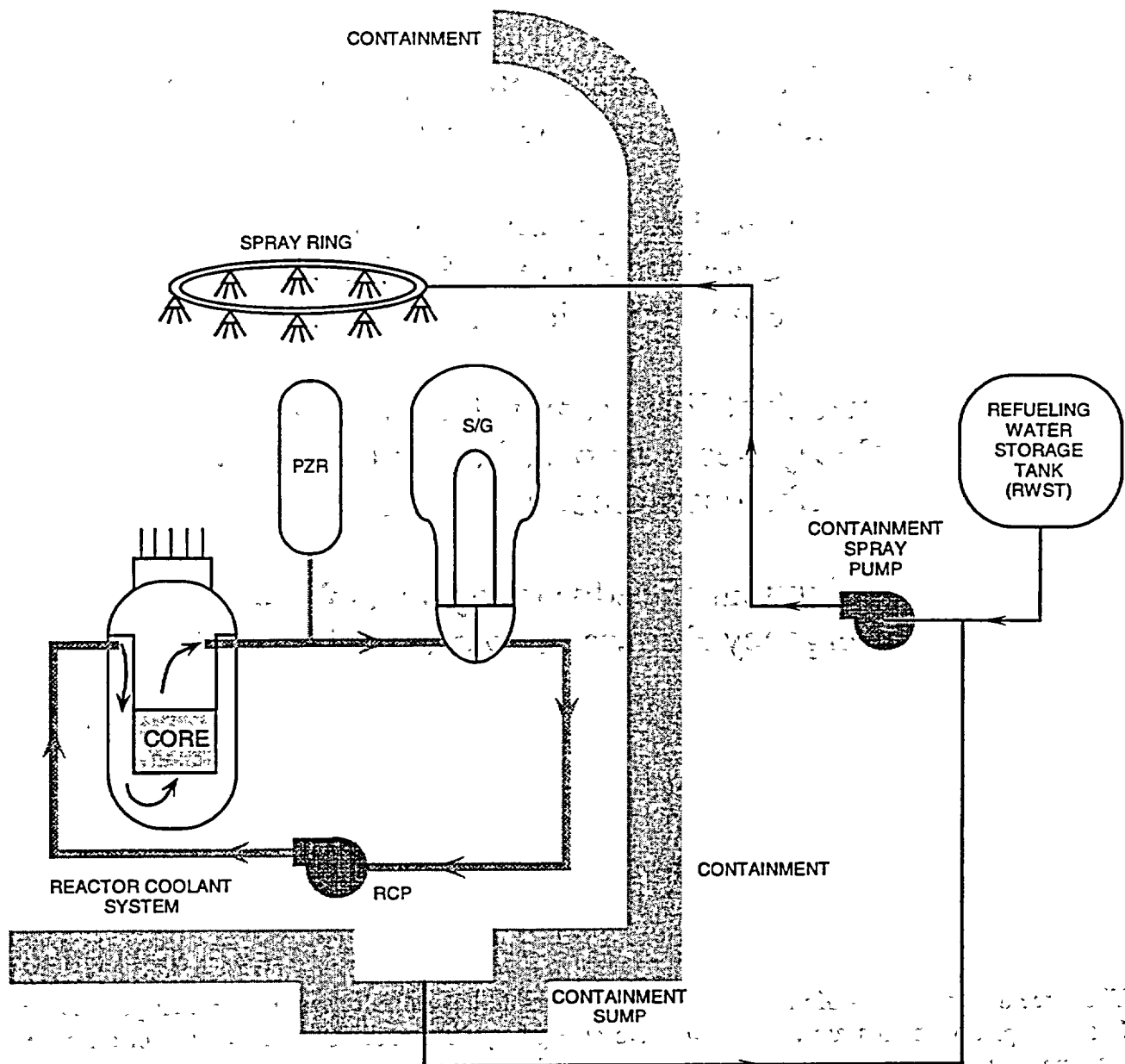
## Emergency Core Cooling Systems



As discussed in previous chapters, the reactor coolant system is located inside the containment building. Containments are designed to withstand the pressures and temperatures that would accompany a high energy fluid (primary coolant, steam, or feedwater) release into the building, but exposure to high temperature and pressure over a long period of time would tend to degrade the concrete. If a break occurred in the primary system, the coolant that is released into the containment building would contain radioactive material (fission products). If the concrete developed any cracks, the high pressure in the containment would tend to force the radioactive material out of the containment and into the environment.

To limit the leakage out of containment following an accident, there is a steel liner that covers the inside surface of the containment building. This liner acts as a vapor proof membrane to prevent any gas from escaping through any cracks that may develop in the concrete.

There are also two systems designed with the purpose of reducing containment temperature and pressure after an accident in the containment building. The fan cooler system circulates the air through heat exchangers to accomplish the cooling. The second system is the containment spray system.



Upon the occurrence of either a secondary break or primary break inside the containment building, the containment atmosphere would become filled with steam. To reduce the pressure and temperature of the building, the containment spray system is automatically started. The containment spray pump will take a suction from the refueling water storage tank and pump the water into spray rings located in the upper part of the containment. The water droplets, being cooler than the steam, will remove heat from the steam, which will cause the steam to condense. This will cause a reduction in the pressure of the building and will also reduce the temperature of the containment atmosphere (similar to the operation of the pressurizer). Like the residual heat removal system, the containment spray system has the capability to take water from the containment sump if the refueling water storage tank goes empty.



Chemical and Volume Control System (W, CE) =  
Makeup and Purification System (B&W)

Cold Leg Accumulator (W) =  
Core Flood Tanks (B&W) =  
Safety Injection Tanks (CE)

Residual Heat Removal System (W) =  
Decay Heat Removal System (B&W) =  
Shutdown Cooling System (CE)

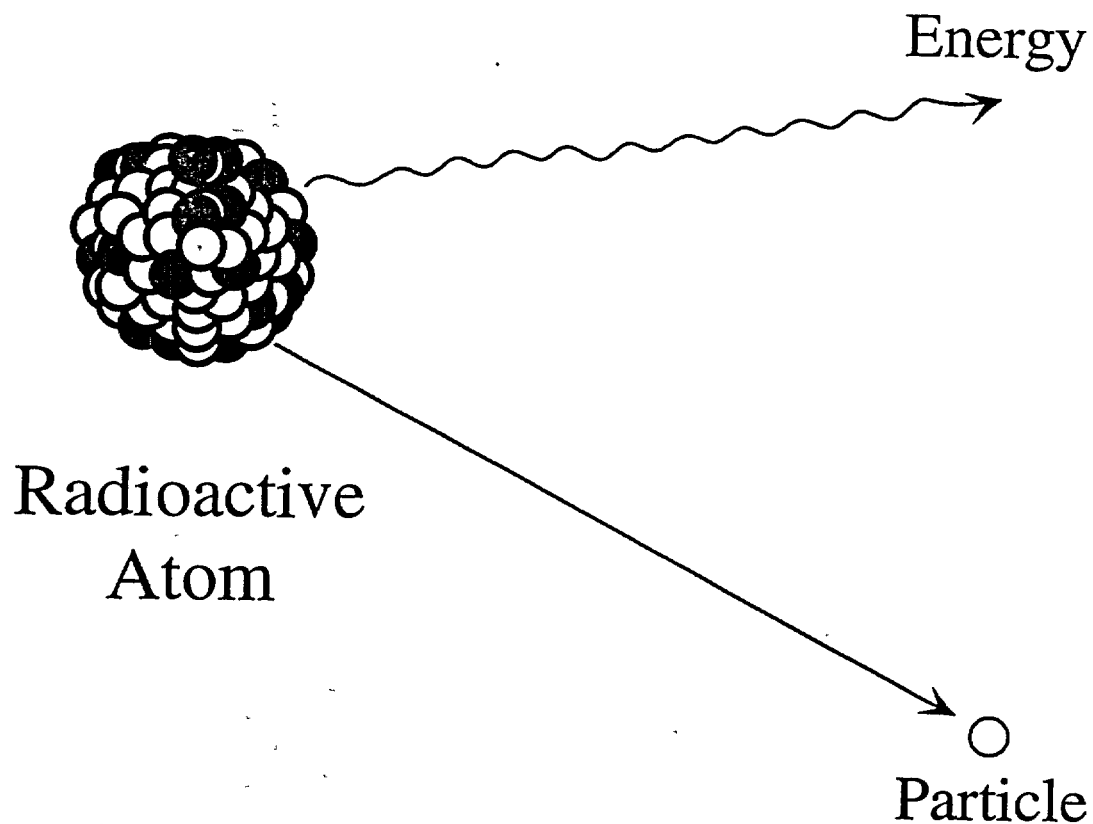
Auxiliary Feedwater System (W) =  
Emergency Feedwater System (B&W, CE)

The three major vendors of pressurized water reactors all have similar systems in their plant designs. For example, all plants are required to have emergency core cooling systems, but not all have an intermediate pressure injection system. One major difference in the designs is that the vendors all call the systems and components by different names. The list above gives some examples of different names even though the function the same.

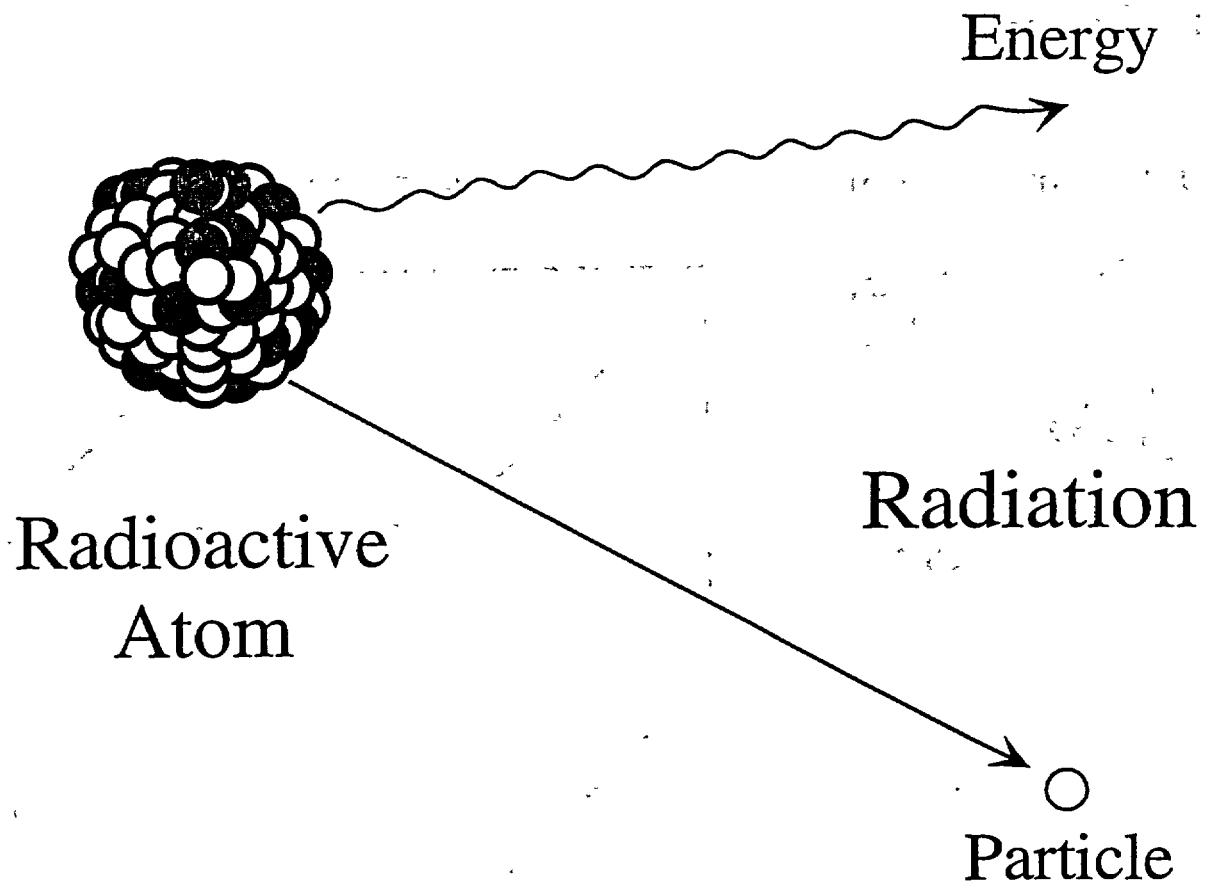
# Radiation Terminology



This section discusses the terms and concepts which are necessary for a meaningful discussion of radiation, its sources, and its risks.



Atoms can be classified as stable or unstable. Unstable atoms have excess energy in their nuclei. A **RADIOACTIVE MATERIAL** contains atoms which are unstable and attempt to become more stable by ejecting particles, electromagnetic energy (photons), or both. When a radioactive atom ejects particles and/or photons, the atom undergoes a process called **DISINTEGRATION** (or decay).



## Radioactive Atoms Emit Radiation

**RADIATION** is the term given to the particles and/or energy emitted by radioactive material as it disintegrates.

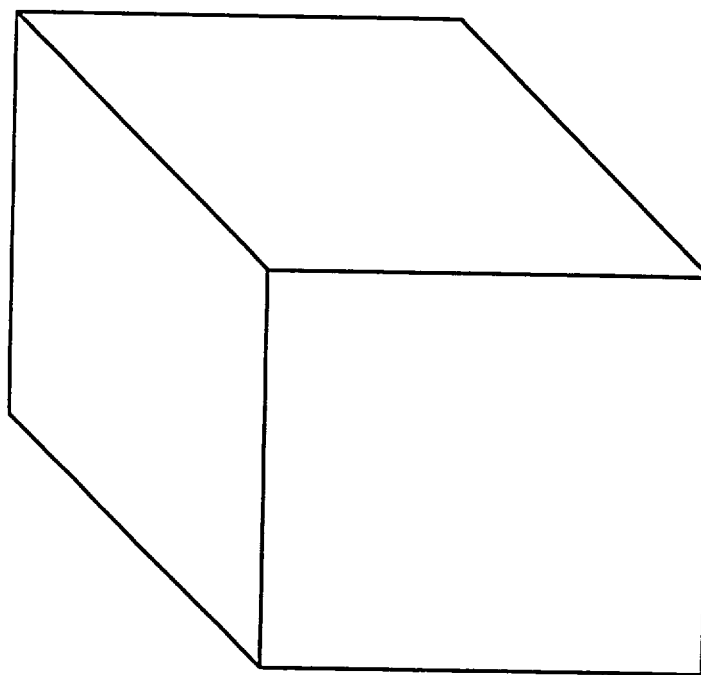
## 1 Curie:

0.001 gm

1 gm

635,600 gm


 ${}^{60}_{27}\text{Co}$ 

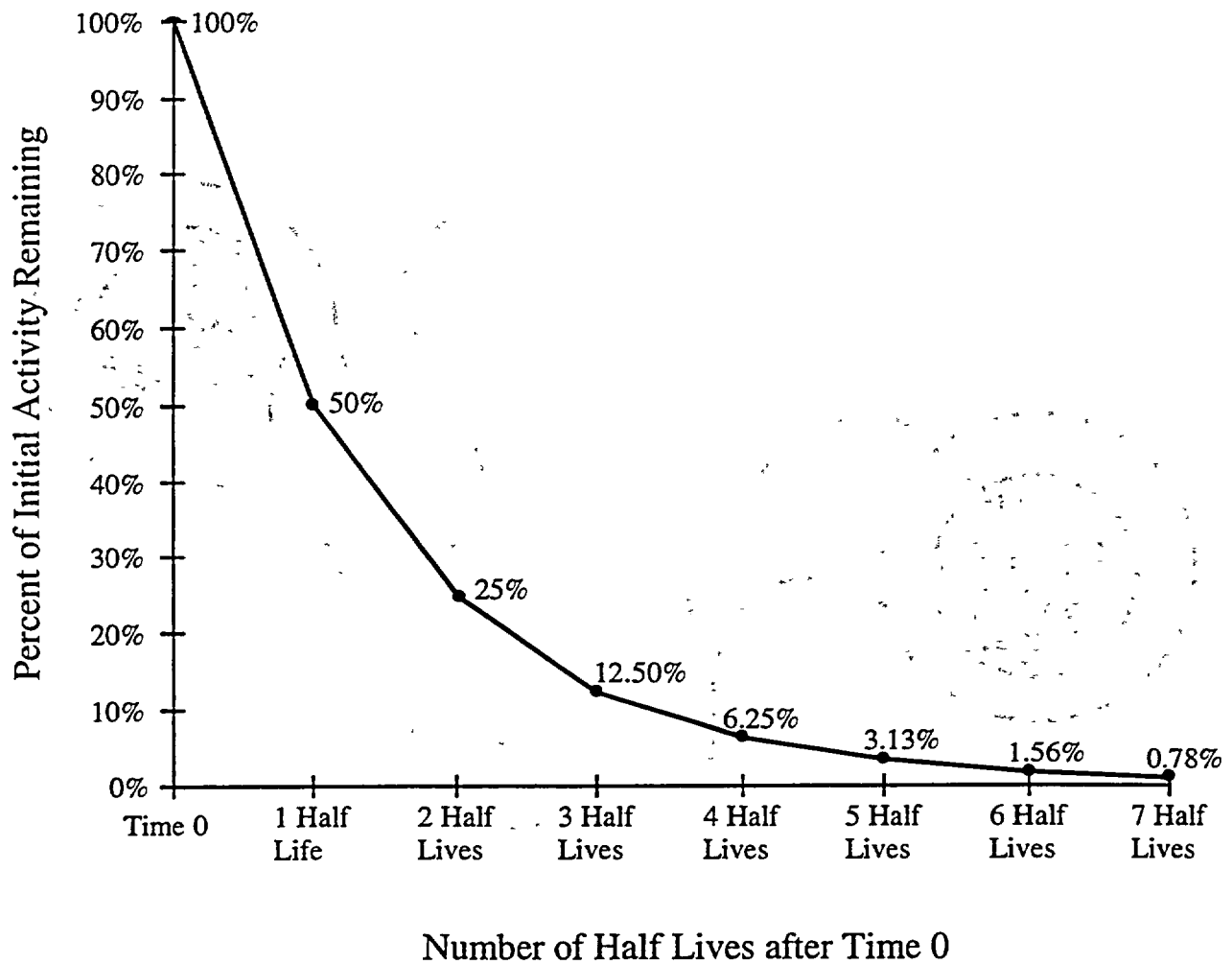
 ${}^{226}_{88}\text{Ra}$ 

 ${}^{238}_{92}\text{U}$ 

$$3.7 \times 10^{10} \text{ Disintegrations per second} = 1 \text{ Curie}$$

RADIOACTIVITY is a term which indicates how many radioactive atoms are disintegrating in a time period and is measured in units of CURIES. One curie is defined as that amount of any radioactive material that will decay at a rate of 37 billion disintegrations per second (based upon the disintegration rate of 1 gram of radium-226).

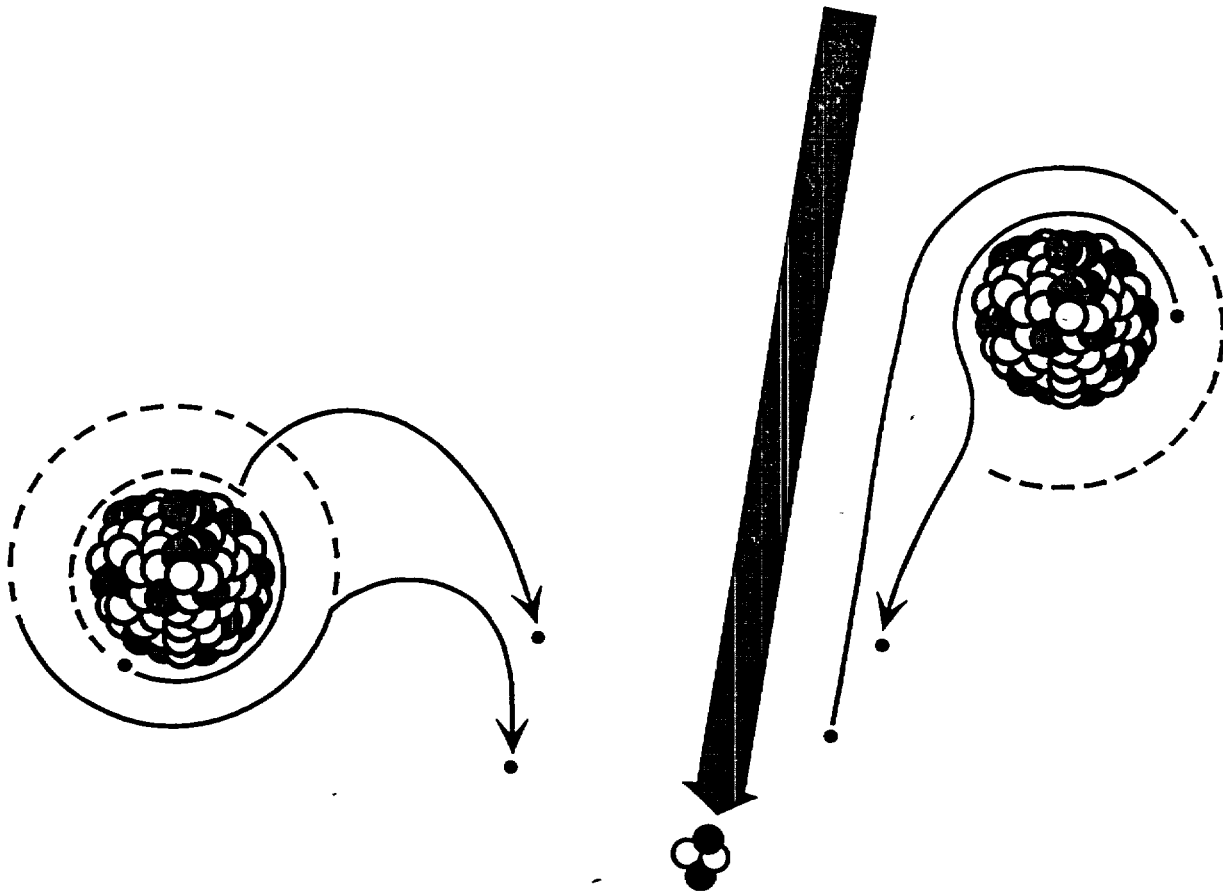
As shown above, the amount of material necessary for 1 curie of radioactivity can vary from an amount too small to be seen (cobalt-60, for example) to more than half a ton (uranium-238).

Radioactivity can also be expressed in units of becquerels, which are discussed on page 5-24.



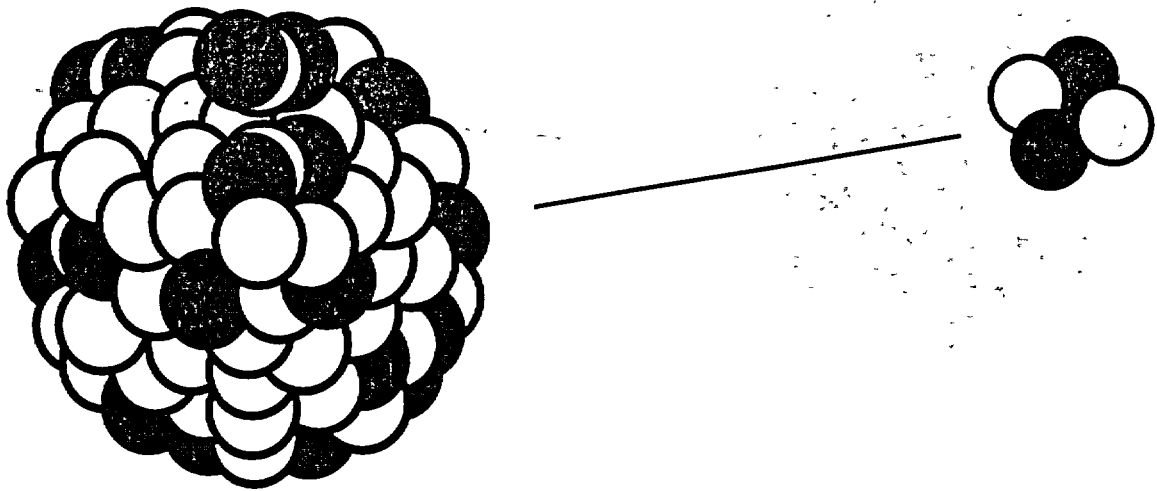
The rate of nuclear decay is measured in terms of HALF LIVES. The half life of any radioactive material is the length of time necessary for one half of the atoms of that material to decay to some other material. During each half life, one half of the atoms which started that half life period will decay.

Half lives range from millionths of a second for highly radioactive fission products to billions of years for long-lived materials (such as naturally occurring uranium). No matter how long or short the half life is, after seven half lives have passed, there is less than 1 percent of the initial activity remaining.



## Ionization

Radiation emitted by radioactive material can produce IONIZATIONS and, therefore, is called IONIZING RADIATION. Ionization is the process of stripping, knocking off, or otherwise removing electrons from their orbital paths, creating "free" electrons and leaving charged nuclei. The negatively charged electrons and positively charged nuclei may interact with other materials to produce chemical or electrostatic changes in the material where the interactions occur. If chemical changes occur in the cells of our bodies, some cellular damage may result. The biological effects of radiation exposure are discussed in Chapter 6.

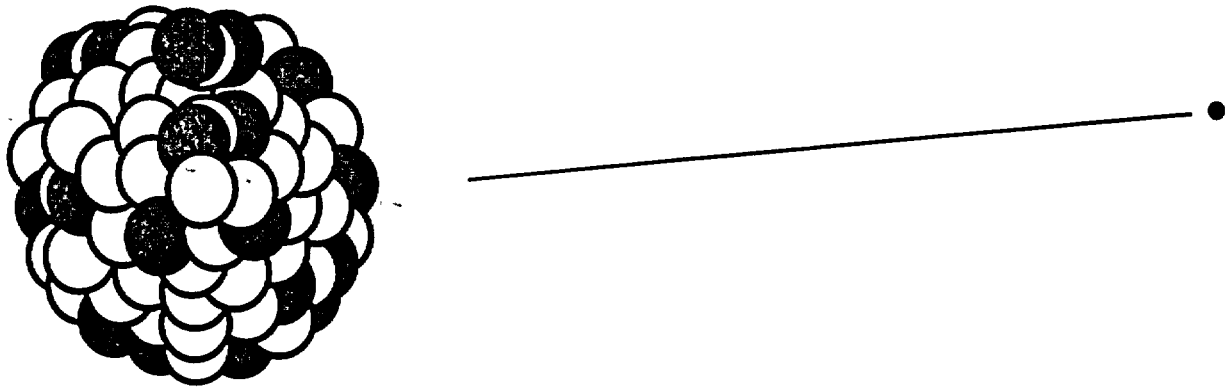


## Alpha Particle

An ALPHA PARTICLE is an ionizing radiation that consists of two protons and two neutrons. The neutrons and protons give the alpha particle a relatively large mass as compared to other ionizing radiation particles. Because of this large size, the alpha particle has a relatively low speed and low penetrating distance (one or two inches in air). The particle tends to travel in a straight line, causing a large number of ionizations in a small area.

Alpha particles are easily shielded (or stopped) by a thin sheet of paper or the body's outer layer of skin. Since they do not penetrate the outer (dead) layer of skin, they present little or no hazard when they are external to the body. However, alpha particles are considered to be an internal hazard, because they can be in contact with live tissue and have the ability to cause a large number of ionizations in a small area. INTERNAL and EXTERNAL HAZARDS refer to whether the radioactive material is inside the body (internal) or outside the body (external).

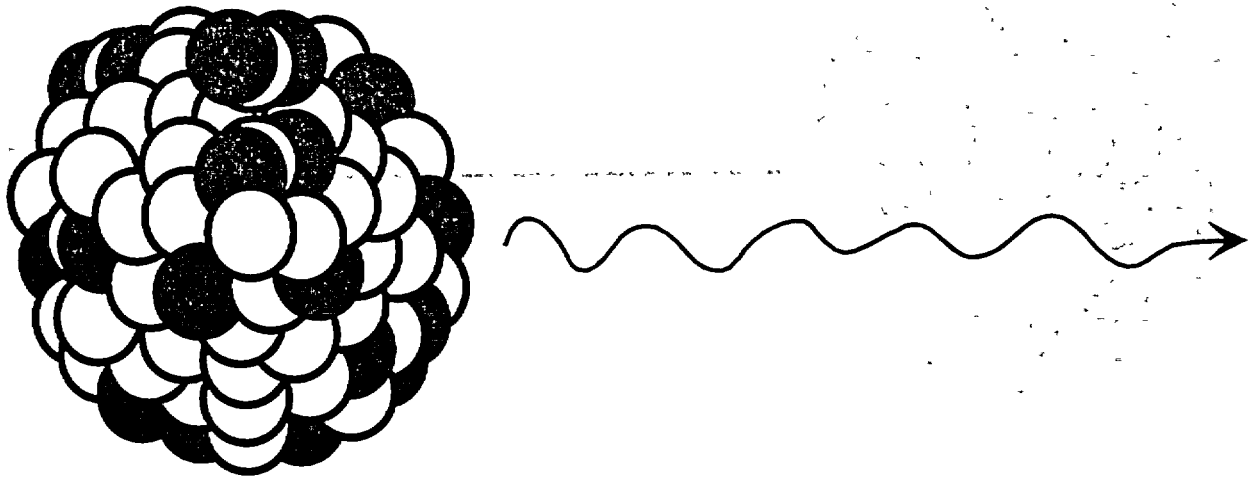




## Beta Particle

A BETA PARTICLE is a high speed ionizing radiation particle that is usually negatively charged. The charge of a beta particle is equal to that of an electron (positive or negative), and its mass is equal to about 1/1800th of that of a proton or neutron. Due to this relatively low mass and charge, the beta particle can travel through about 10 feet of air and can penetrate very thin layers of materials (for example, aluminum). However, clothing will stop most beta particles.

The beta particle can penetrate into the live layers of the skin tissue and is considered both an internal and an external hazard. Beta particles can also be an external hazard to the lens of the eye. Beta particles are best shielded by thin layers of light metals (such as aluminum or copper) and plastics.

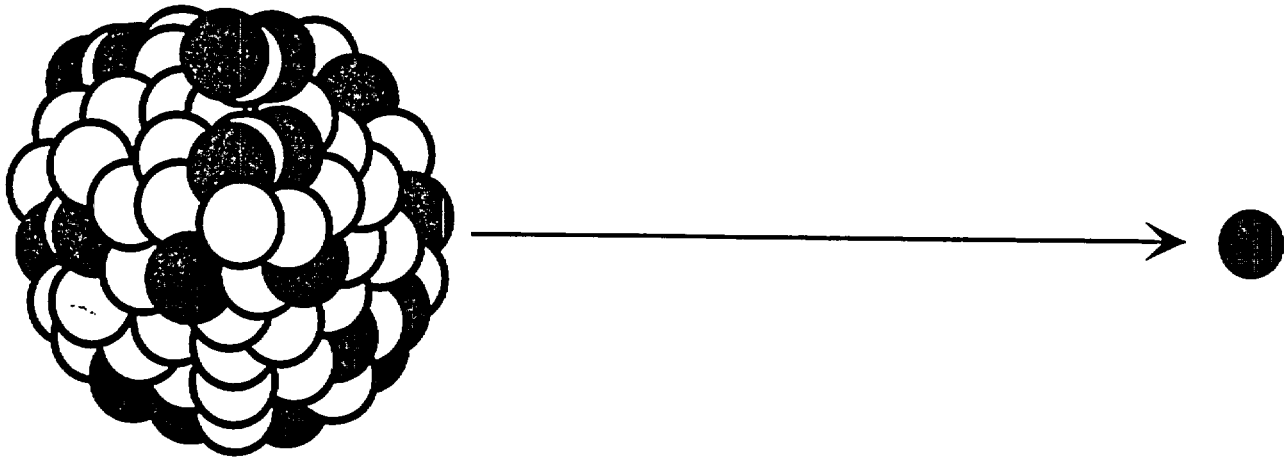


## Gamma Ray

A GAMMA RAY is an ionizing radiation in the form of electromagnetic energy (no rest mass, no charge) similar in many respects to visible light (but far more energetic). Due to the high energy, no charge, and no rest mass, gamma rays can travel thousands of feet in air and can easily pass through the human body.

Because of their penetrating capability, gamma rays are considered both an internal and external hazard. The best shielding materials for gamma rays are very dense materials such as lead, concrete, and uranium.

**NOTE:** X-rays are similar to gamma rays in penetration and damage potential. X-rays, however, are produced by changes in electron orbit position rather than by nuclear decay or fission.



## Neutron Particle

The NEUTRON PARTICLE is an ionizing radiation emitted by nuclear fission and by the decay of some radioactive atoms. Neutrons can range from high speed, high energy particles to low speed, low energy particles (called thermal neutrons). Neutrons can travel hundreds of feet in air and can easily penetrate the human body.

Neutrons are considered both an internal and external hazard, although the likelihood of an internal, neutron emitting, radioactive material is extremely unlikely. The best shielding materials for neutrons would be those that contain hydrogen atoms, such as water, polyethylene, and concrete.

The nucleus of a hydrogen atom contains a proton. Since a proton and a neutron have almost identical masses, a neutron hitting a hydrogen atom gives up a great amount of its energy, and therefore, the distance traveled by the neutron is limited. This is like a cue ball hitting another billiard ball. Since they are the same size, the cue ball can be made to stop and the other ball will start moving. But, if a ping pong ball is thrown against a bowling ball, the ping pong ball will bounce off with very little change in velocity, only a change in direction. Therefore, heavy atoms, like lead, are not good at stopping neutrons.

# Units for Exposure and Dose Measurements

ROENTGEN

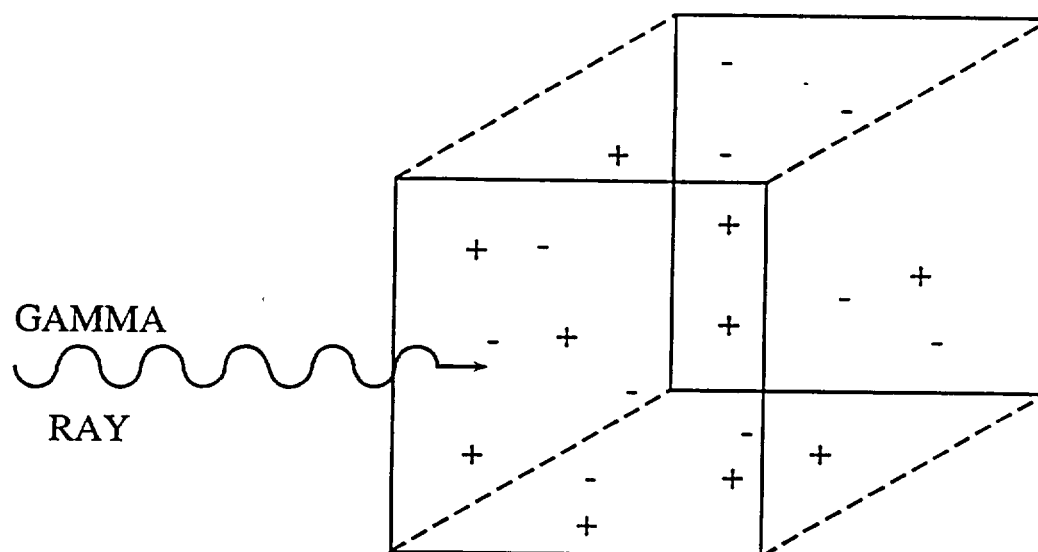
RAD

REM

When ionizing radiation interacts with a material, it can cause ionizations. The ionizations can be measured, and the effects of the radiation can be estimated. Because of these ionizations, radioactive material and exposure to ionizing radiation can be monitored and controlled.

The commonly used units in the United States for radiation exposure and dose measurements are the ROENTGEN, the RAD, and the REM.

**NOTE:** The unit of Roentgen is no longer recognized in 10 CFR Part 20, and consequently, the roentgen is being phased out as an official unit for dose of record. It will, however, still be seen on radiation survey instruments, and on radiation surveys, until the older models can be replaced. The radiation dose of record must be recorded in rad or rem.

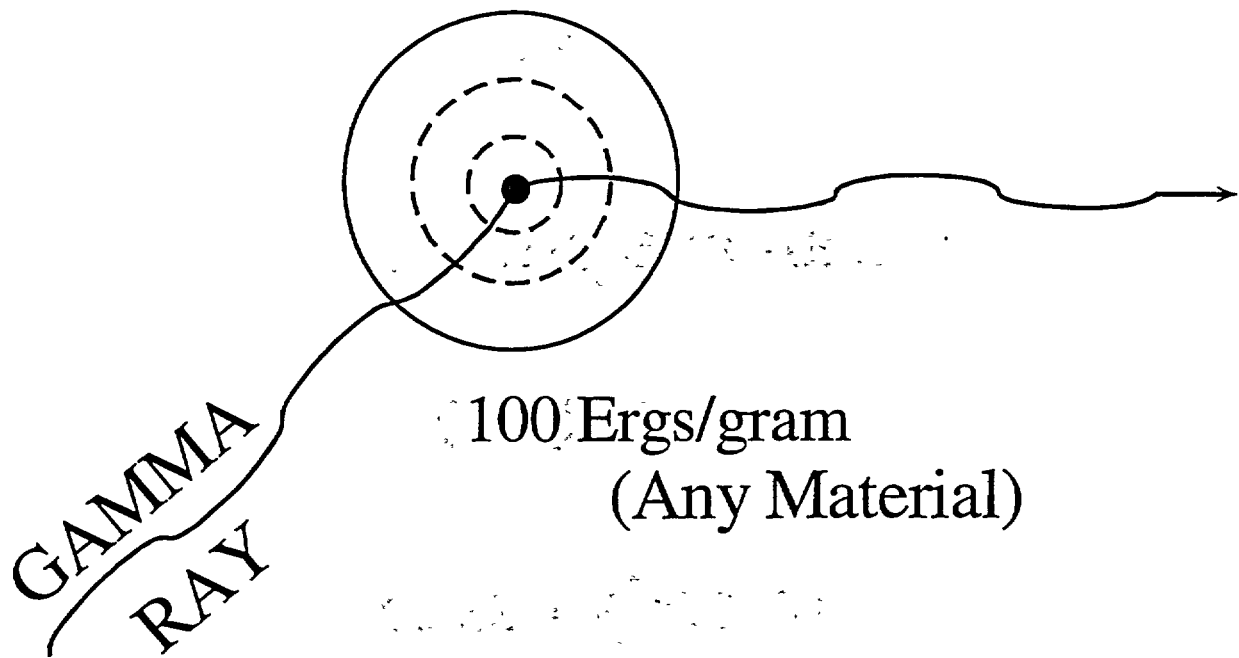


1 ESU/cm<sup>3</sup> Dry Air

## Roentgen

The ROENTGEN (R) is a measure of exposure to X-ray or gamma ray radiation. One roentgen is that amount of X-ray or gamma radiation that will deposit enough energy to strip about two billion electrons from their orbits (called one electrostatic unit) in one cubic centimeter of dry air. The roentgen technically applies only to ionization in dry air from X-ray or gamma radiation and does not apply to damage to body tissues.

NOTE: As stated earlier, the unit of roentgen is being phased out as an official record of dose, but radiation survey instrument faces will still read out in R or multiples of R until they can be replaced with instruments reading out in rem or rad.



## Radiation Absorbed Dose (RAD)

The RAD (Radiation Absorbed Dose) is a measure of the absorbed dose (energy deposited) in a material. One RAD is the deposition of one hundred ergs of energy in one gram of any material (NRC Regulations use per gram of body tissue) due to the ionization from any type of radiation. One erg of energy is equal to about one ten billionth of a BTU, or about one ten millionth of a watt.

# REM

## Damage produced

## by 1 RAD

## in body tissue

The REM is based on the biological damage caused by ionization in human body tissue. It is a term for dose equivalence and equals the biological damage that would be caused by one RAD of dose.

The REM accounts for the fact that not all types of radiation are equally effective in producing biological change or damage. That is, the damage from one rad deposited by beta radiation is less than that caused by one rad of alpha radiation. The REM is numerically equal to the dose in RADs multiplied by a QUALITY FACTOR, which accounts for the difference in the amount of biological damage caused by the different types of radiation.

## FOR GAMMA AND X-RAYS:

1 Roentgen =

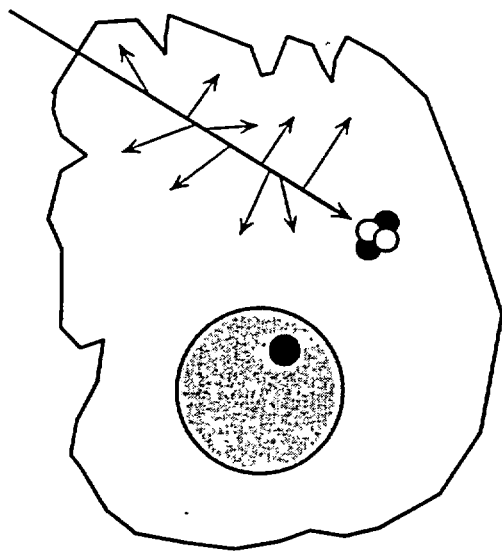
1 RAD =

1 REM

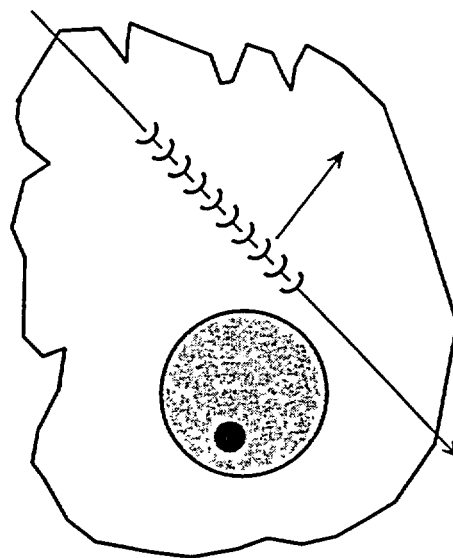
Gamma ray radiation provides the consistency among the units of exposure and dose. Although slight corrections have been made to early historical data, one Roentgen of exposure of gamma or X-ray radiation is approximately equal to one RAD of absorbed energy (dose), which equals one REM of biological damage in humans (dose equivalent).

Again, this relationship is only true for gamma and X-ray radiation and is not true for the particulate (alpha, beta, or neutron) radiations. For this reason, and also the fact that the Roentgen is NOT a fundamental unit, the Roentgen is being phased out as a unit for the official dose of record.





1 RAD Alpha  
or  
20 Rem ( $Q = 20$ )



1 RAD Gamma  
or  
1 Rem ( $Q = 1$ )

Particulate ionizing radiation (alpha and neutron) has been found to cause more biological damage than electromagnetic radiation (gamma and X-ray), even when the same amount of energy has been deposited. For example, one RAD of alpha radiation can be expected to cause about twenty times the damage caused by one RAD of gamma radiation. This difference in ability to cause damage is corrected for by a QUALITY FACTOR (Q).

# DOSE

## Energy Deposition

## "Damage"

1 RAD Gamma	=	1 REM
1 RAD Beta	=	1 REM
1 RAD Neutron	=	10 REM
1 RAD Alpha	=	20 REM

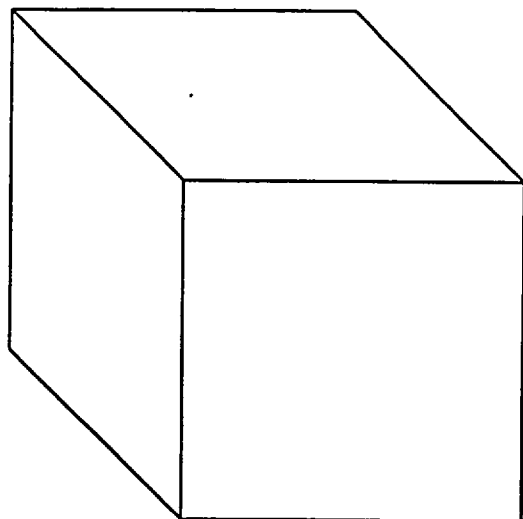
$$\text{REM} = \text{RAD} \times \text{Quality Factor}$$

The QUALITY FACTOR converts the absorbed dose in RAD to the dose equivalent in REM. As shown, quality factors are highest for the alpha radiation, which deposits its energy within the smallest volume.

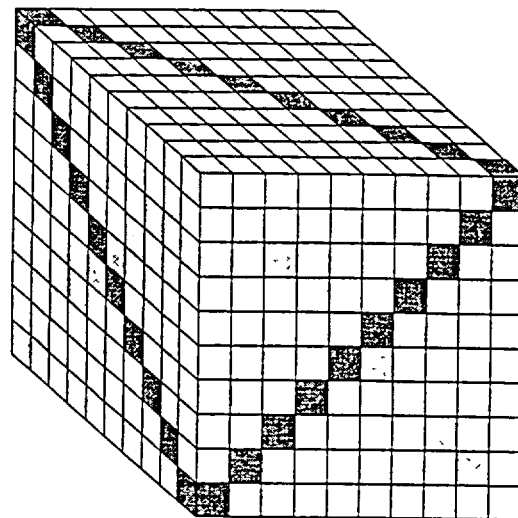
REM

vs.

MILLIREM



=



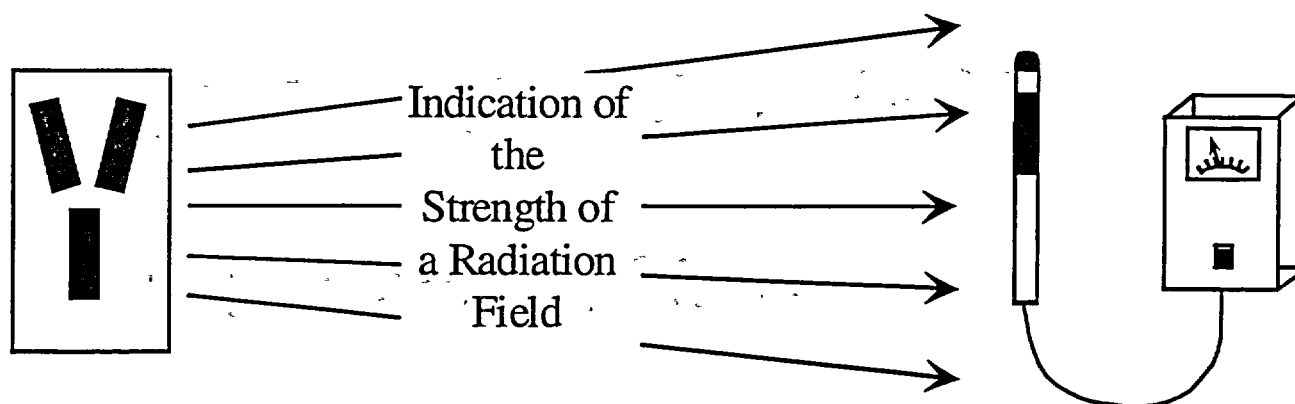
$$1 \text{ REM} = 1000 \text{ mREM}$$

$$1 \text{ mrem} = 1/1000\text{th REM}$$

The units used in a discussion of radiation and radioactivity may be prefixed to indicate fractions (or multiples) of the standard unit. The table below lists the more common prefixes for scientific use.

Prefixes

d	deci	(= 10E-1)	da	deka	(= 10)
c	centi	(= 10E-2)	h	hecto	(= 10E2)
m	milli	(= 10E-3)	k	kilo	(= 10E3)
μ	micro	(= 10E-6)	M	mega	(= 10E6)
n	nano	(= 10E-9)	G	giga	(= 10E9)
p	pico	(= 10E-12)	T	terra	(= 10E12)
f	femto	(= 10E-15)			
a	atto	(= 10E-18)			



## DOSE RATE

The DOSE RATE is the rate at which a person would (or did) receive a radiation dose (or dose equivalent). It is a measure of radiation dose intensity (or strength). Commonly used dose equivalent rates are:

mrem/hr

rem/hr

mrem/wk

rem/wk

rem/quarter

rem/year

$$\begin{aligned}\text{DOSE} &= \text{Dose Rate} \times \text{Time} \\ &= 50 \text{ mrem/hr} \times \frac{1}{2} \text{ hour} \\ &= 25 \text{ mrem}\end{aligned}$$

The DOSE is equal to the strength of the radiation field (dose rate) multiplied by the length of time spent in that field. The example above indicates a person could expect to receive a dose of 25 millirems by staying in a 50 millirems/hour field for thirty minutes.

## STAY TIME CALCULATIONS

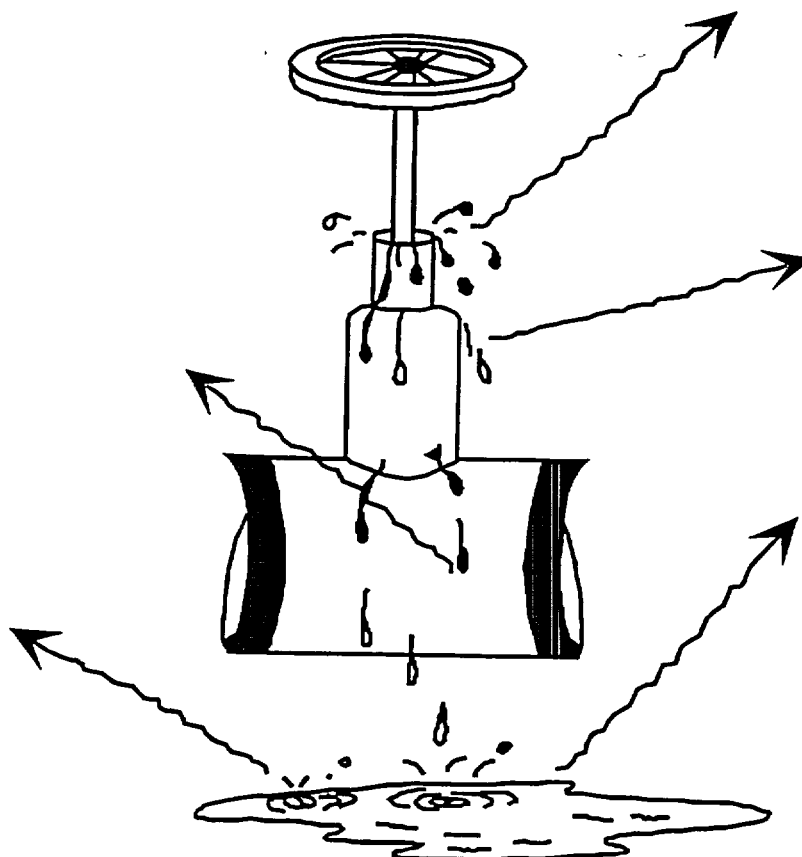
$$\text{Stay Time} = \frac{\text{Dose "Limit"}}{\text{Dose Rate}}$$

For Example:

$$\begin{aligned}\text{Stay Time} &= \frac{100 \text{ millirems limit}}{50 \text{ millirems/hr}} \\ &= 2 \text{ hours}\end{aligned}$$

STAY TIME is an exposure control value equal to the length of time a person can remain in a radiation field before exceeding some DOSE LIMIT. In the example above, a dose limit of 100 millirems has been established. With a dose rate of 50 millirems/hour, the stay time is calculated to be two hours by dividing the dose limit by the dose rate.

# Contamination



**CONTAMINATION** is generally referred to as some quantity of radioactive material in a location where it is not intended or desired to be. Radioactive contamination is radioactive atoms (material) that have escaped the system or structure that would normally contain them. Radioactive contamination can be wet or dry, fixed or removable, and settled or airborne. Since radioactive contamination is radioactive material, ionizing radiation is emitted by the contamination.

A **CONTAMINATED AREA** is an area that contains some type of radioactive contamination. Some examples of contaminated areas that require periodic access would be the primary side of the steam generator for a pressurized water reactor and the main turbine for a boiling water reactor. Methods of protection against radiation and contamination are discussed in Chapter 9.

## International System of Units (SI)

### Special Units

### SI Units

Curie

Becquerel

RAD

Gray

REM

Sievert

USNRC regulations (10 CFR Part 20) now lists both the special units and the equivalent internationally accepted system of units and measures (SI). The SI units shown above have replaced the curie, RAD, and REM in some technical literature.

The relationships between the special units and the SI units are shown on the following pages.



$$1 \text{ Curie} = 3.7 \times 10^{10} \text{ disintegrations/second}$$

$$1 \text{ Becquerel} = 1 \text{ disintegration/second}$$

$$1 \text{ Becquerel} = 2.7 \times 10^{-11} \text{ Curie}$$

One curie is defined as the amount of any radioactive material that decays at the rate of 37 billion disintegrations per second. The SI unit for activity is the becquerel. It is equal to one disintegration per second. Therefore, one curie equals 37 billion becquerels.

$$1 \text{ RAD} = 0.01 \text{ Gray}$$

$$1 \text{ Gray} = 100 \text{ RADs}$$

The Gray is the SI unit of absorbed dose. A Gray is equal to 0.1 Joule of energy deposited in one kilogram of matter. Therefore, one RAD is equivalent to 1/100 of a gray, and one gray is equal to 100 RADs.

$$1 \text{ REM} = 0.01 \text{ Sievert}$$

$$1 \text{ Sievert} = 100 \text{ REM}$$

The sievert is the SI unit of dose equivalent. In the same way that converting from the absorbed dose (RAD) to the dose equivalent (REM) involved the use of quality factors, the conversion of grays to sieverts also uses quality factors.

One rem equals 1/100th of a sievert, and one sievert equals 100 rems.

# Natural and Man-Made Radiation Sources

All living creatures, from the beginning of time, have been, and are still being, exposed to radiation.

This chapter will discuss the sources of this radiation, which are:

- Natural Background Radiation
- Man-Made Sources of Radiation

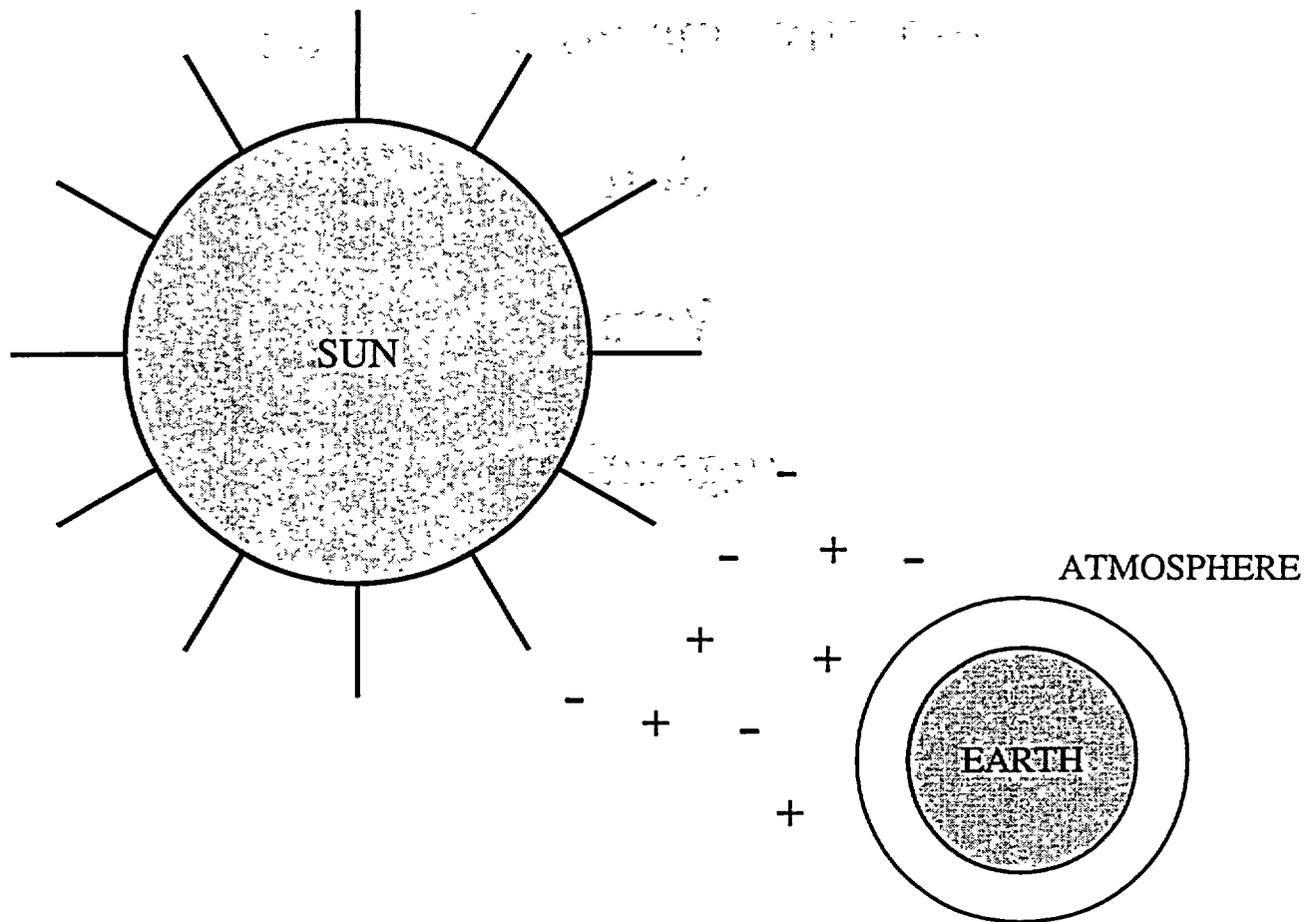
# Natural Background Sources:

Cosmic Radiation  
Terrestrial Radiation  
Internal Radiation

Natural background radiation comes from three sources:

- Cosmic Radiation
- Terrestrial Radiation
- Internal Radiation

## Cosmic Radiation



The earth, and all living things on it, are constantly bombarded by radiation from space, similar to a steady drizzle of rain. Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of radiation, typically beta and gamma radiation. The dose from cosmic radiation varies in different parts of the world due to differences in elevation and to the effects of the earth's magnetic field.

# Terrestrial Radiation

Radioactive material found in:

Soil

Water

Vegetation

Radioactive material is also found throughout nature. It is in the soil, water, and vegetation. Low levels of uranium, thorium, and their decay products are found everywhere. Some of these materials are ingested with food and water, while others, such as radon, are inhaled. The dose from terrestrial sources also varies in different parts of the world. Locations with higher concentrations of uranium and thorium in their soil have higher dose levels.

The major isotopes of concern for terrestrial radiation are uranium and the decay products of uranium, such as thorium, radium, and radon.

# Internal Radiation

Potassium-40

Carbon-14

Lead-210

In addition to the cosmic and terrestrial sources, all people also have radioactive potassium-40, carbon-14, lead-210, and other isotopes inside their bodies from birth. The variation in dose from one person to another is not as great as the variation in dose from cosmic and terrestrial sources. The average annual dose to a person from internal radioactive material is about 39 millirems/year.



Man-made radiation sources result  
in exposures to:

Members of the public

Occupationally exposed individuals

Although all people are exposed to natural sources of radiation, there are two distinct groups exposed to man-made radiation sources. These two groups are:

- Members of the public
- Occupationally exposed individuals

A member of the public is defined in 10 CFR Part 20 as any individual except when that individual is receiving an occupational dose.

Occupational dose is the dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation or to radioactive material. This does not include the dose received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive materials from voluntary participation in medical research programs, or as a member of the public.

Man-made radiation sources that result in an exposure to members of the public:

Tobacco  
Televisions  
Medical X-rays  
Smoke detectors  
Lantern mantles  
Nuclear medicine  
Building materials

By far, the most significant source of man-made radiation exposure to the public is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy. Some of the major isotopes would be I-131, Tc-99m, Co-60, Ir-192, Cs-137, and others.

In addition, members of the public are exposed to radiation from consumer products, such as tobacco (thorium), building materials, combustible fuels (gas, coal, etc.), ophthalmic glass, televisions, luminous watches and dials (tritium), airport X-ray systems, smoke detectors (americium), road construction materials, electron tubes, fluorescent lamp starters, lantern mantles (thorium), etc.

Of lesser magnitude, members of the public are exposed to radiation from the nuclear fuel cycle, which includes the entire sequence from mining and milling of uranium to the actual production of power at a nuclear plant. This would be uranium and its daughter products.

The final sources of exposure to the public would be shipment of radioactive materials and residual fallout from nuclear weapons testing and accidents, such as Chernobyl.

## Occupationally Exposed Individuals:

Fuel cycle  
Radiography  
X-ray technicians  
Nuclear power plant  
U.S. NRC inspectors  
Nuclear medicine technicians

Occupationally exposed individuals, on the other hand, are exposed according to their occupations and to the sources with which they work. Occupationally exposed individuals, however, are monitored for radiation exposure with dosimeters so that their exposures are well documented in comparison to the doses received by members of the public.

Some of the isotopes of concern would be uranium and its daughter products, cobalt-60, cesium-137, americium-241, and others.

# Ionizing Radiation Exposure to the Public

## Man-Made Radiation Sources:

Medical X-rays  
Nuclear Medicine  
Consumer Products  
Other

-----  
Total of 18%

Other < 1%

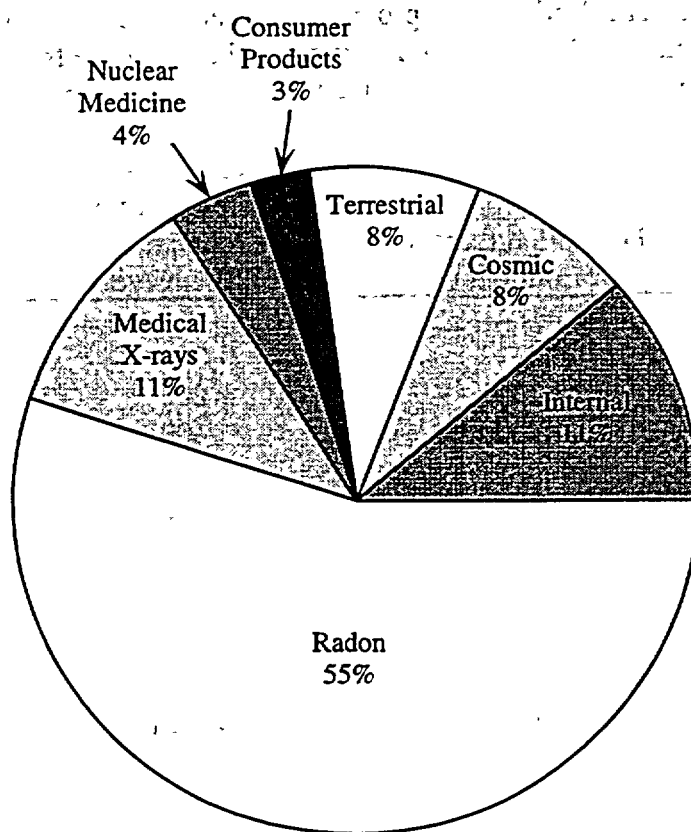
This includes:

Occupational - 0.3%

Fallout - < 0.3%

Nuclear Fuel Cycle - 0.1%

Miscellaneous - 0.1%



## Natural Radiation Sources:

Radon

Internal

Terrestrial

Cosmic

-----  
Total of 82%

The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, *Ionizing Radiation Exposure of the Population of the United States, 1987*.

This chart shows that of the total dose of about 360 millirems/year, natural sources of radiation account for about 82% of all public exposure, while man-made sources account for the remaining 18%.

# Radiation Exposure to the U. S. Population

The following table is extracted from material contained in NCRP Report No. 93, Ionizing Radiation Exposure of the Population of the United States, 1987.

The first column shows the sources of radiation exposure, and the second column shows an estimate of the number of people exposed to that source. For natural sources, the entire United States population is assumed to be exposed. The third column provides the average dose (in units of millirems) to those exposed (number in column 2). The last column averages the total dose from the specific source over the entire U. S. population. For natural sources, the third and fourth columns are identical.

Exposure Source	Population Exposed (millions)	Average Dose Equivalent to Exposed Population (millirems/year)	Average Dose Equivalent to U.S. Population (millirems/year)
Natural:			
Radon	230	200	200
Other	230	100	100
Occupational	0.93	230	0.9
Nuclear Fuel Cycle <sup>1</sup>	---	---	0.05
Consumer Products:			
Tobacco <sup>2</sup>	50	---	---
Other	120	5 - 30	5 - 13
Environment	25	0.6	0.06
Medical:			
Diagnostic X-rays <sup>3</sup>	---	---	39
Nuclear medicine <sup>4</sup>	---	---	14
Approximate Total	230	---	360

<sup>1</sup>Collective dose to regional population within 50 miles of each facility.

<sup>2</sup>Difficult to determine a whole body dose equivalent. However, the dose to a portion of the lungs is estimated to be 16,000 millirems/year.

<sup>3</sup>Number of persons unknown. However, 180 million examinations performed with an average dose of 50 millirems per examination.

<sup>4</sup>Number of persons unknown. However, 7.4 million examinations performed with an average dose of 430 millirems per examination.

## COMPUTE YOUR OWN RADIATION DOSE

Cosmic radiation that reaches the earth at sea level:

27 mrem/yr

Based upon the elevation at which you live, add 1 mrem/yr for every 250 feet:

Examples: Atlanta - 1050 ft., Chicago - 595 ft., Dallas - 435 ft., Denver - 5280 ft., Las Vegas - 2000 ft., Minneapolis - 815 ft., Pittsburgh - 1200 ft., Washington, D. C. - 400 ft.

Based upon where you live, add the following for terrestrial radiation:

If you live in states that border the Gulf or Atlantic coasts (from Texas east and then north), add 23 mrem/yr

If you live in the Colorado Plateau area (around Denver), add 90 mrem/yr

If you live in middle America (rest of U. S.), add 46 mrem/yr

If you live in a stone, brick or concrete building, add 7 mrem/yr:

Radiation in our bodies from the food and water we ingest (potassium-40):

Radiation from the air due to radon (U.S. average):

Fallout from weapons testing:

(actually less than 1 mrem/yr, but add 1 mrem/yr to be conservative)

1 mrem/yr

If you travel on jet planes, add 1 mrem/yr per 1,000 miles of travel:

If you have porcelain crowns or false teeth, add 0.07 mrem/yr:

*Some of the radiation sources listed result in an exposure to only part of the body. For example, false teeth result in a radiation dose to the mouth. The annual dose numbers given here represent the effective dose to the whole body.*

If you use gas lantern mantles when camping, add 0.003 mrem/yr:

If you wear a luminous wristwatch (LCD), add 0.06 mrem/yr:

If you use luggage inspection at airports, add 0.002 mrem/yr:

If you watch television add 1 mrem/yr:

(actually less than 1 mrem/yr, but add 1 mrem/yr to be conservative)

1 mrem/yr

If you use a video display terminal, add 1 mrem/yr:

(actually less than 1 mrem/yr, but add 1 mrem/yr to be conservative)

1 mrem/yr

If you have a smoke detector, add 0.008 mrem/yr:

Total yearly dose this page:

## COMPUTE YOUR OWN RADIATION DOSE

(Continued)

Total from previous page: \_\_\_\_\_

If you wear a plutonium-powered cardiac pacemaker, add 100 mrem/yr: \_\_\_\_\_

For diagnostic X-rays, add an average of 50 mrem/yr per X-ray: \_\_\_\_\_

Examples of diagnostic X-rays are upper and lower gastrointestinal and chest X-rays

For nuclear medicine procedures, add an average of 430 mrem/yr per procedure: \_\_\_\_\_

An example of a nuclear medicine procedure would be a thyroid scan

If you live within 50 miles of a nuclear power plant, add 0.009 mrem/yr: \_\_\_\_\_

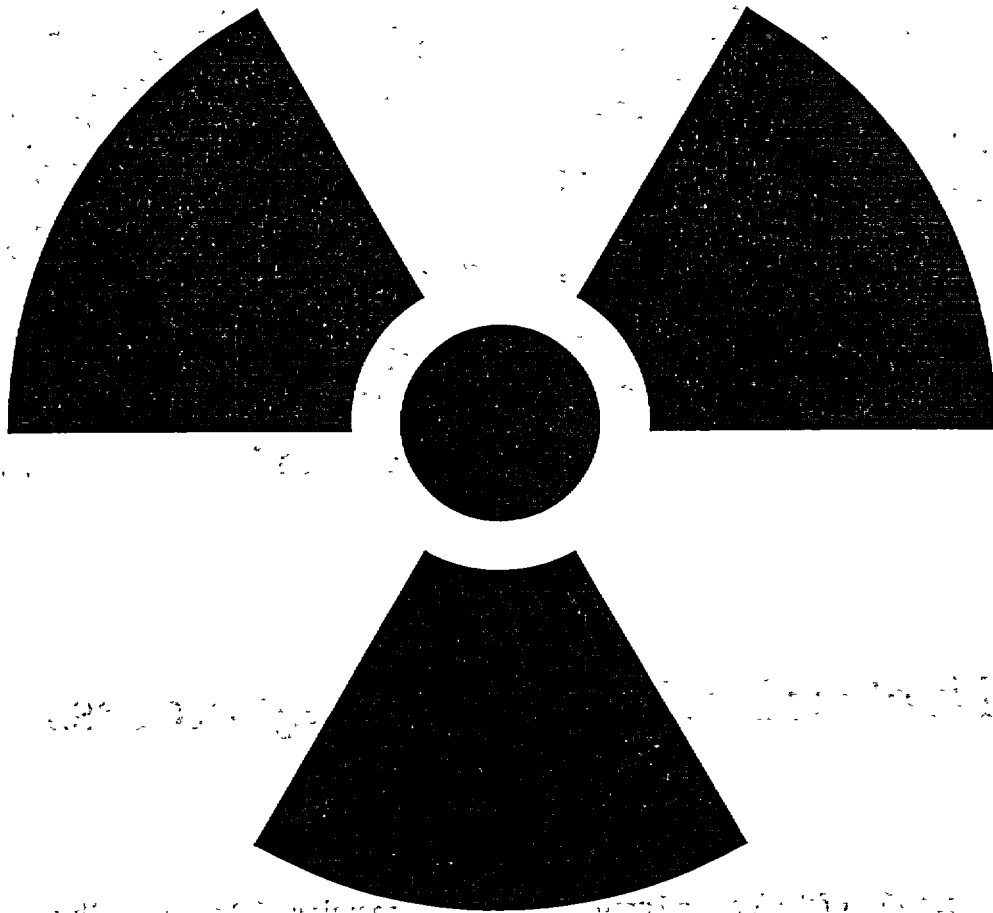
If you live within 50 miles of a coal-fired electrical utility plant, add 0.03 mrem/yr: \_\_\_\_\_

If you smoke, add an estimated 1,300 mrem/yr due to radon decay products: \_\_\_\_\_

YOUR AVERAGE TOTAL DOSE IN MILLIREMS PER YEAR: \_\_\_\_\_

Sources: National Council on Radiation and Measurement Reports 92, 93, 94, 95, and 100; the American Nuclear Society

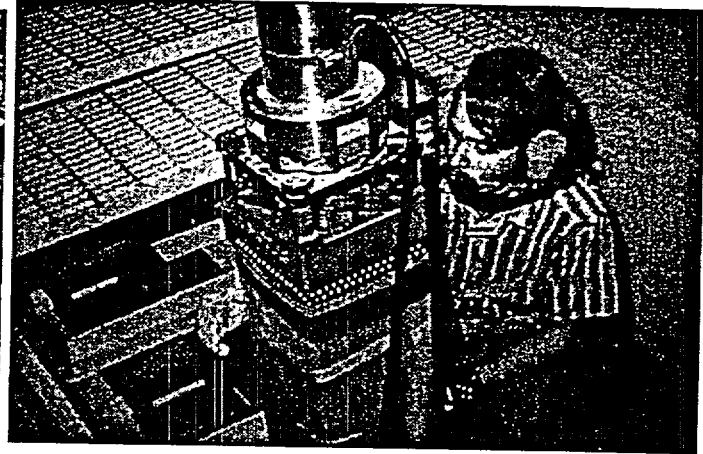
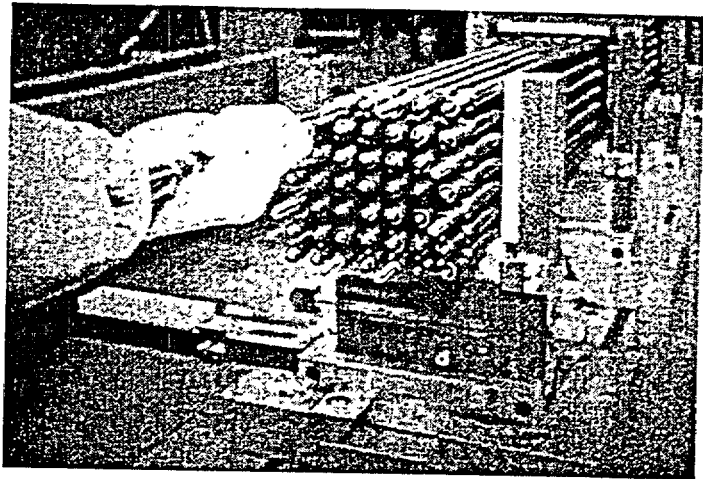
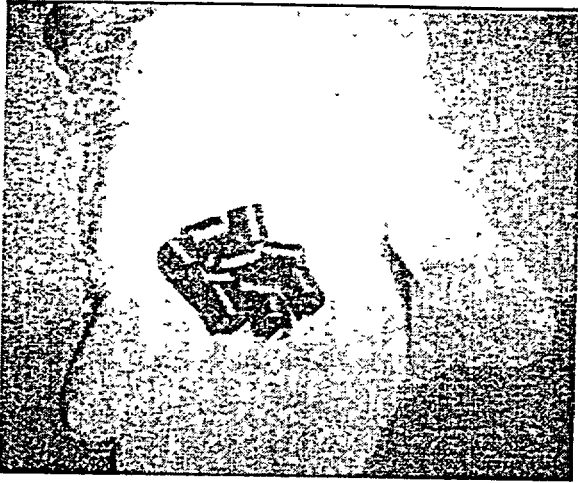
# Radiation Sources at Nuclear Plants



This chapter will discuss the sources of radiation at nuclear power plants. These sources are:

- Nuclear fuel decay
- Fission process
- Fission product decay
- Activation products
- Calibration sources

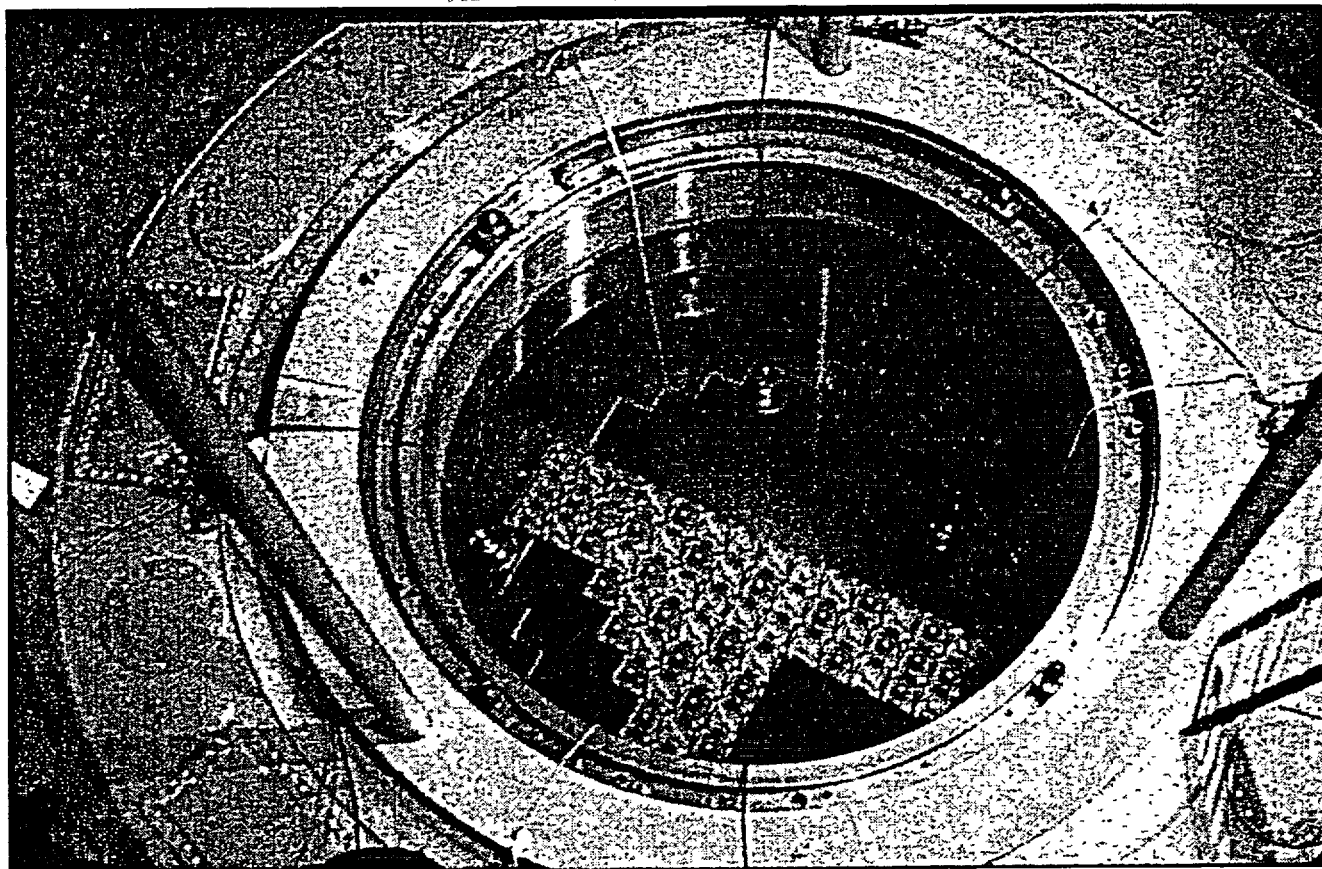




## Nuclear Fuel Natural Decay Process

Uranium-238 (about 96% of the fuel) and uranium-235 (the remaining 4%) are naturally radioactive and disintegrate (decay) by the emission of alpha particles and gamma rays into daughter products. Beta particles are also released from the fuel as the daughter products continue the natural decay process toward a stable form (lead). Since the fuel is sealed in airtight fuel rods, there should be little or no alpha or beta radiation problem at the nuclear plant due to the natural decay of the fuel unless there is some fuel rod damage.

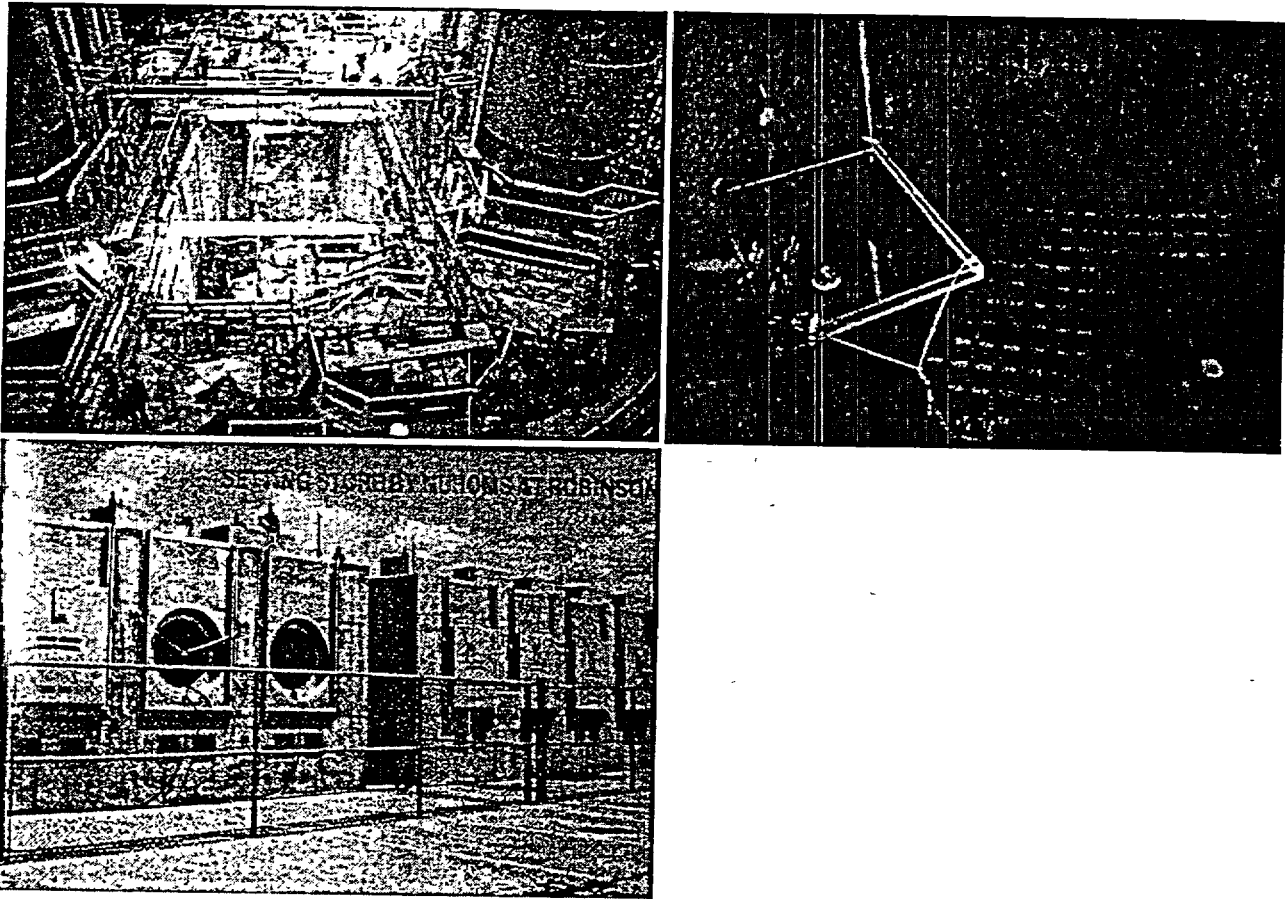
The natural decay process of the fuel is not a major contributor to a worker's dose at the power plants. This is because of the low radiation levels associated with fuel that has not operated in the reactor core.



## Fission Process

During the fission process, uranium atoms split into two or three smaller atoms, which are called fission products. Powerful (high-energy) gamma rays and high speed neutrons are released during and immediately following the fission process. Since neutrons and gamma rays can travel long distances in air, very high radiation levels are present in the vicinity of the reactor vessel during power operation.

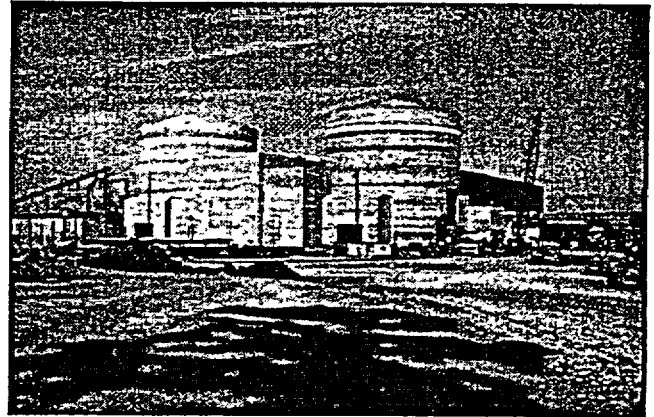
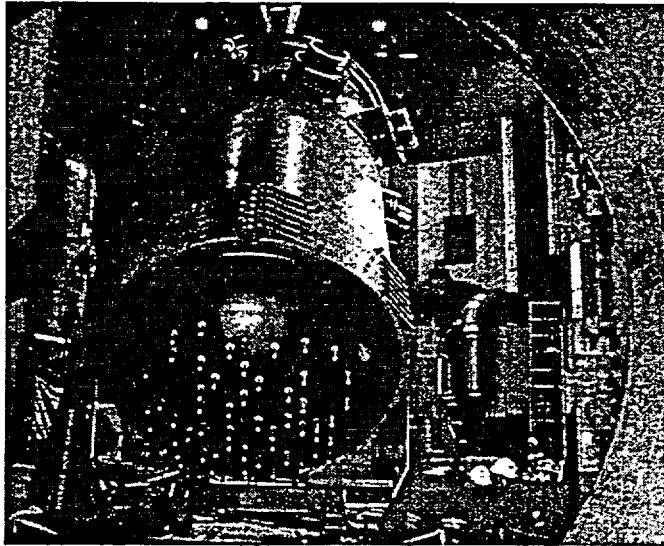
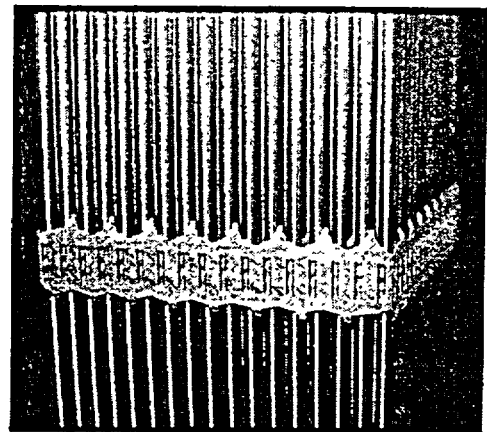
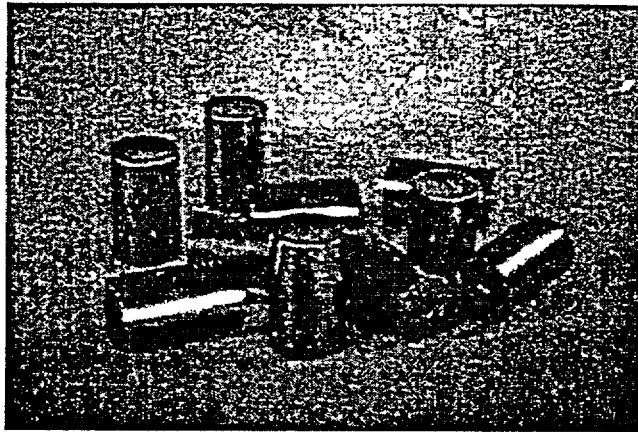
The fission process is not a major contributor to a worker's dose at the power plants. This is because the fission process is occurring in the reactor core which is contained in the reactor vessel. The reactor vessel is located within the reactor cavity inside the containment, and workers are not normally allowed around the reactor vessel during operation.



## Fission Product Decay

The fission products, which are produced by the fissioning of the uranium fuel, are intensely radioactive. Most of these fission products will decay rapidly, since they have very short half-lives. However, several have very long half-lives and decay very slowly. Fission products generally decay by beta and gamma emission.

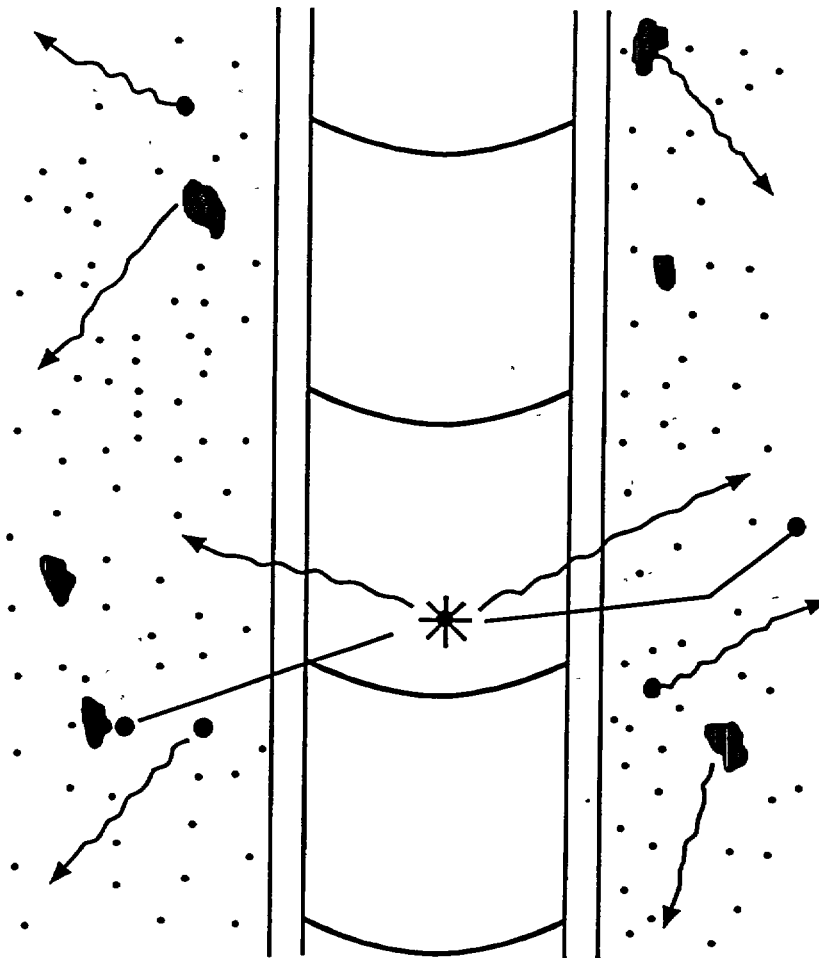
The decay of the fission products generally occurs within the reactor vessel, and, therefore, they are not a significant contributor to the radiation dose of workers at the power plant during operation. The gamma rays contribute to the radiation levels near the reactor vessel. Since workers are not normally present in the vessel area during operation, they are not a significant source of exposure. During refueling, however, the fuel is removed from the reactor vessel. At this time, the workers could be exposed to the radiation from the fission products. However, refueling is performed under water to limit the radiation dose the workers receive.



## Fission Product Barriers

Since a significant fission product release could seriously jeopardize public health and safety (and the environment), a system of fission product barriers is part of every power reactor design. The barriers are designed to keep the highly radioactive fission products from reaching the environment by keeping the fission products within the reactor core area.

Most of the fission products will stay in the pellet. But, if the pellet is damaged or due to natural diffusion, the fission products could get out of the pellet into the fuel rod. Since the fuel rods are contained within the reactor vessel, any leakage from the fuel rods will be contained within the reactor coolant system. If the reactor coolant system loses its integrity, the containment would contain the fission products.



## Activation of Water & Corrosion Products

Some materials in the vicinity of the reactor core (impurities in the reactor coolant and the reactor coolant itself) will absorb some of the neutrons produced during the fission process and will be changed from a stable form to an unstable (radioactive) form. This process is called activation, and the radioactive isotopes formed are called activation products. These activation products are located in the reactor coolant system, unlike the fission products which are located inside the fuel rods, and are, therefore, easily transported by the reactor coolant system to any support system that connects to the reactor coolant system. Activation products are the source of most radioactive contamination at nuclear power plants and are also the source of most occupational radiation exposure at the plants.

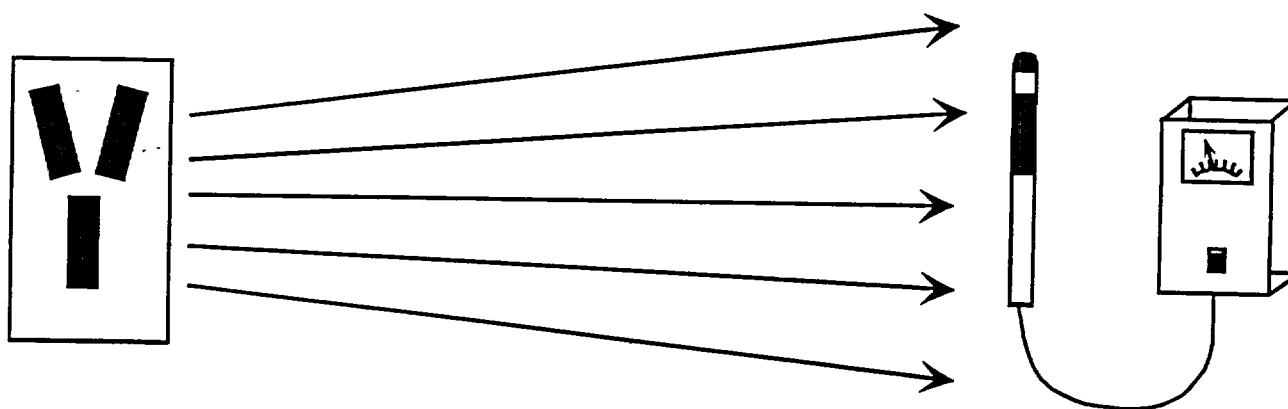
If the activation products or any other impurities plate out on reactor coolant system surfaces, the deposits are called CRUD. Prior to going into a refueling outage, some plants will add a chemical to the reactor coolant system to force the CRUD off the surfaces, and then use the cleanup system to remove the material from the coolant. This helps to reduce the radiation levels present during the refueling outage.

MATERIAL	RADIATION	HALF-LIFE
Krypton-85	Beta/Gamma	10 years
Strontium-90	Beta	28 years
Iodine-131	Beta/Gamma	8 days
Cesium-137	Beta/Gamma	30 years
Carbon-14	Beta	5770 years
Zinc-65	Beta/Gamma	245 days
Cobalt-60	Beta/Gamma	5 years
Iron-59	Beta/Gamma	45 days
Tritium (Hydrogen-3)	Beta	12 years

The list above shows some of the radioactive materials produced either by fission (fission products) or by neutron absorption (activation products). The first five isotopes on the list are fission products, and the remaining four are examples of activation products. These materials are of particular interest because of their:

- Relatively long half-life,
- Relatively large abundance in the reactor, and/or
- Ability to chemically interact in biological systems.

Not included in the list above, but of extreme importance, is the isotope nitrogen-16 (N-16). This isotope has a very short half-life (about seven seconds), but emits an extremely powerful gamma ray. N-16 is formed when an oxygen-16 atom absorbs a neutron and decays. Since every molecule of water has an oxygen atom, there is a large amount of N-16 produced in the core. N-16 is a major concern for shielding due to the high energy of the gamma ray emitted. Also, any system that contains primary coolant and exits containment must be of concern. One method of minimizing the radiation from N-16 is to allow the flow of coolant to circulate in a loop for a time period that permits the N-16 to decay, or by slowing down the flow to allow the decay (about a 1 minute delay is sufficient).



## Instrument Calibration Sources

Small quantities of radioactive material (called sources) are stored on the plant site to allow instrument technicians to properly test and calibrate radiation detection instruments. These sources are completely sealed and are stored in isolated areas when not in use.

Plant calibration sources are not a major contributor to a worker's dose at a power plant.

# Dose Standards and Methods for Protection Against Radiation and Contamination

This section will discuss the NRC dose standards and the methods used to protect individuals from the harmful effects of radiation and contamination.



# NRC Dose Limits

(from 10 CFR Part 20)

For members of the public:

Less than 2 millirems in any one hour from external radiation sources in any unrestricted area

Less than 100 millirems in a calendar year from both external and internal sources of radiation in unrestricted and controlled areas

The NRC limits the handling and use of radioactive materials such that no member of the public will receive a radiation dose of 2 millirems in any one hour from external radiation sources in an unrestricted area, or 100 millirems in a calendar year from both external and internal sources of radiation from each licensee.

Additionally, the NRC has provided design objectives for power reactor licensees to keep offsite doses as far below the 10 CFR Part 20 limits as is reasonably achievable. These guidelines can be found in 10 CFR Part 50.

Permissible dose levels in unrestricted areas during the transport of radioactive material can be found in 10 CFR Part 71.

# NRC Dose Limits

(from 10 CFR Part 20)

## Occupational Limits:

	<u>Annual Limit</u>
Whole Body (sum of external and internal dose)	5 rems
Extremity	50 rems
Skin of Whole Body	50 rems
Maximum Exposed Organ (sum of external and internal dose)	50 rems
Lens of the Eye	15 rems
Minor	0.5 rem

*The dose equivalent to the embryo/fetus of a declared pregnant woman has a limit of 0.5 rem over the gestation period.*

*Planned Special Exposure (PSE), an infrequent exposure for a special, high-dose job. The yearly limit is equal to the annual limit with a lifetime maximum of 5 times the annual limit. For example, the PSE limit for the whole body is 5 rems in a year, in addition to the above occupation limits, with a lifetime maximum of 25 rems.*

The NRC exposure limits shown above apply to all NRC licensees and are designed such that:

- 1) No worker at a nuclear facility will receive an acute whole body radiation exposure sufficient to trigger the radiation syndrome
- 2) The risk of cancer (although not zero) will not be higher than the risk of cancer from other occupations.

Licensees are also required by 10 CFR Part 20 to keep radiation exposures as low as reasonably achievable (ALARA).

*Note: The whole body and skin of the whole body includes all of the body except the hands, wrists, forearms, elbows, knees, legs below the knees, feet, and ankles.*

Now that the limits are known, how to protect the body from radiation will be discussed.

# Protection Against External Radiation Sources:

Time

Distance

Shielding

The three protective measures listed above (time, distance, and shielding) are primarily utilized to reduce the dose from any external source of radiation. Time and distance are also applicable for reducing the intake of radioactive material (internal dose), although once the radioactive material is inside the body, little can be done to reduce the dose.

However, the total dose (sum of internal and external dose) should be minimized, since overall risk is proportional to the total dose. In some cases, this may mean accepting a small intake of radioactive material to reduce the external dose. The important thing is to keep the total dose as low as reasonably achievable. Recall that the limits for whole body (5 rems/year) and maximum exposed organ (50 rems/year) apply to total dose.

Pages 9-5 to 9-11 will discuss how time, distance, and shielding are used to limit external exposure.

Pages 9-12 and 9-13 will discuss internal exposure control and protection from contamination.

Given:

$$\text{Dose Rate} \times \text{Time} = \text{Dose}$$

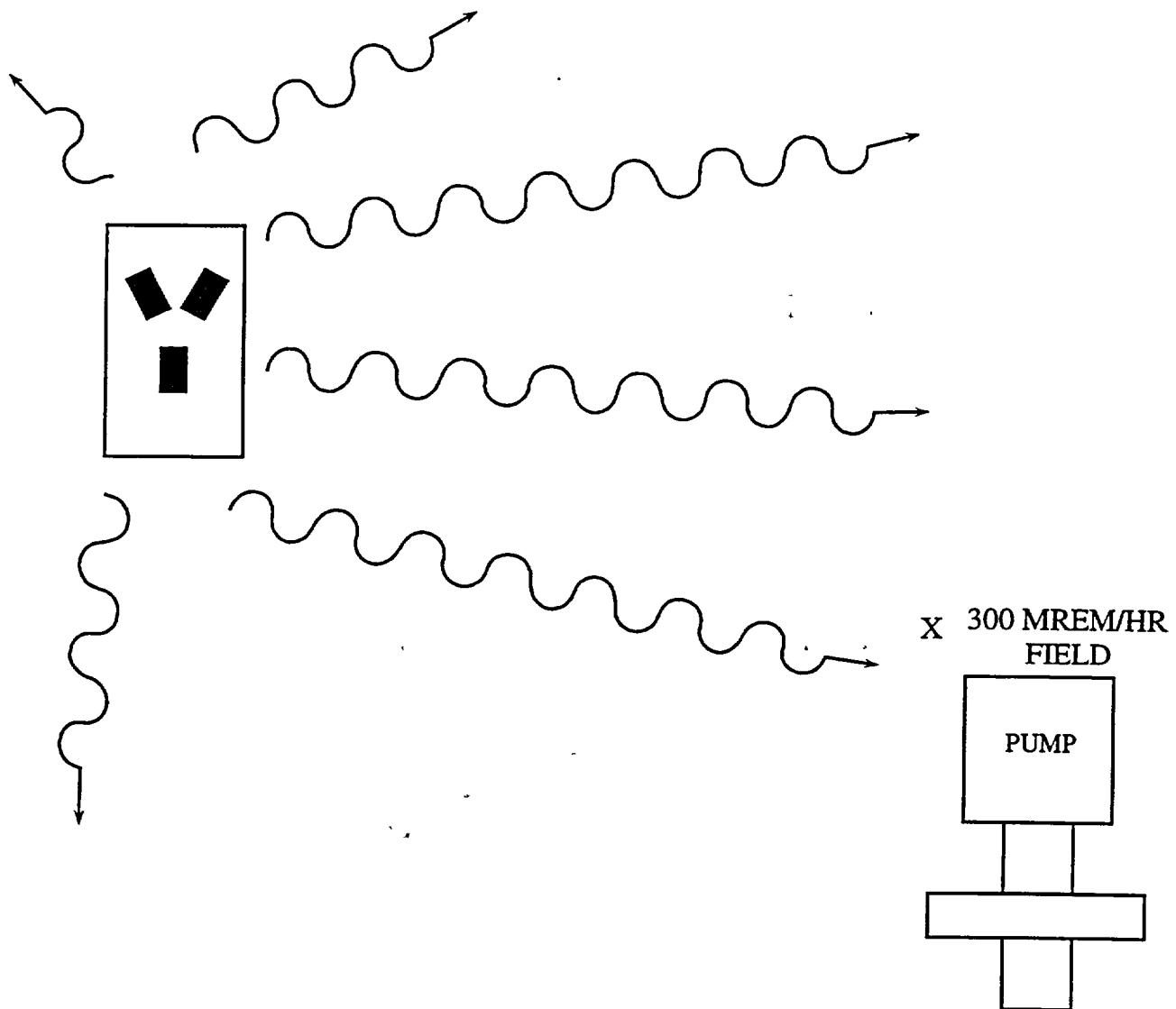
Therefore,

Minimize Exposure Time  
to  
Minimize Dose

The dose a person receives from external radiation is directly proportional to the length of time spent in a radiation field. Therefore, minimizing the amount of time spent in a radiation field will minimize the dose received. Some methods that can be used to minimize the time spent in a radiation field are:

- Plan and rehearse the job under realistic conditions
- Know the exact location of work prior to entering the radiation area
- Ensure all necessary tools are available at the job location
- Establish good communications
- Do not loiter in the area

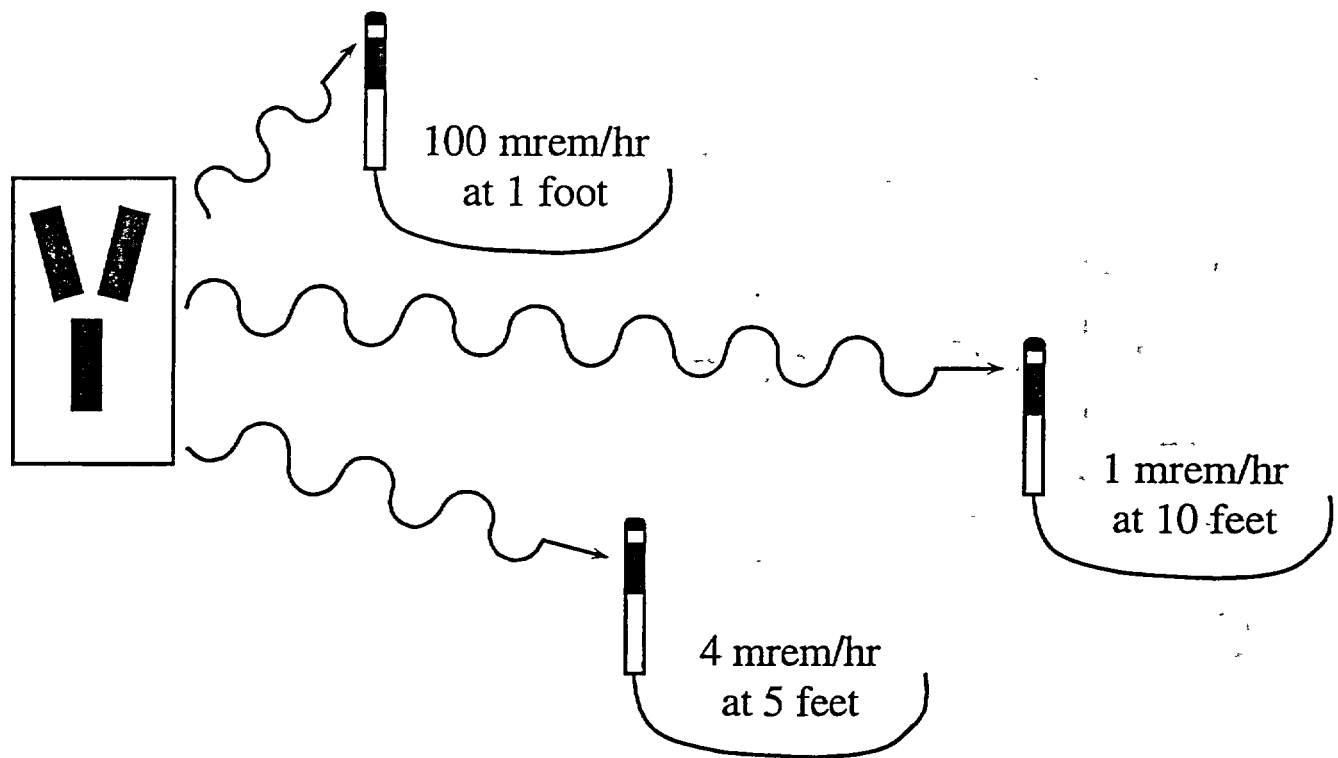
Similarly, minimizing the time spent in an area with airborne radioactivity will minimize the internal dose, since the intake of radioactive material (that being inhaled) is directly proportional to the inhalation time (volume of air being breathed).



## Minimize Time

Assuming a radiation field of 300 millirems/hour, an individual working in this area would receive:

- 75 millirems in 15 minutes,
- 150 millirems in 30 minutes,
- 300 millirems in 1 hour, or
- 600 millirems in 2 hours.

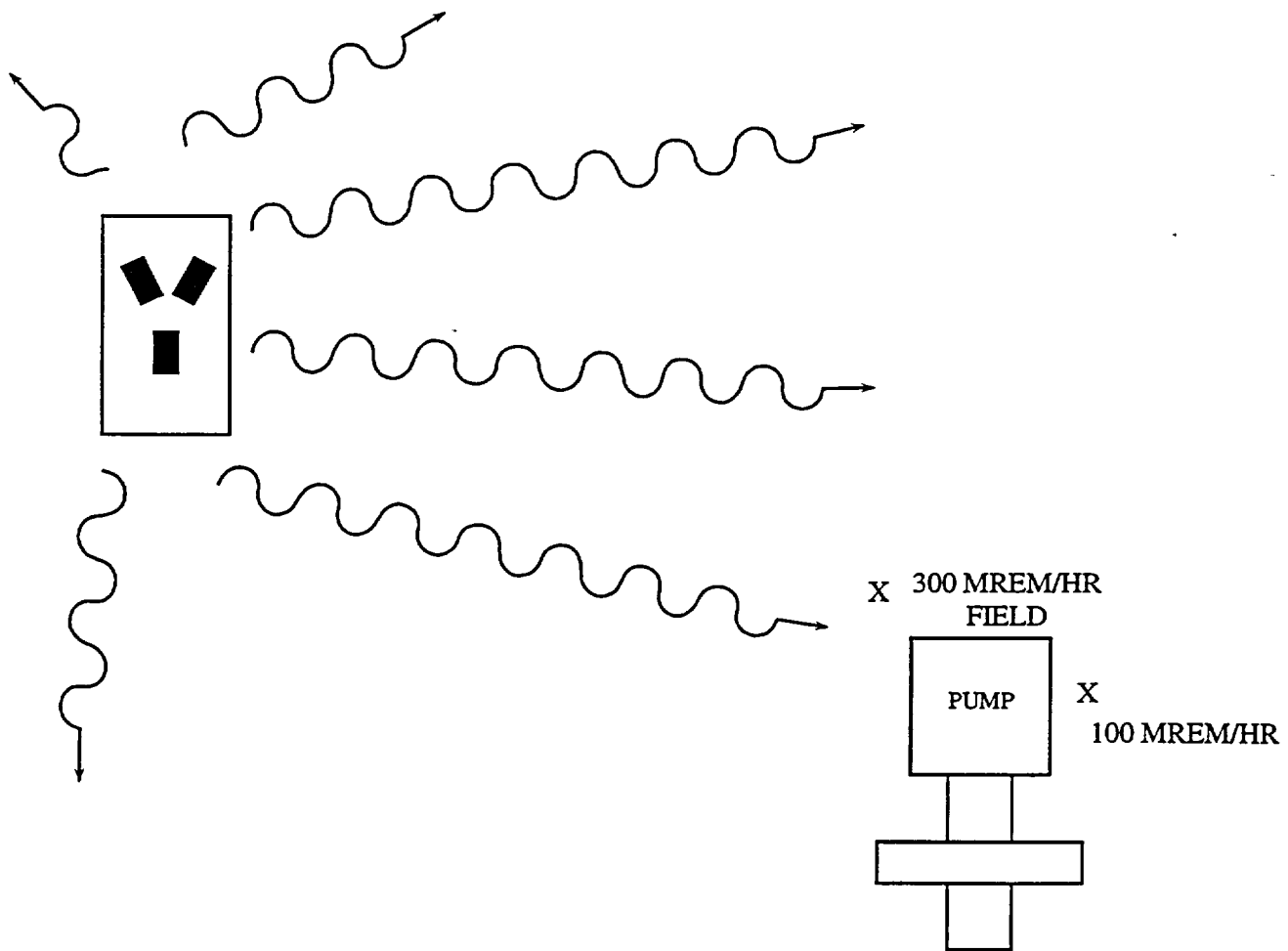


## Maximize Distance to Minimize Dose

Many radiation sources are “point sources” (the radiation appears to emit from one spot some distance away). The radiation dose from these sources can be significantly reduced by applying the protective measure of “distance” as demonstrated above. The dose a person receives from an external radiation source is inversely proportional to the square of the distance from the source ( $1/d^2$ ). Therefore, if the dose rate at one foot is 100 millirems/hour, the dose rate at 10 feet would be  $1/10^2$  of that, or 1 millirem/hour. Some ways to increase the distance on a job are:

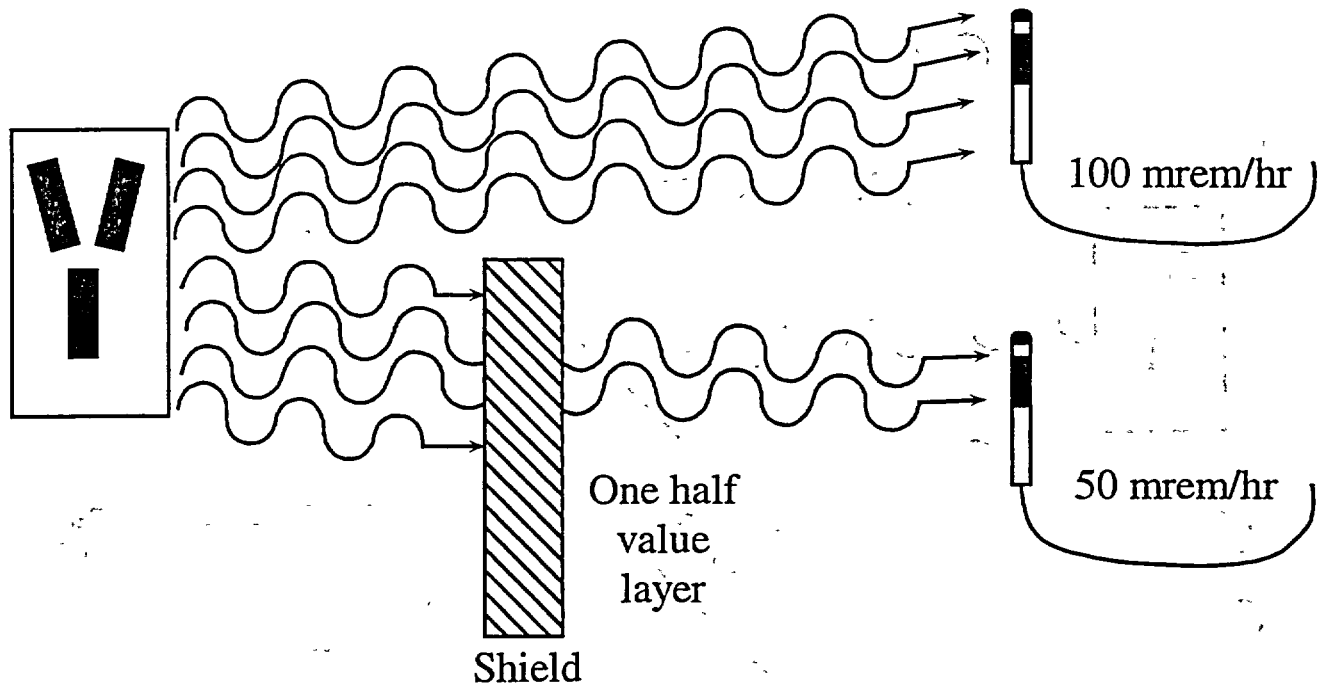
- Using extension tools,
- Utilizing remote operating stations, and
- Staying away from hot spots.

Staying as far away as possible from a source of airborne radioactivity will minimize the intake of radioactivity, because the activity will disperse and become less concentrated (in most cases) as it moves away from the point of release.



## Maximize Distance

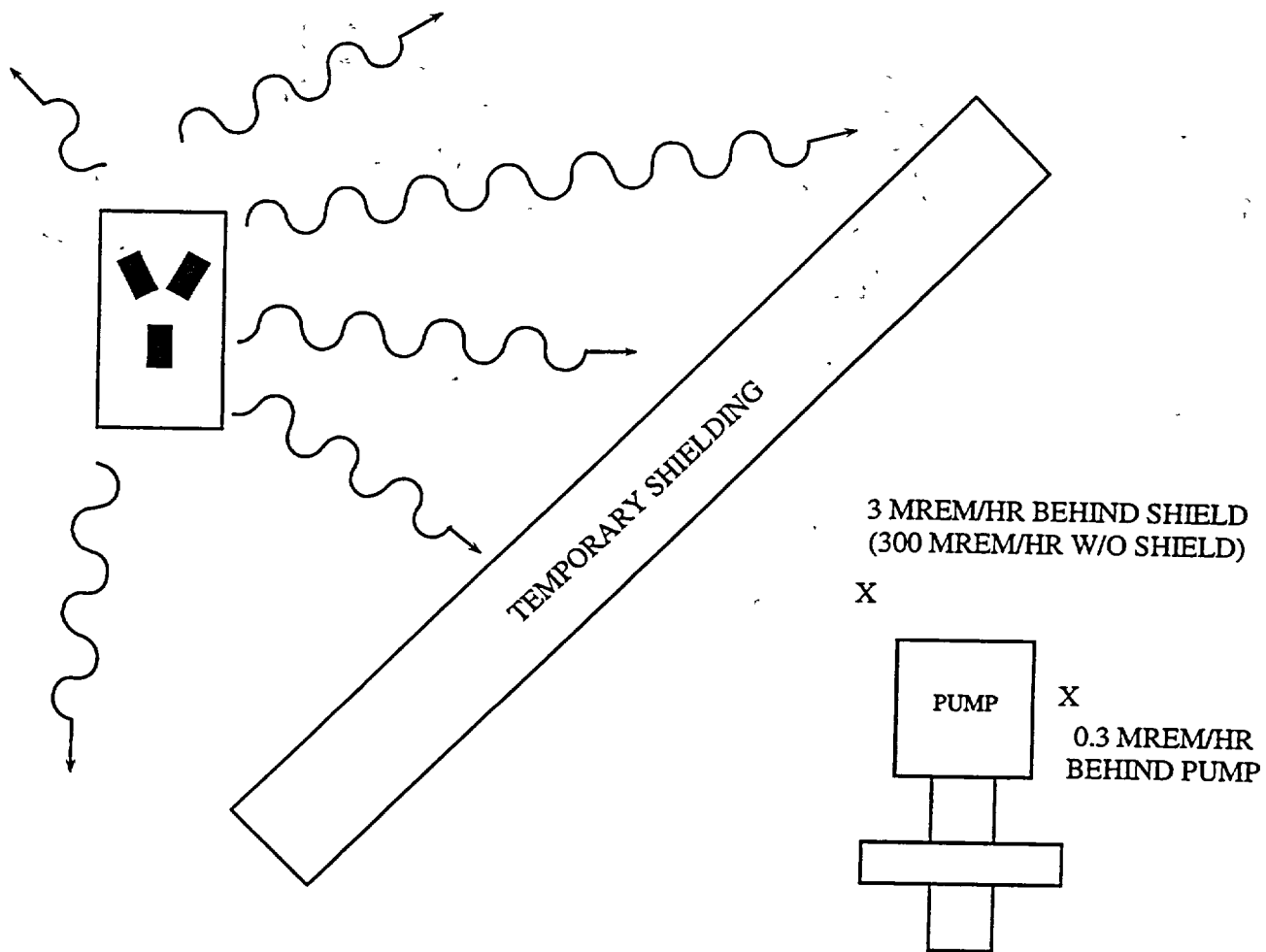
By moving a few feet away from a nearby source of radiation, the dose rate can be significantly reduced. Therefore, a person performing a job can have a longer stay time to perform the needed task.



## Maximize Shielding to Minimize Dose

Shielding is one of the most effective means of reducing radiation exposure. The example above shows that the installation of one half-value layer (half-thickness) of shielding will reduce the dose rate by a factor of two at a set distance from the source of radiation. By locating the shielding as close as possible to the source, dose rates can be reduced in a large area, and thus reduce the dose to many workers (some of which, perhaps, could not reduce their exposure time or work further from the source).





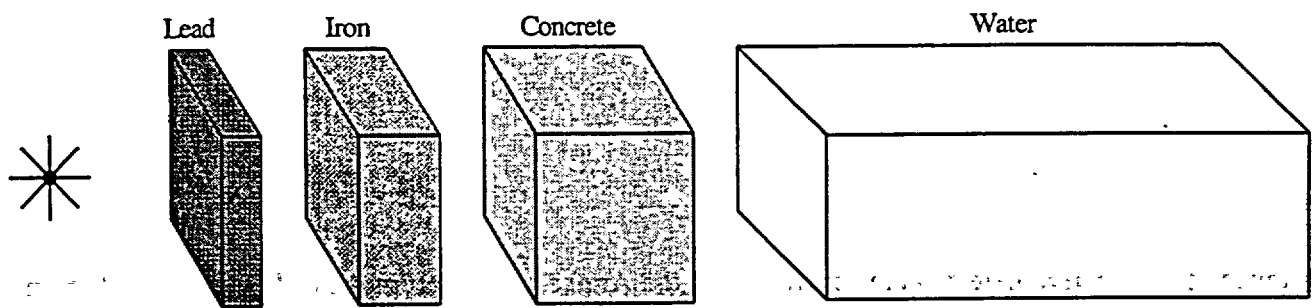
## Temporary and Installed Shielding

The two major types of shielding at the plant are installed shielding and temporary shielding. Installed shielding is permanent shielding installed at the plant for the purpose of reducing the radiation levels in some areas. An example of permanent shielding is the concrete shield walls located in the containment.

Temporary shielding can take the form of lead sheets, lead bricks, or bags filled with lead shot. This type of shielding can be placed near the source to reduce the radiation levels in large areas. It can also be shaped as needed to provide the maximum shielding effectiveness.

Installed equipment can also be used as shielding material. In the drawing above, the dose rate without the temporary shielding would be 300 millirems/hour. The installation of the temporary shielding reduces the dose rate to 3 millirems/hour. However, if the worker can perform the job from the far side of the pump, the dose rate can be reduced to 0.3 millirem/hour due to the effectiveness of the pump acting as a shield.

# Relative Effectiveness of Various Shielding Materials



Materials differ in their ability to shield (absorb) radiation. The figure above shows the relative effectiveness of four common shield materials (lead, iron, concrete, and water) for gamma radiation. To have the same gamma radiation exposure level at the outside of each material, it takes about twice as much iron as lead, about twice as much concrete as iron, and about three times as much water as concrete.

A thumb rule that can be used is that it takes 2 inches of lead to reduce the dose rate by a factor of 10. Therefore, if a radiation detector measured the dose rate at a certain distance to be 100 millirems/hour, 2 inches of lead would reduce the dose rate to 10 millirems/hour. This value is called a tenth-value thickness of lead. To accomplish the same reduction using the other materials would require 4 inches of iron/steel, 8 inches of concrete, or 24 inches of water. These values are only thumb rules. The exact amount of material required depends upon the energy of the radiation (gamma ray) that is being shielded against.

# Internal Exposure Control

$$1 \text{ ALI} = 2000 \text{ DAC-hr} = 5 \text{ Rems}$$

Intakes of radioactive material are controlled by the Annual Limit on Intake (ALI), expressed in units of microcuries. The ALI is the primary limit for internal exposure control, and in the absence of any external radiation, a worker may intake one ALI in a year. One ALI equals 5 rems internal dose.

Concentrations of radioactive materials in air are limited by the Derived Air Concentrations (DACs), which are derived from the ALI. The DACs are derived assuming a worker breathes 1.2 cubic meters of air per hour for 2000 hours per year. Therefore:

$$\text{DAC (microcuries / ml)} = \frac{\text{ALI (microcuries)}}{2.4 \times 10^9 \text{ ml}}$$

If a worker breathes air containing radioactive material at a concentration of 1 DAC for one hour, then the worker has been exposed to 1 DAC-hr. Therefore:

$$1 \text{ ALI} = 2000 \text{ DAC-hr} = 5 \text{ rems}$$

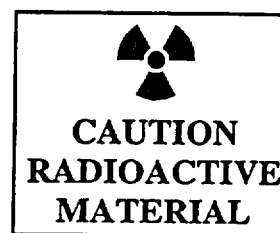
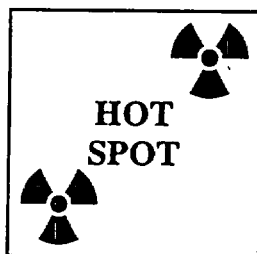
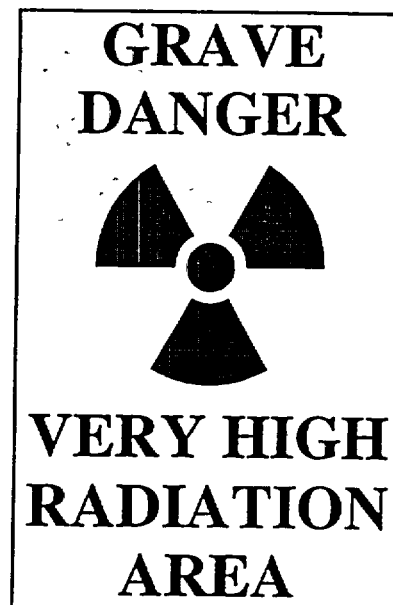
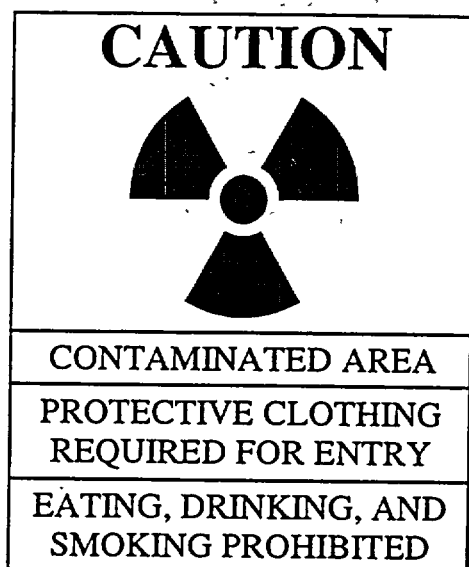
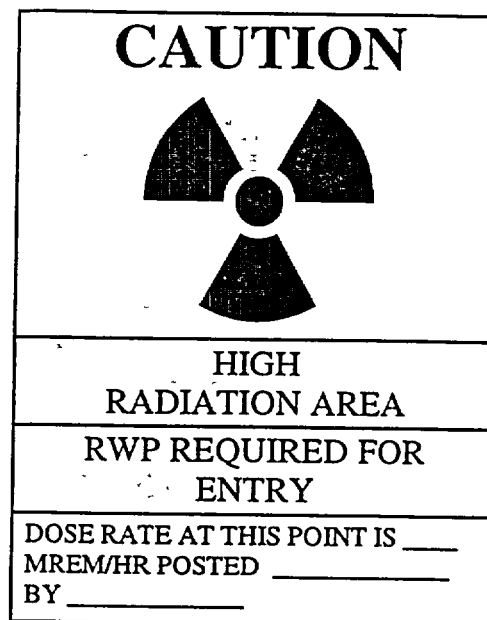
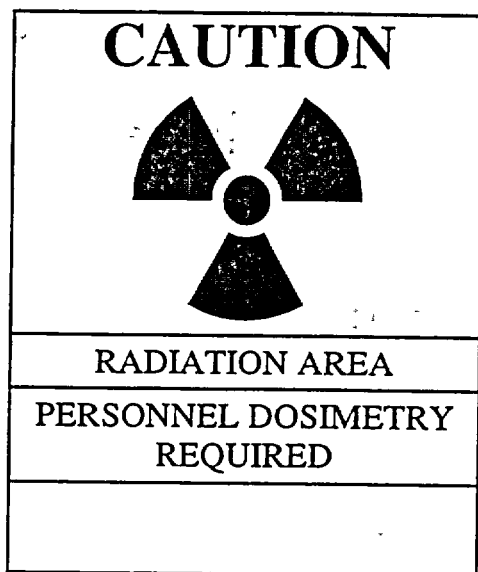
Since the operational limit of 5 rems applies to the sum of the internal and external exposures, if a worker has some external dose, the ALI must be modified or offset to account for the external dose. For example, assume the worker has 2 rems from external sources of radiation. Only 3 more rems are allowed from internal radiation before the worker reaches the occupational whole body limit. Expressed in DAC-hr, this would be:

$$\frac{3}{5} \times 2000 \text{ DAC-hr} = 1200 \text{ DAC-hr}$$

# Protection Against Contamination

- Utilize containments
- Maintain access control
- Conduct frequent surveys
- Utilize protective clothing
- Wear respiratory protection
- Practice good housekeeping
- Conduct follow up bioassays
- Minimize radioactive leakage

The protective measures listed above are used to prevent, detect, and/or contain radioactive contamination. Since radioactive contamination can be inhaled and/or ingested, the above measures are also considered to be methods of protection against internal doses.



Above are some common radiation signs and labels. These are commonly used to warn people of radiation areas, contaminated areas, and locations where radioactive material is found. The international symbol for radioactive material and radiation is a magenta or black three-bladed design on a yellow background.