UNITED STATES

NUCLEAR REGULATORY COMMISSION

OFFICE OF PUBLIC AFFAIRS

NUCLEAR POWER AND RADIATION

WORKSHOP MANUAL

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UNITED STATES

NUCLEAR REGULATORY COMMISSION

OFFICE OF INSPECTION AND ENFORCEMENT

REACTOR CONCEPTS

G - 100

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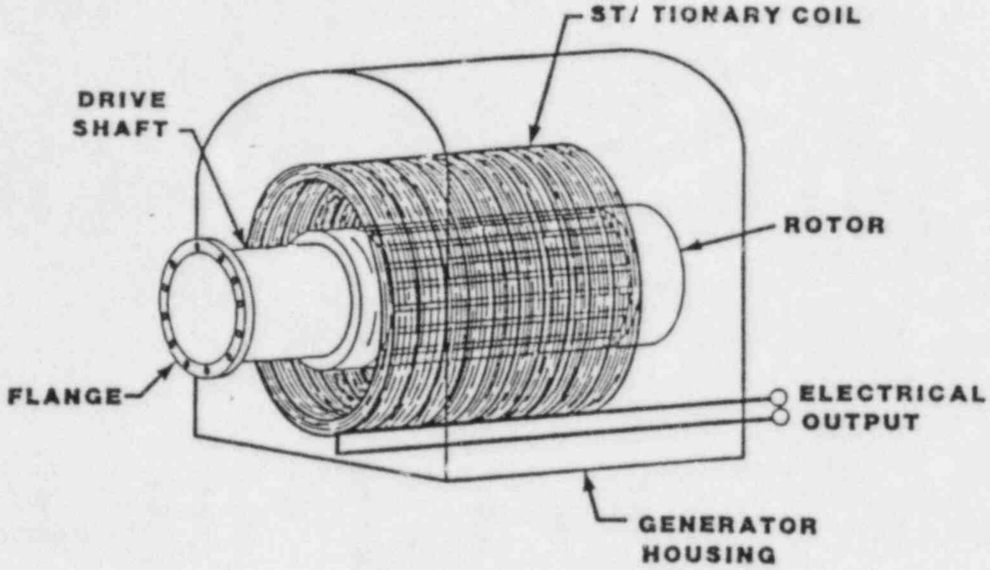
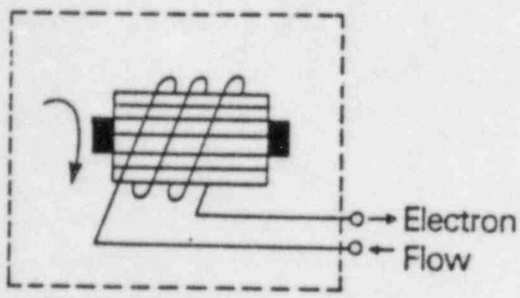
NUCLEAR POWER FOR ELECTRICAL GENERATION

The purpose of a Nuclear Power Plant is not to produce or release "Nuclear Power" but to generate electricity. It should not be surprising then that a nuclear power plant has many similarities to other electrical generating facilities. It should also be obvious that nuclear plants have some significant differences from other plants. Some of these differences could lead to an adverse effect on public health and safety.

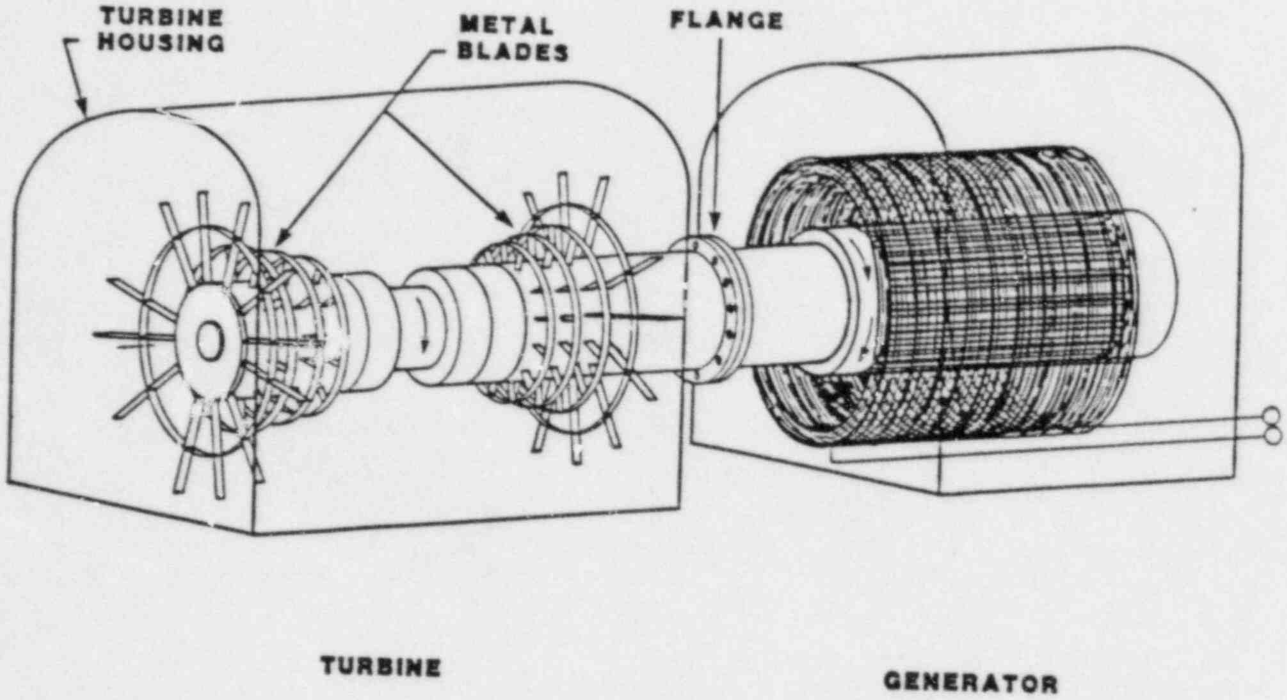


ELECTRICAL GENERATOR



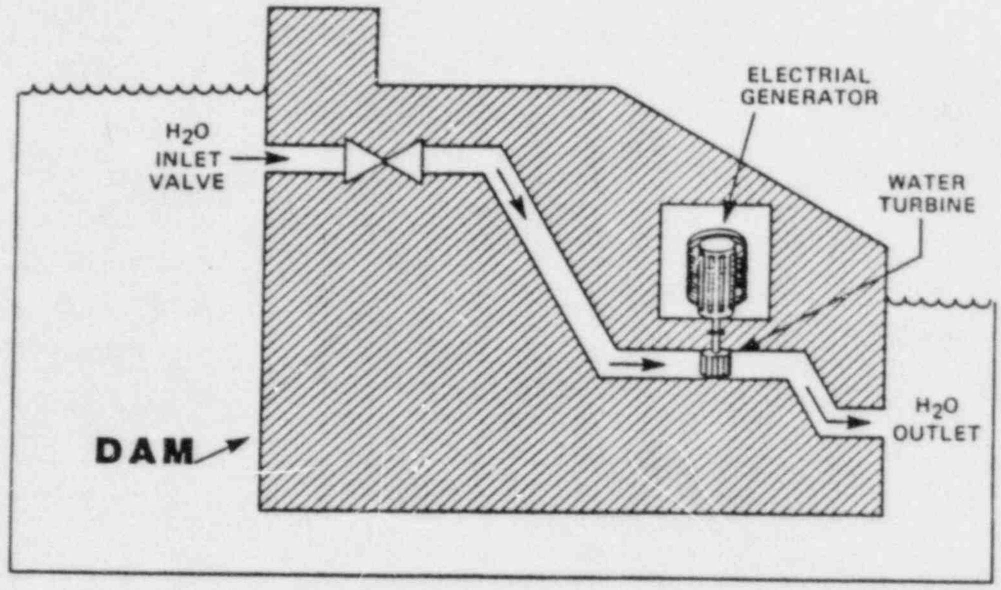
ELECTRICAL
GENERATOR

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, creating a flow of electrons inside the wire. This flow of electrons is called electricity. Some mechanical device (wind turbine, water turbine, steam turbine, etc.) must be available to provide rotation.

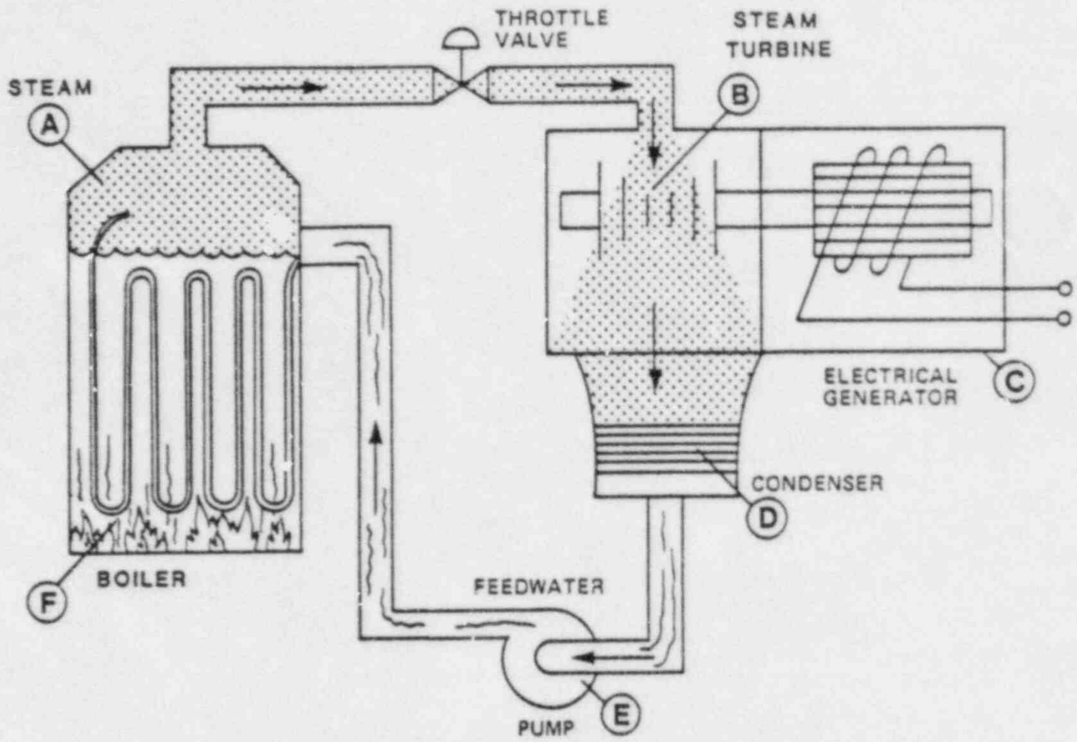


When a turbine is attached (flanged) to the electrical generator, the kinetic energy (i.e., motion) of the wind, falling water, or steam pushes against the fan-type blades of the turbine, causing the turbine, and the attached rotor of the electrical generator to spin and produce electricity.

HYDROELECTRIC PLANT

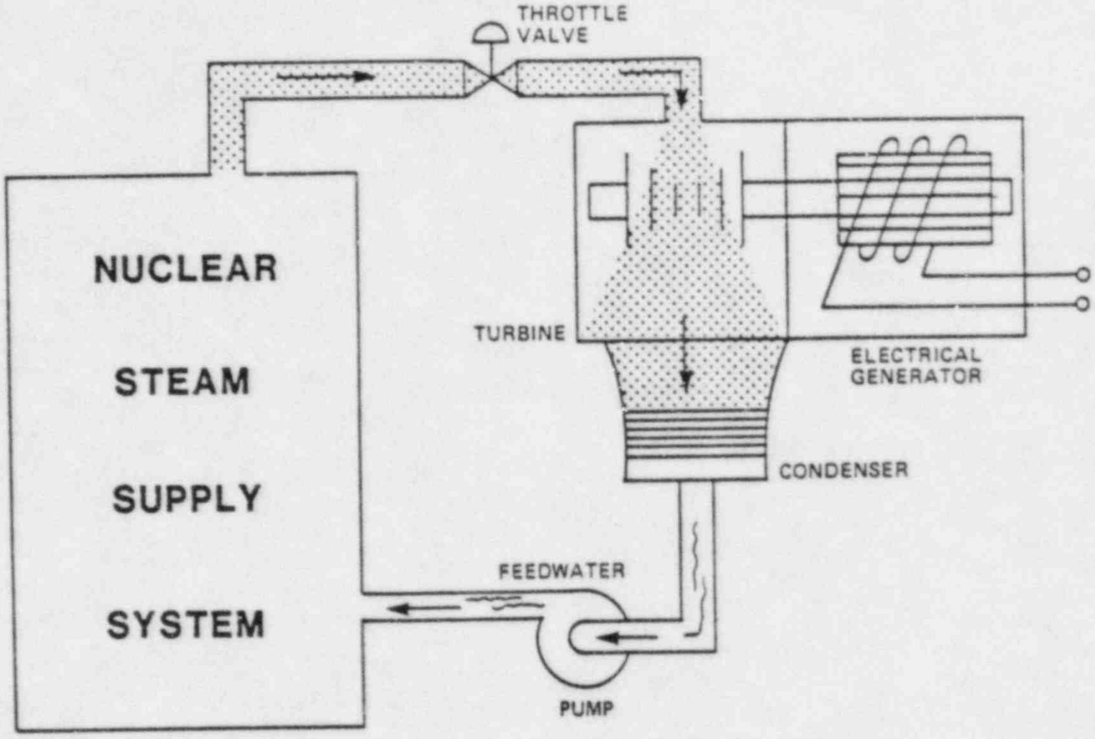


In a hydroelectric power plant, water flowing from a high level to a lower level travels through the metal blades of a water turbine, causing the rotor of the electrical generator to spin and produce electricity.



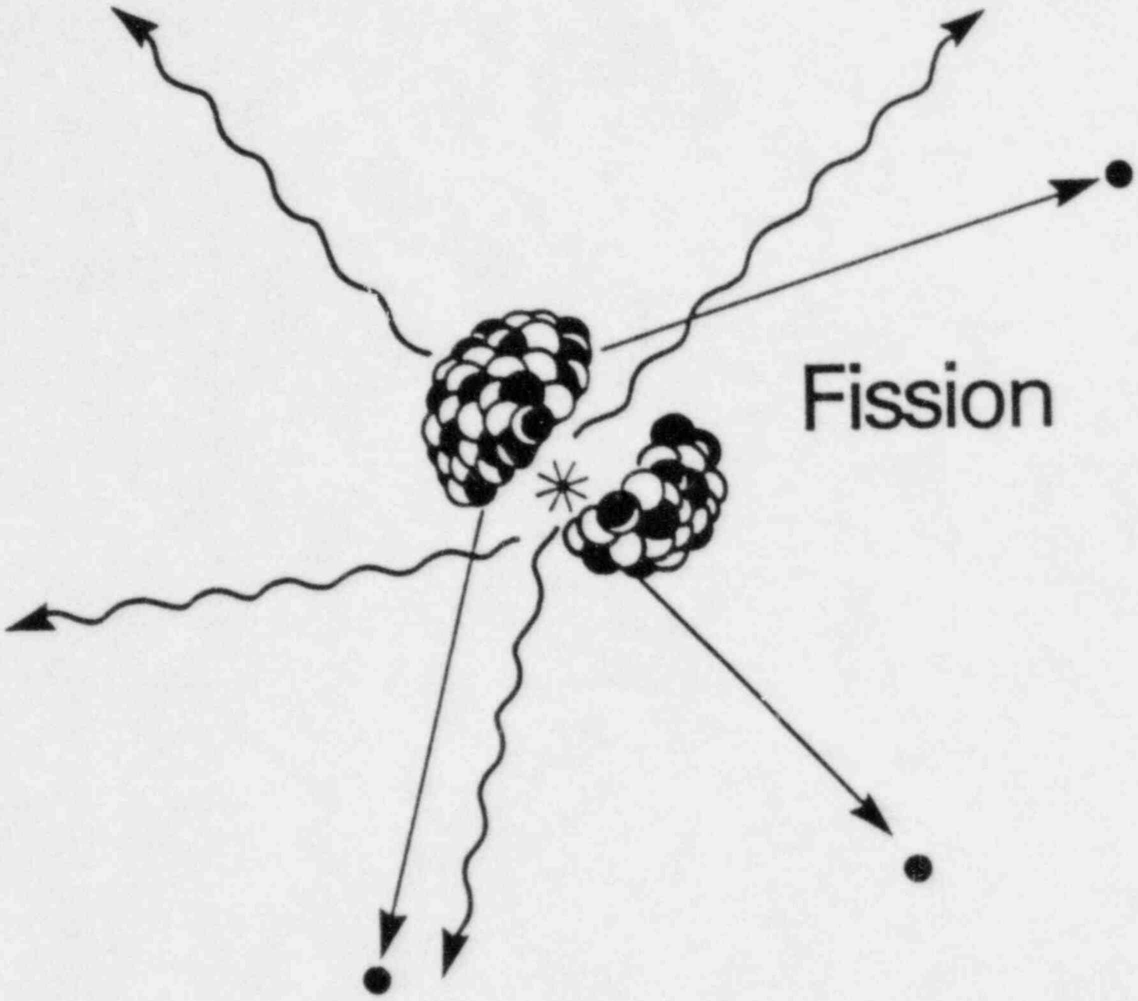
FOSSIL FUEL STEAM PLANT

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), where it travels through the blades of the turbine, which spins the electrical generator (C), resulting in a flow of electricity. After leaving the turbine, the steam is converted back (condensed) 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.



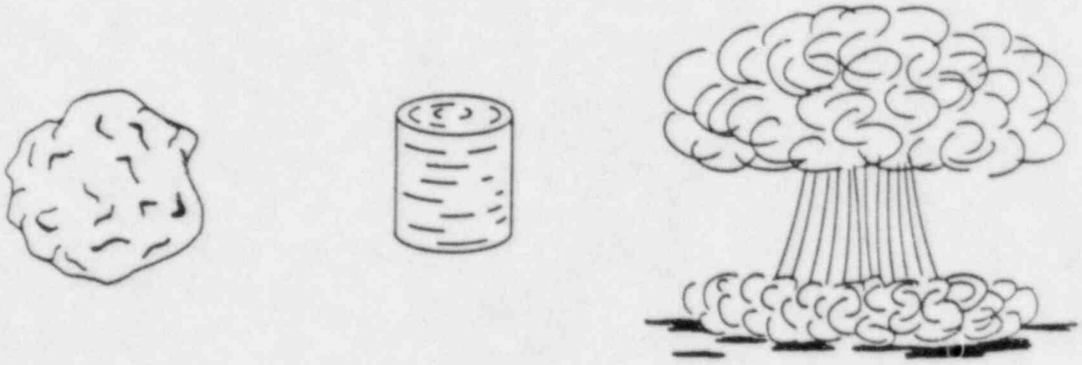
NUCLEAR FUEL STEAM PLANT

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 the components necessary to produce high pressure steam for the production of electricity.



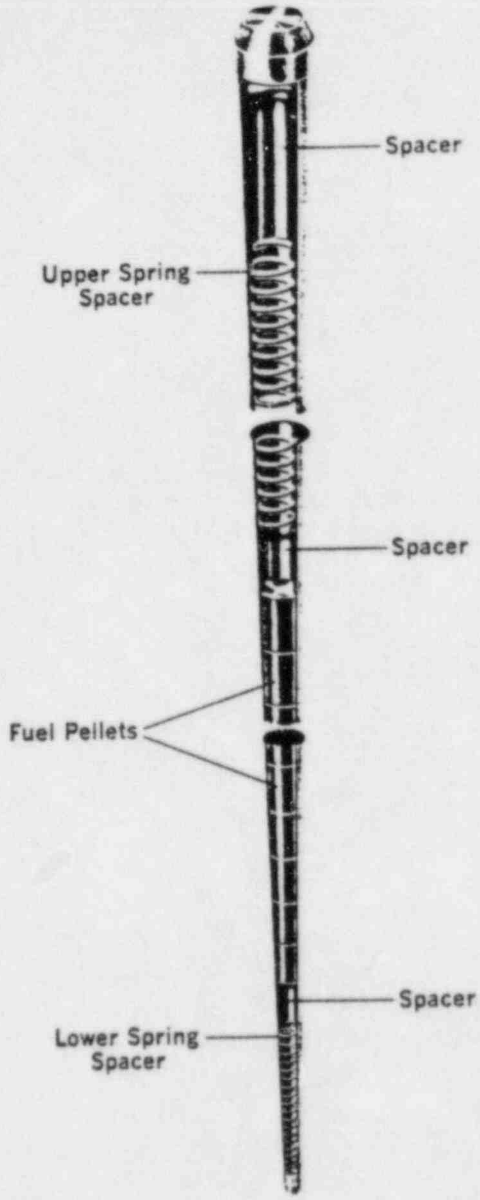
Like a fossil-fueled plant, a nuclear power plant boils water to produce electricity. Unlike a fossil-fueled plant, however, the nuclear plant's energy does not come from the combustion of fuel but from the fission (or splitting) of fuel atoms.

ENRICHMENT
(% U-235)



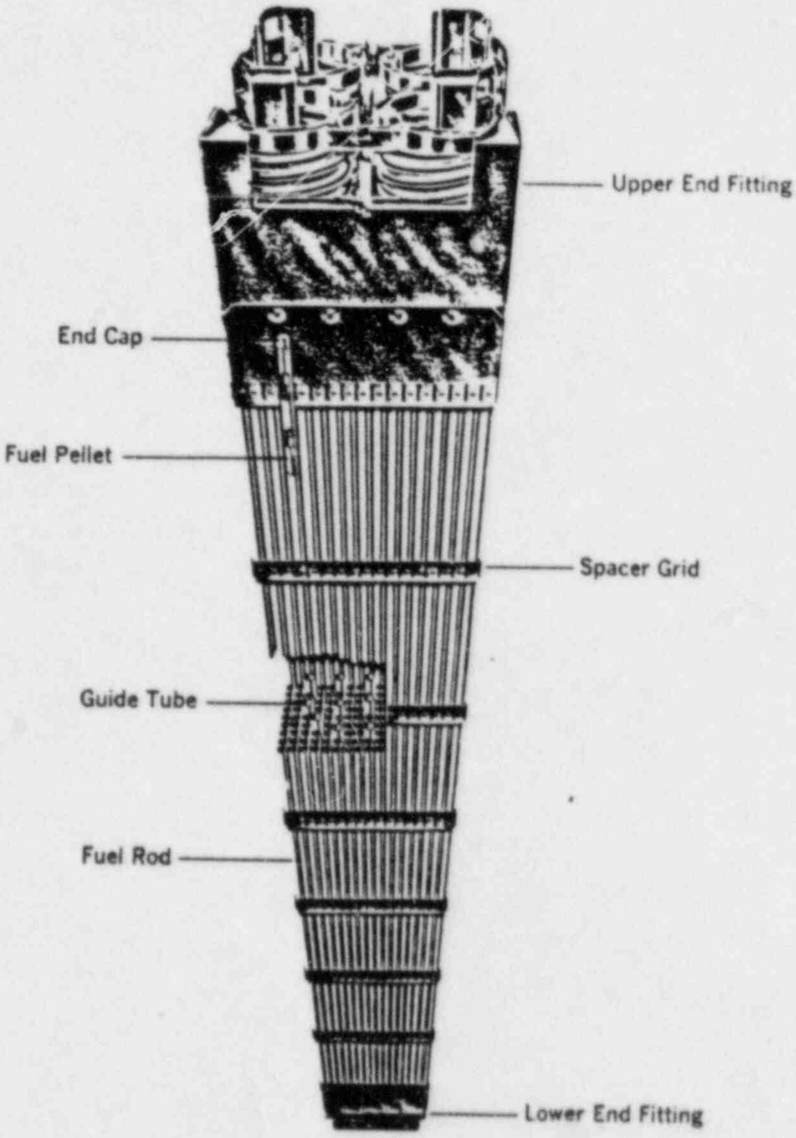
URANIUM ORE	FUEL PELLET	NUCLEAR WEAPON
.7%	3.5%	>97%

Most power reactors (capable of producing electricity) in the United States use a "slightly enriched" uranium fuel. "Enrichment" refers to the percentage of the easily fissionable U-235 atoms present in the fuel to the less fissionable U-238 atoms (which are far more abundant in nature). "Weapons Grade" Uranium is very highly enriched (greater than 97% U-235).



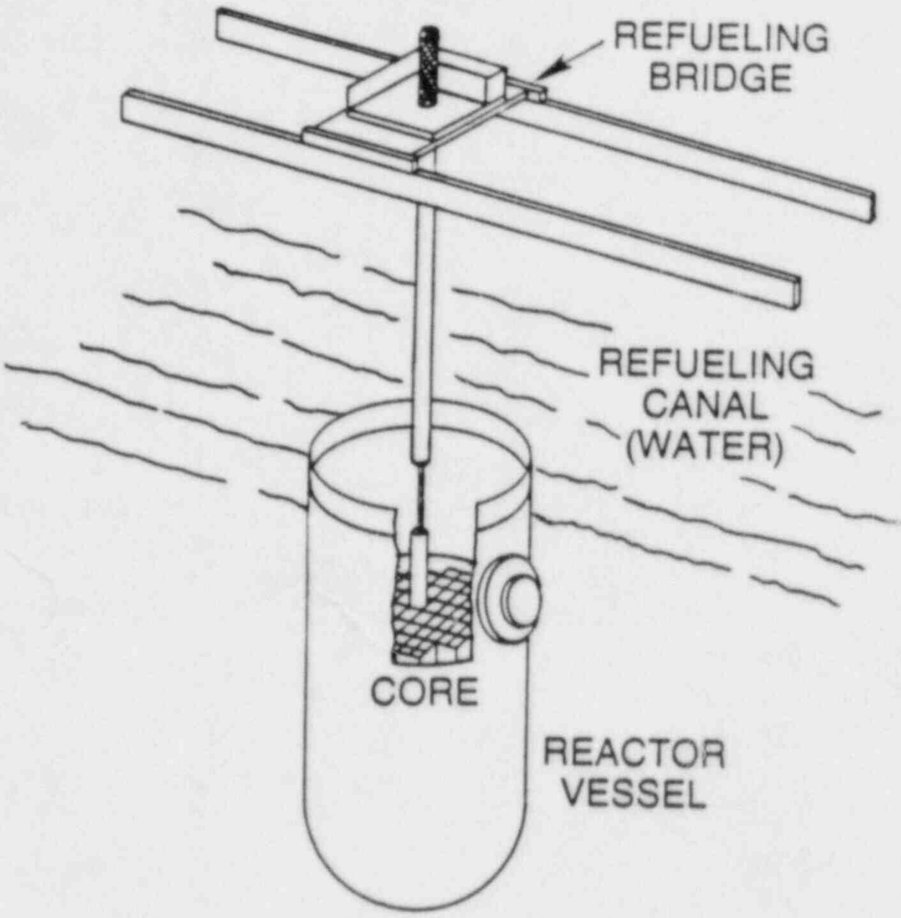
Babcock & Wilcox

Once fabricated, ceramic uranium dioxide (UO_2) fuel pellets, each about 3/4 in. diameter and about 5/8 in. long, are inserted, one on top of the other, into 12-foot long, slender metal tubes. The tubes are generally made of zirconium alloy, aluminum, or stainless steel. The tube material is known as "cladding." When a tube is filled with the uranium fuel pellets, pressurized with helium gas and sealed, it is referred to as a "fuel rod."

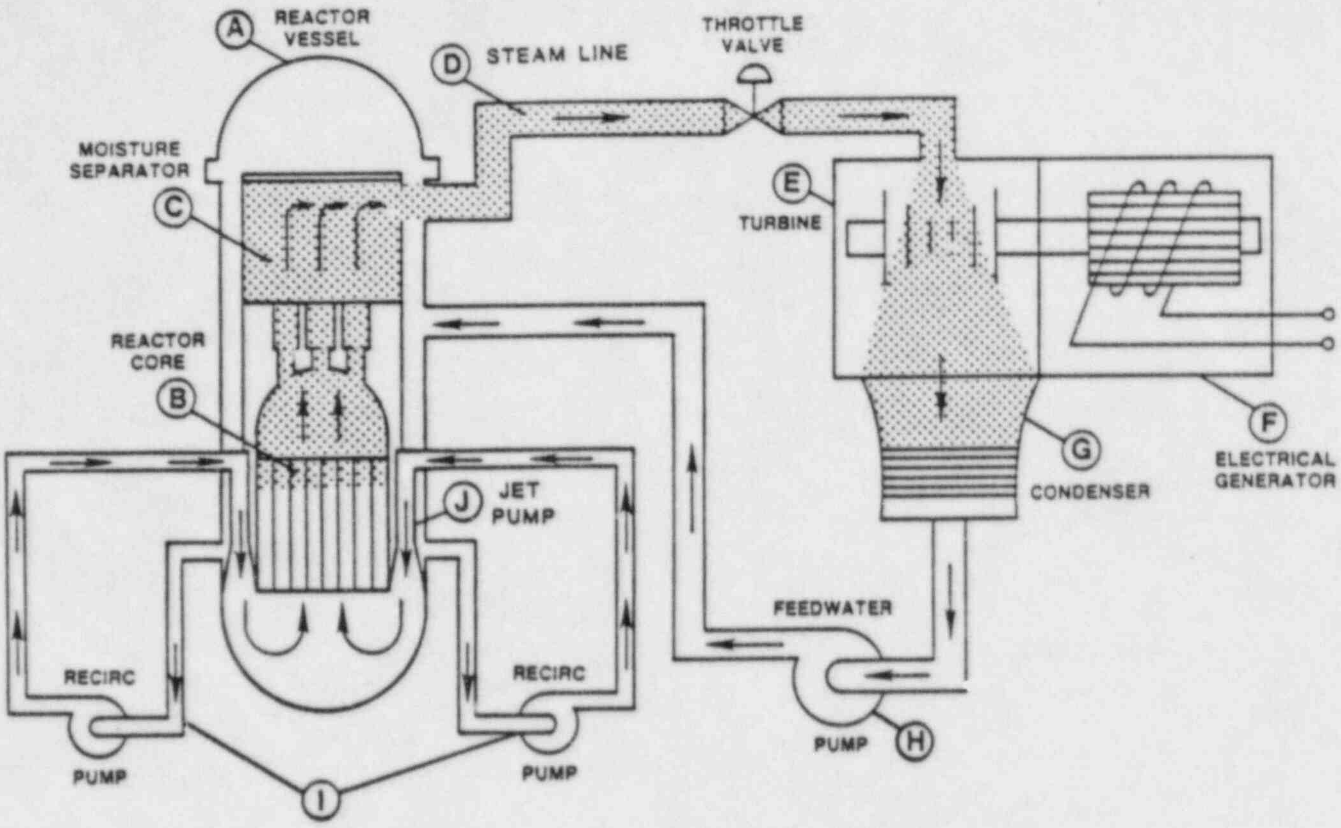


Babcock & Wilcox

At the fuel fabrication facility, fuel rods are bundled together into "fuel assemblies" or "fuel elements." Spacer grids separate the individual rods to allow for the necessary flow of coolant water between them. The number of fuel rods per fuel assembly varies, depending on the type and size of the reactor.

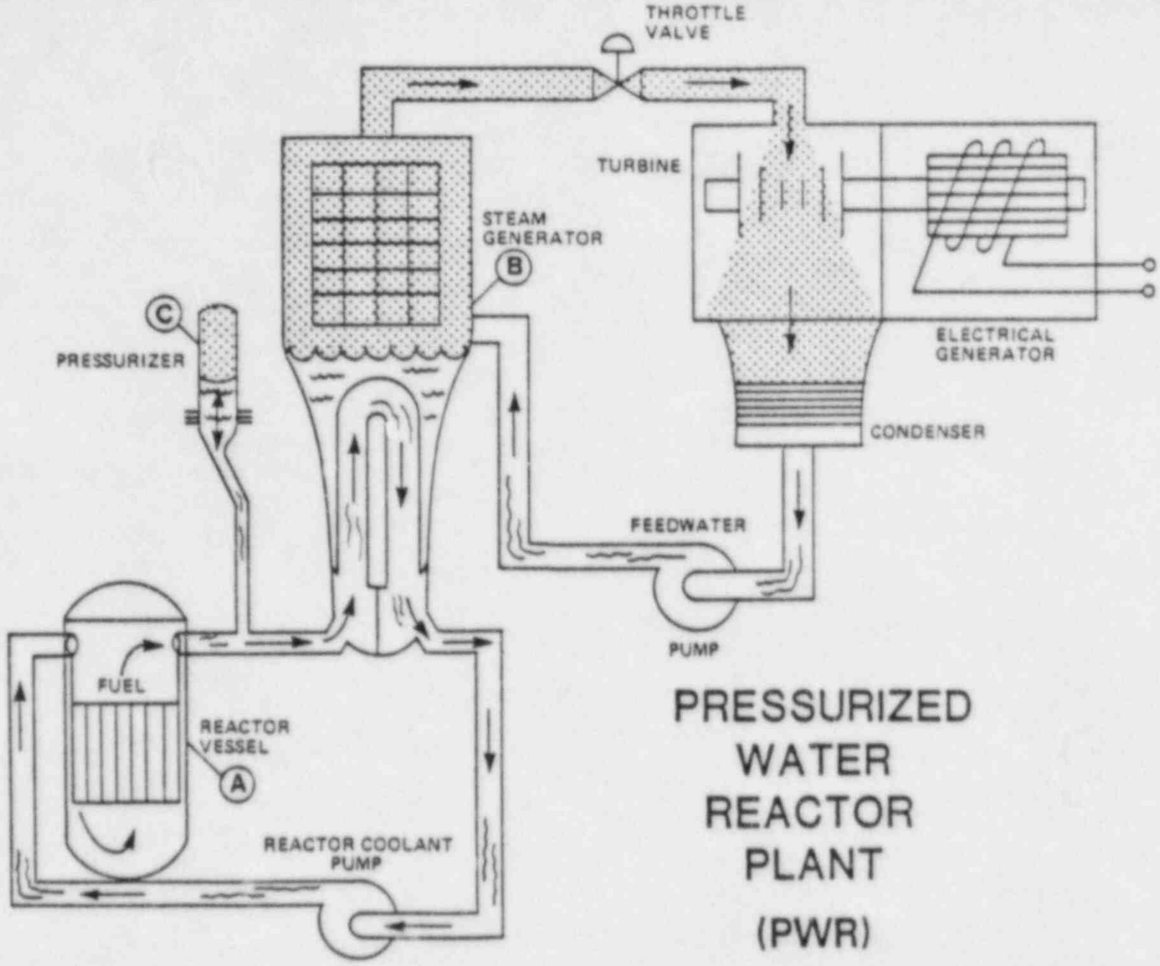


At the nuclear power plant, the fuel assemblies are inserted vertically into the reactor vessel (a large steel tank filled with water). The fuel is placed in a precise grid pattern known as the reactor "core."



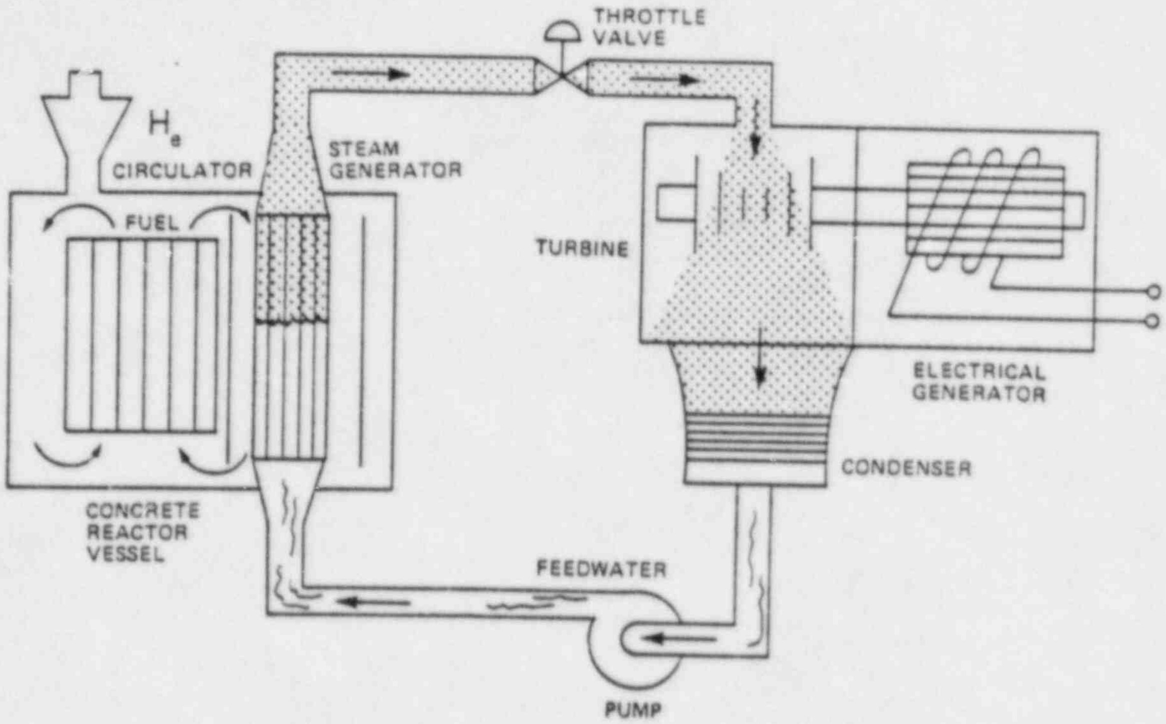
BOILING WATER REACTOR PLANT (BWR)

The Boiling Water Reactor (BWR) operates in essentially the same way as a fossil-fueled generating plant. Inside the reactor vessel (A) heat from the fission of uranium fuel in the reactor core (B) boils coolant water into steam. The steam travels through a moisture separator (C) and is piped (D) to the turbine (E), which turns the electrical generator (F). The steam is condensed back into water in the condenser (G). The water is then pumped (H) back to the reactor vessel to be reboiled. The recirculation pumps (I) and jet pumps (J) take a portion of the coolant water and reinject it into the reactor vessel to increase the mixing and flow of reactor coolant. Boiling water reactor systems are manufactured in the U.S. by the General Electric Company, San Jose, CA. BWR's make up about 1/3 of the power reactors in the United States.



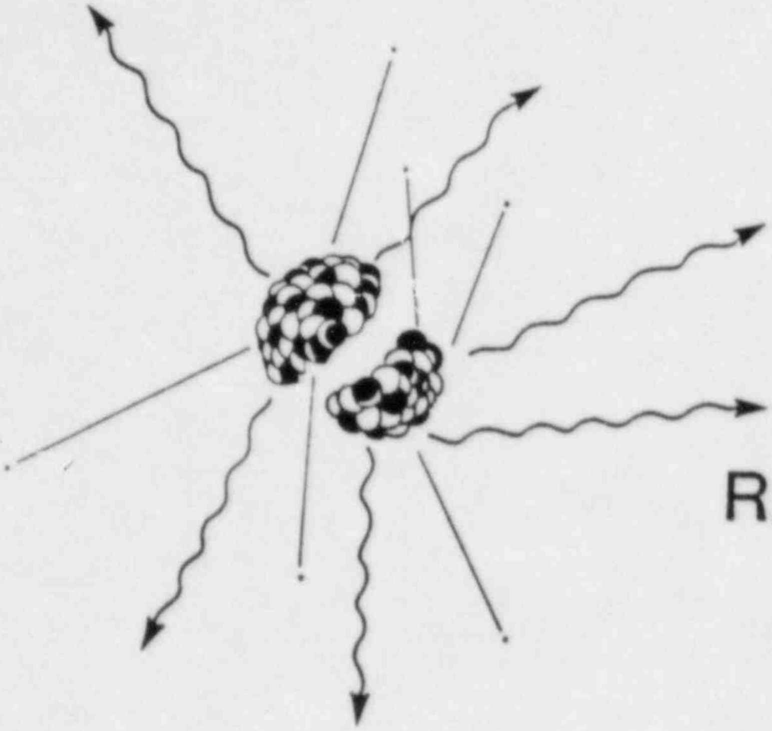
PRESSURIZED WATER REACTOR PLANT (PWR)

The Pressurized Water Reactor 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 reactor coolant (water) under very high pressure (about 2200 pounds per square inch) to prevent it from boiling, even at operating temperatures of about 600 degrees F. Pressurized water reactors make up about 2/3 of the Power Reactors in the U.S. PWR's are manufactured by the Westinghouse Electric Company, Pittsburgh, PA; Babcock & Wilcox Company, Lynchburg, VA; and the Combustion Engineering Company, Windsor, CN.



HIGH TEMPERATURE GAS-COOLED REACTOR PLANT (HTGR)

Another type of reactor uses helium gas instead of water as its coolant. The only High Temperature Gas Cooled Reactor (HTGR) in the U.S. is the Fort St. Vrain plant in Colorado. The plant was manufactured by General Atomic Company of La Jolla, CA. HTGRs are widely used in other countries.

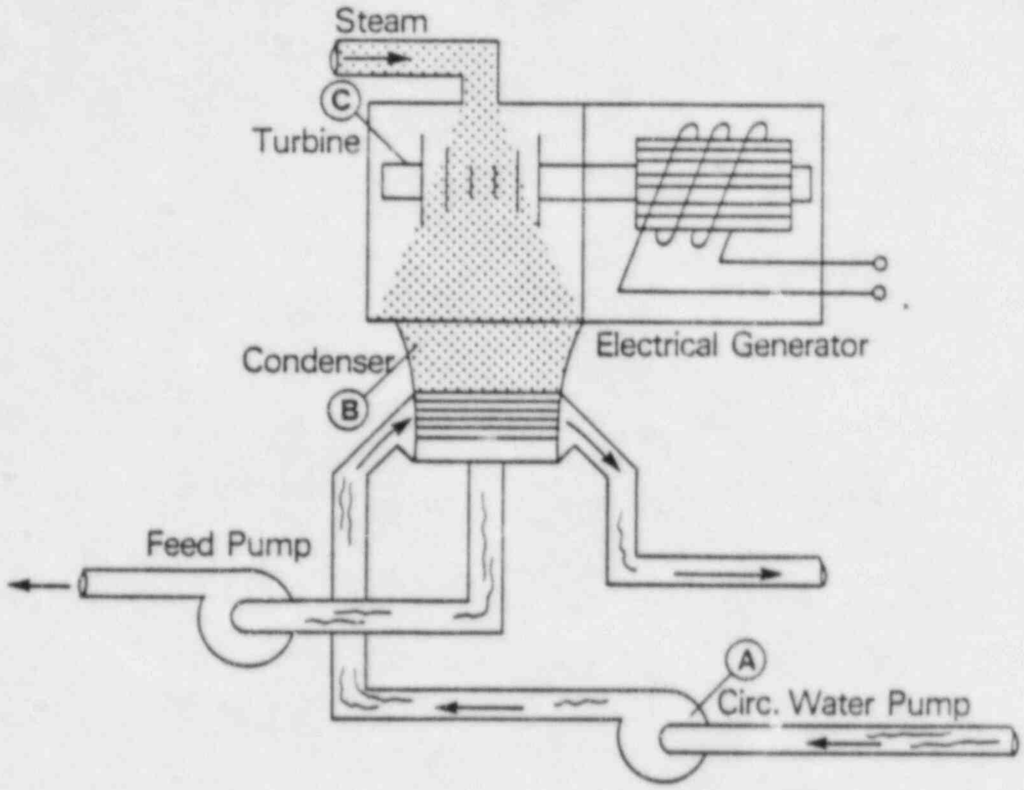


Fission Product Decay:

RADIATION

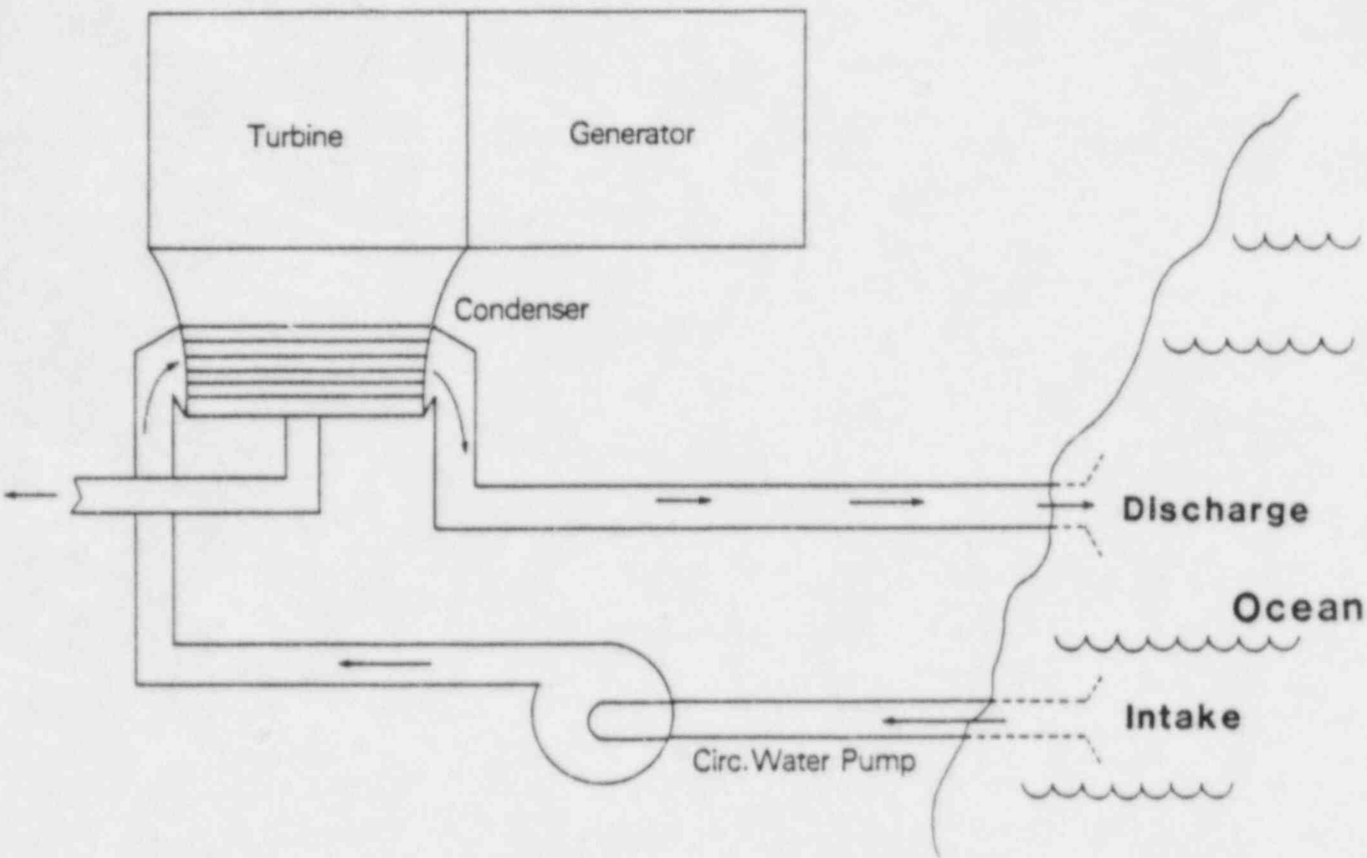
DECAY HEAT

Since nuclear power plants produce electricity by fission rather than combustion their byproducts are very different than those associated with fossil-fueled plants. "Fission products" are highly radioactive atoms produced by the splitting of the larger uranium atoms. Because of the intense radiation associated with fission products a system of "barriers" has been developed to prevent these atoms from escaping into the environment. The rapid rate of decay of most fission products causes a significant amount of energy to be generated inside the fuel pellets. This energy is called "Decay (Residual) Heat" and unless removed could result in damage to portions of the barrier system, or even to the fuel pellets themselves. "Radiation," "Decay Heat" and "Fission Product Barriers" are all discussed further in subsequent sections of this manual.

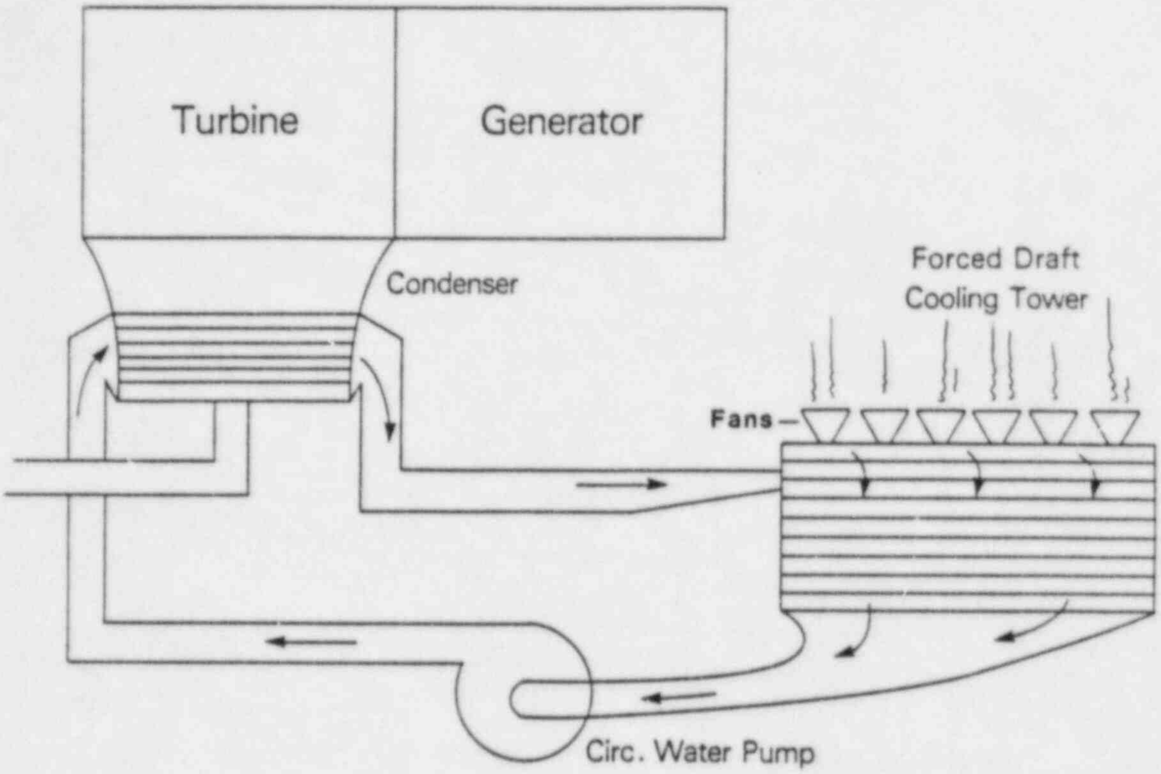


CIRCULATING WATER SYSTEM

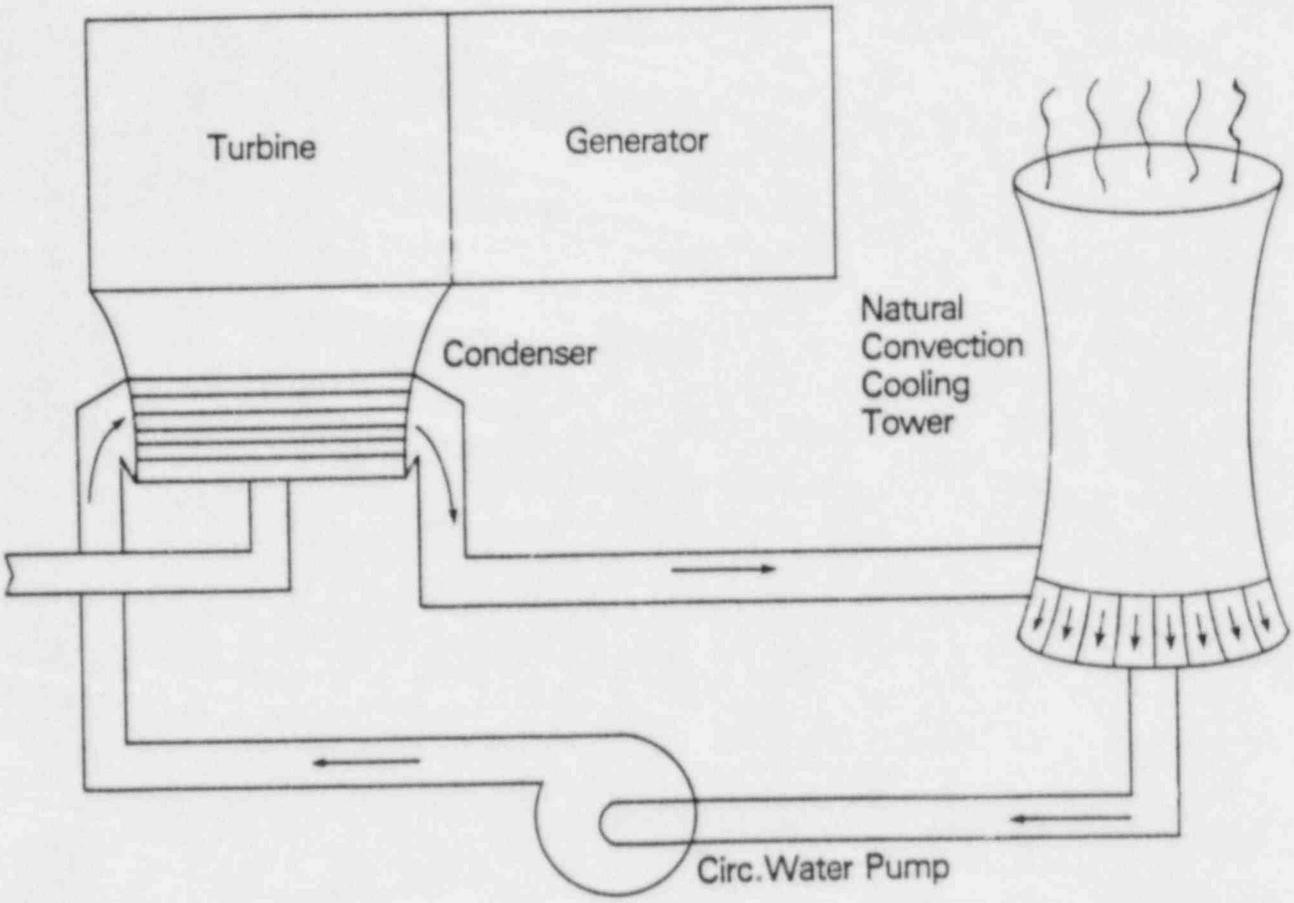
To operate properly all steam plants whether nuclear or fossil fueled, need a circulating water system to remove excess (waste) heat from the steam system and transfer that heat to the environment. The circulating water system pumps water (A) from the environment (river, lake, ocean) through thousands of thin metal tubes in the plant's condensor (B). Steam exiting the plant's turbines (C) rapidly cools and condenses into water when it comes in with contact the much cooler tubes. Since the tubes provide a barrier there should be no physical contact between the steam and the environmental circulating water. Because the condenser's operation produces a vacuum, any tube leakage in this system will produce an "inflow" of water to the condenser rather than an "outflow" to the environment.



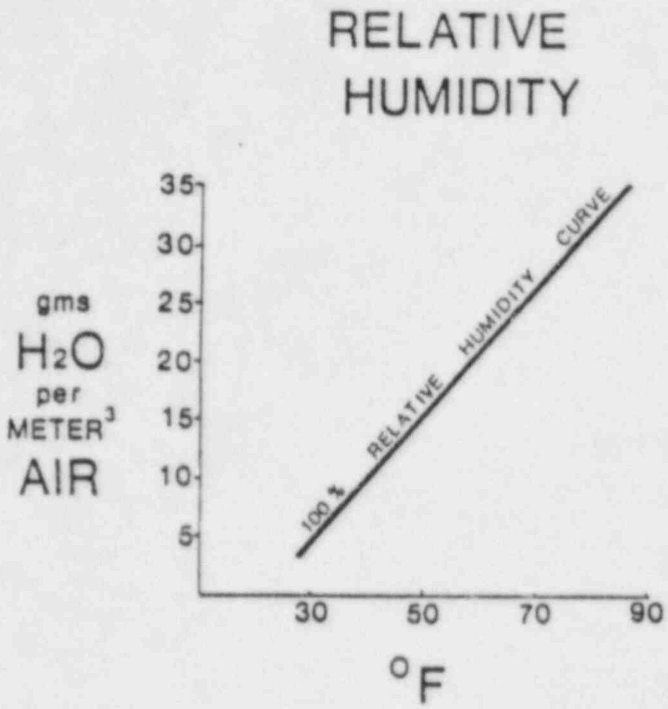
Power plants located on the ocean (or other large bodies of water) will often discharge their circulating water directly back to the ocean under strict environmental protection regulations. Water is taken from the ocean, pumped through the thousands of small tubes in the condenser to remove the plant's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



Most nuclear power plants not located on the ocean need cooling towers to remove waste heat from the circulating water system. One type is the forced draft cooling tower, in which circulating water from the condensor is permitted to splash downward through the cooling tower transferring some of its heat into air. Several large electrical fans located at the top of the cooling tower provide forced air circulation for more efficient cooling.

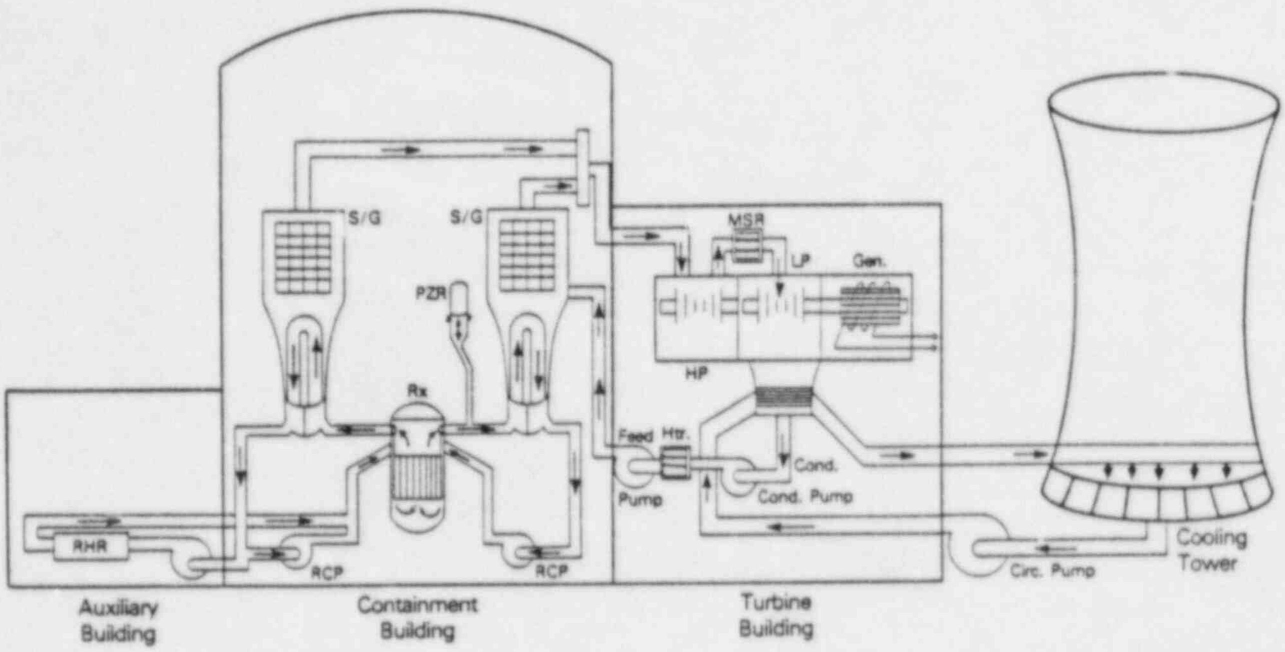


The taller, hourglass shaped natural convection cooling towers do not require fans to exhaust waste heat from the circulating water system into the air. Rather, the natural tendency of hot air to rise removes the waste heat as the circulating water splashes down inside the cooling tower.



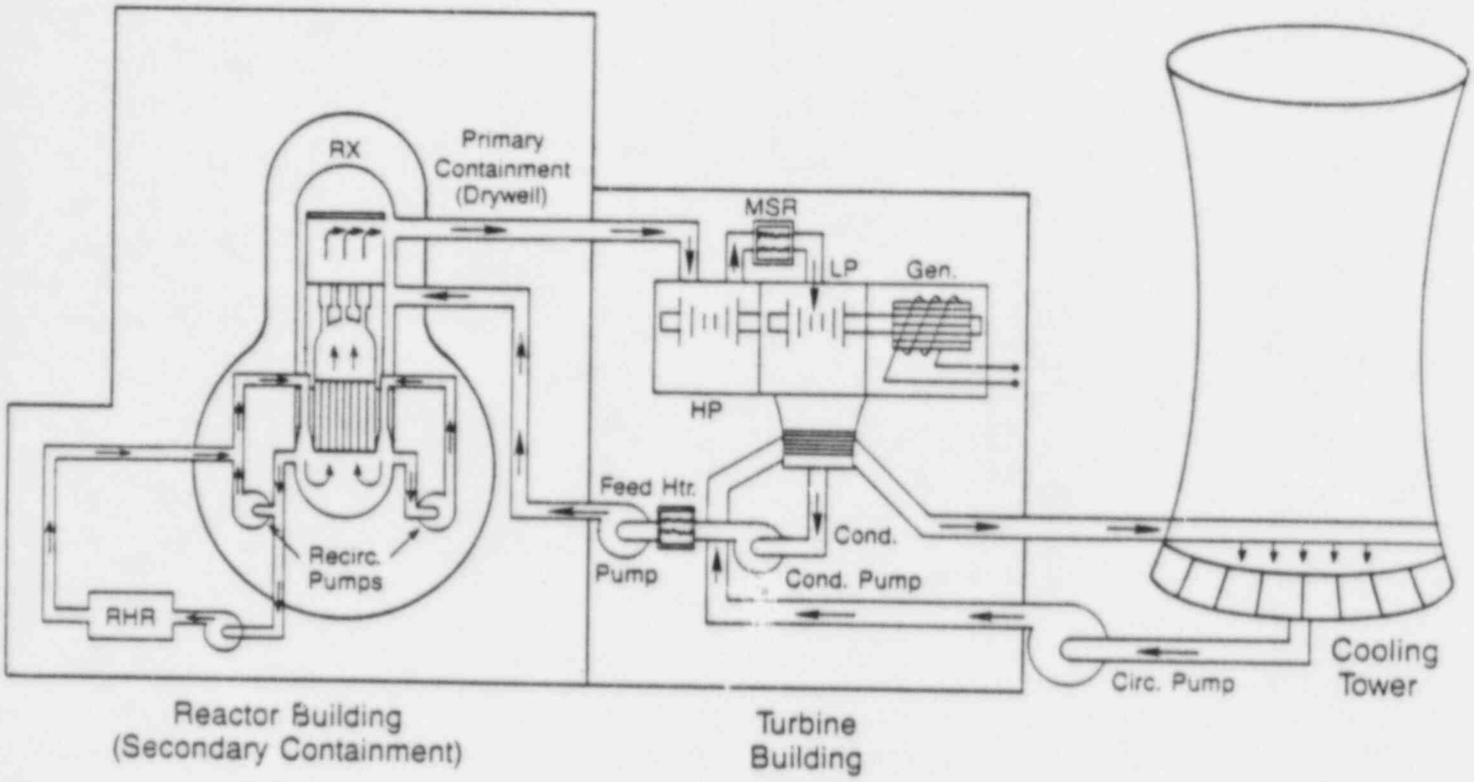
The "steam" vented from the top of a cooling tower is really luke warm water vapor -- and it's not radioactive. As the warm, wet air from inside the cooling tower contacts the cooler, dryer air above the cooling tower, its ability to hold moisture is reduced. The released cloud of water vapor is visible only until it can be dispersed and absorbed by the air. The graph above shows air's ability to hold water as air temperature changes.

TYPICAL REACTOR PLANT LAYOUT
(PRESSURIZED WATER REACTOR)



The major structures at a pressurized water nuclear plant are the containment building, which houses the reactor and its high pressure steam generating equipment; the turbine building, which houses steam turbines, condensers and the electrical generator; the auxiliary building, which houses normal and emergency support systems (such as the Residual Heat Removal System, fuel handling and storage equipment, laboratories, maintenance areas and the control room. Depending on the plant location, there may or may not be a cooling tower to remove waste heat from the facility.

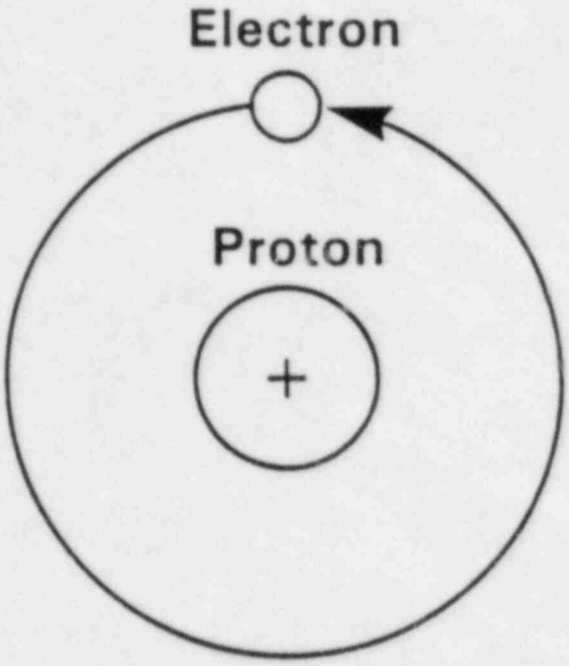
TYPICAL REACTOR PLANT LAYOUT
(Boiling Water Reactor)



The major structures at a Boiling Water Nuclear Plant are the <u>Primary Containment</u> (Drywell), which houses the reactor and recirculation pumps, the <u>Reactor Building</u> (Secondary Containment) which surrounds the Primary Containment and serves many of the functions of a PWR's Auxiliary Building and the <u>Turbine Building</u>. Depending on the plant location there may or may not be a <u>cooling tower</u> to remove waste heat from the facility.

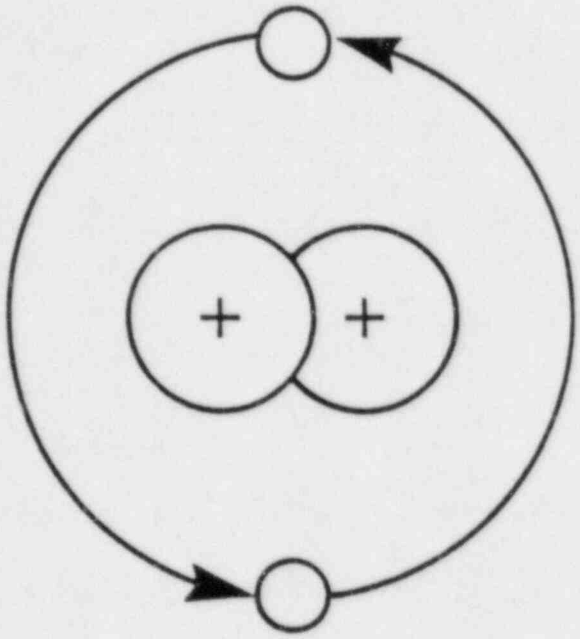
THE FISSION PROCESS AND HEAT PRODUCTION

A nuclear power plant converts the energy within atomic nuclei 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.



$_1H$ Hydrogen

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, derived from the number of protons, is 1.



$_2He$ **Helium**

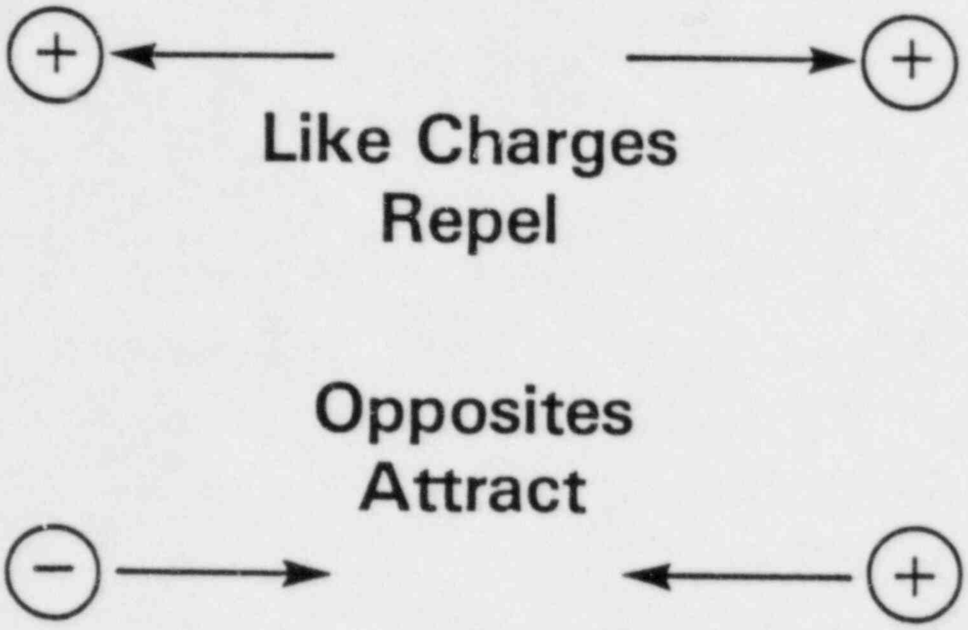
More complex atoms have more protons and electrons, but each unique combination of protons and electrons represents a different chemical element. Helium, for example, with two protons has an atomic number of two.

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	57 La	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	89 Ac															

58 Ce	59 Pr	60 No	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pd	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

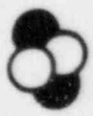
Each element has been assigned a chemical symbol. Elements are listed by increasing atomic number and grouped by similar chemical characteristics on the Periodic Table of Elements.



Electrostatic Force

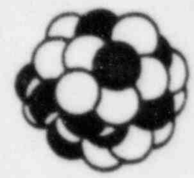
Since all protons are positively charged, and since like charges repel, electrostatic force tends to push protons away from each other.

Neutrons



Provide
Nuclear
Attractive
Force

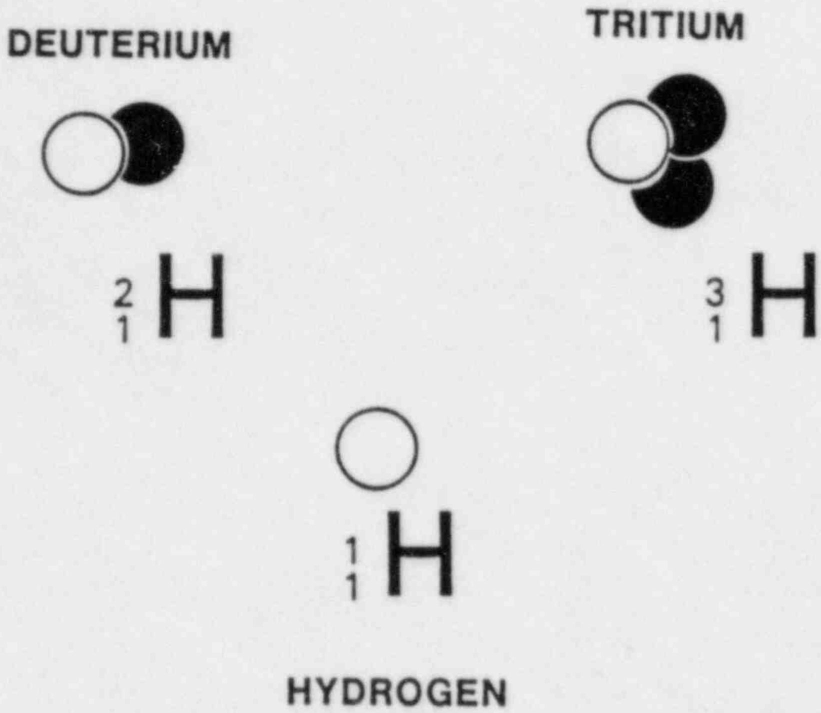
No
Electrostatic
Repulsion



Hold Larger Atoms Together

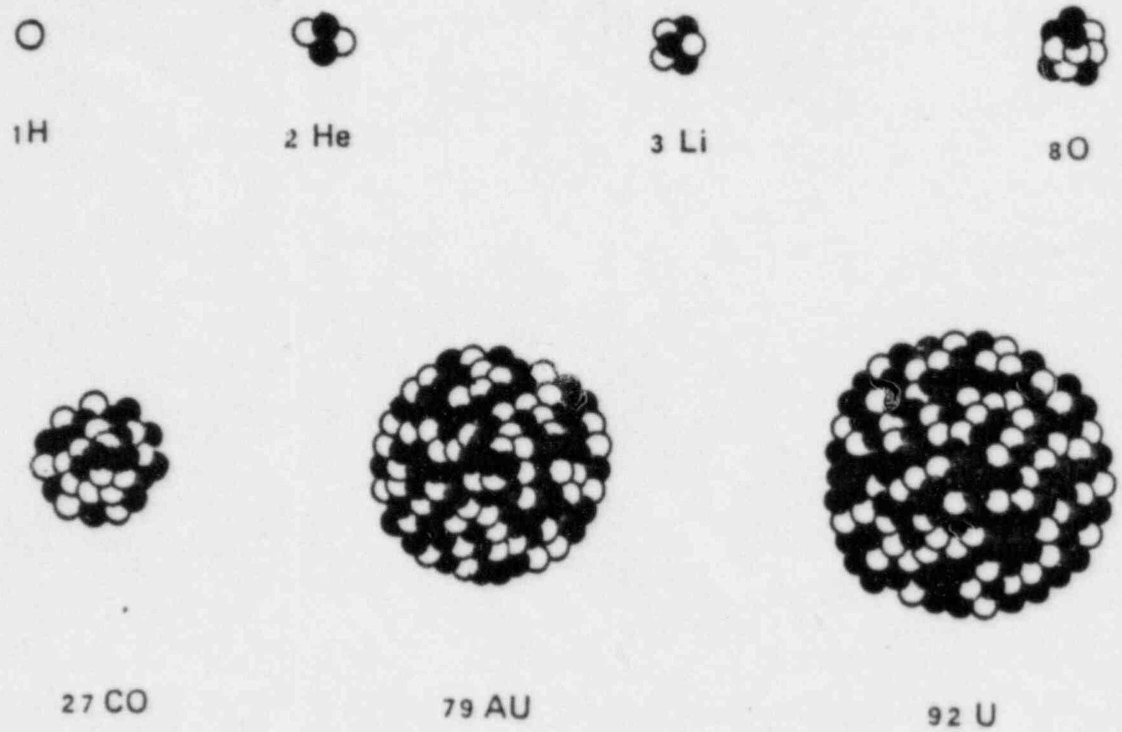
Neutrons, with no electrical charge, provide the attractive nuclear force to offset electrostatic repulsive forces and hold atoms together. All atoms found in nature (except the the basic hydrogen atom) have one or more neutrons in their nuclei.

Hydrogen Isotopes



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"); Basic hydrogen (one proton, no neutrons); deuterium (one proton, one neutron) and tritium (one proton, two neutrons).

ATOMIC NUMBERS



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, gold-79, 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 writings since this number will never change for the element under discussion.

Naturally Occurring Carbon

$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

6 Protons	6 Protons	6 Protons
6 Neutrons	7 Neutrons	8 Neutrons

Since chemical elements can have different numbers of neutrons, the use of isotopic numbers (or mass numbers) is necessary to distinquish one isotope from another. Naturally occurring isotopes of the element carbon are shown above. The isotopic number (shown to the upper left 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

$^{63}_{29}Cu$ $^{65}_{29}Cu$

29 Protons **29 Protons**

34 Neutrons **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:

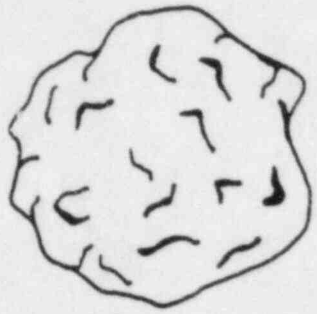
$^{63}_{29}$CU, ^{63}CU, CU^{63}, CU-63, copper-63

All refer to the same isotope of copper.

Naturally Occurring Uranium

$^{234}_{92}U$	$^{235}_{92}U$	$^{238}_{92}U$
92 Protons	92 Protons	92 Protons
142 Neutrons	143 Neutrons	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. About .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 can be manufactured and used to fuel some types of reactors.



URANIUM ORE

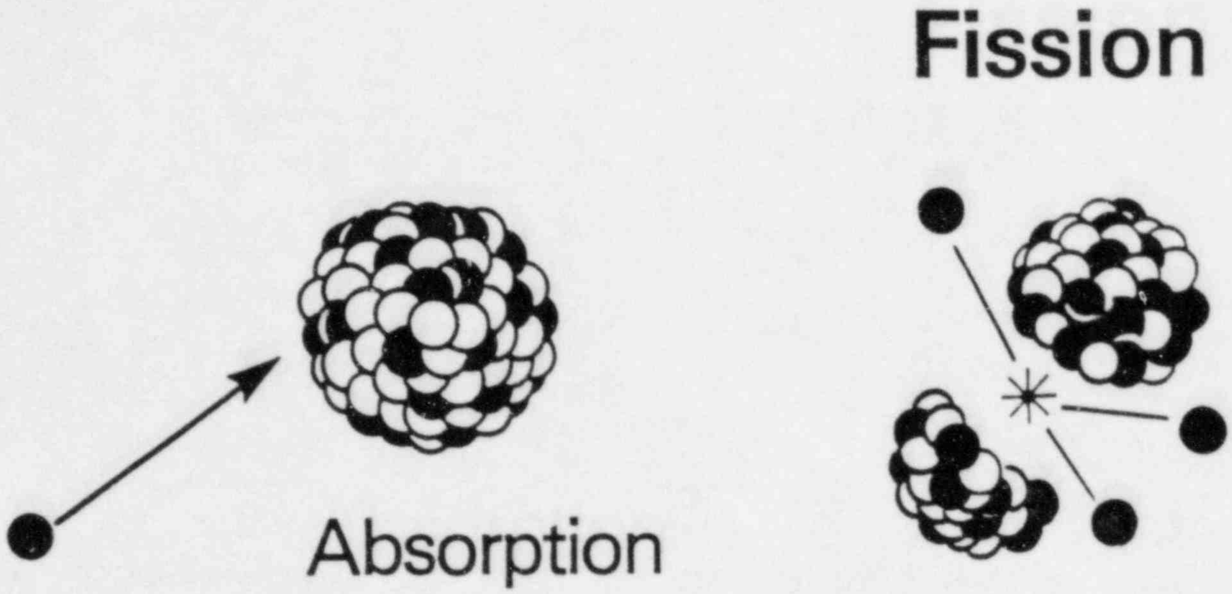
.7%

FUEL PELLET

3.5%

ENRICHMENT (% U-235)

Uranium-235 (enriched from .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 undergo 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.

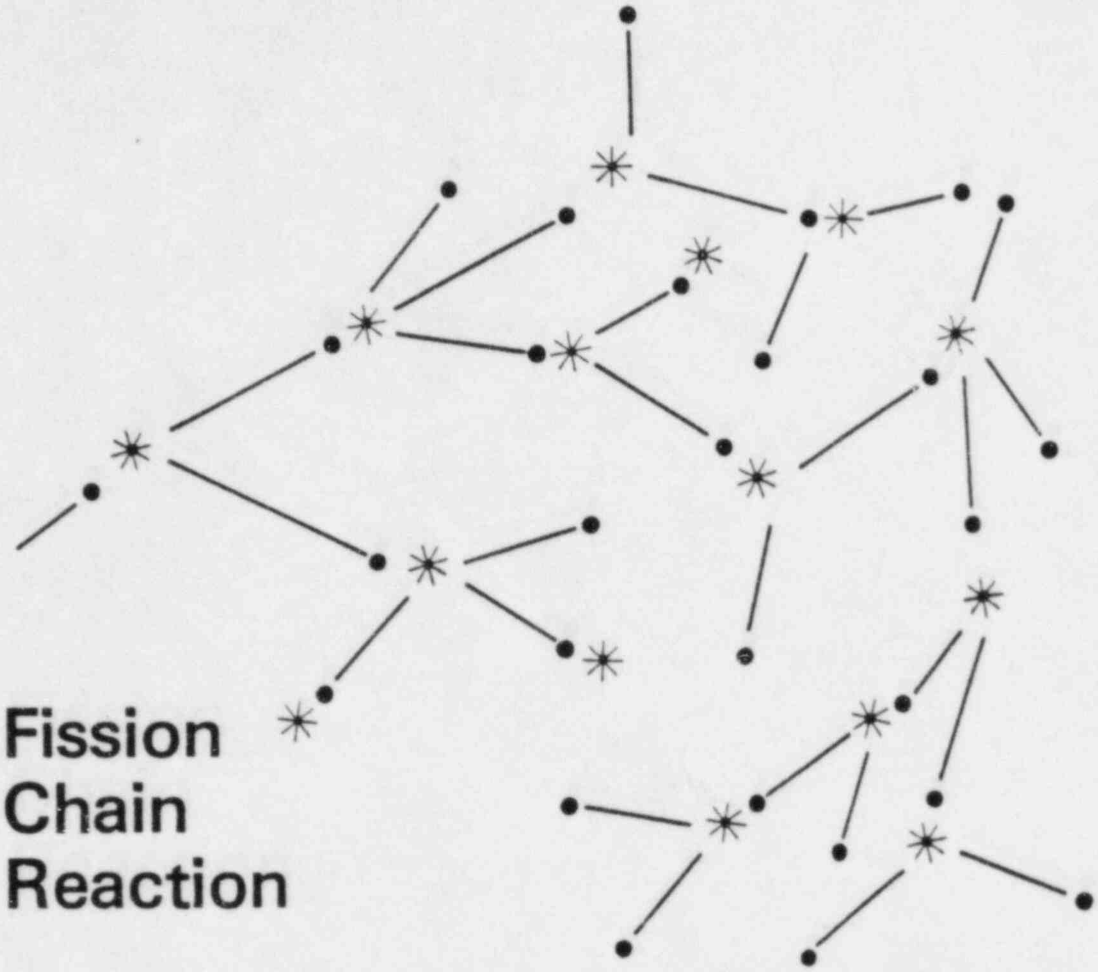
(4) The fission of U-236 releases two or three additional neutrons which can be used to cause other fissions and establish a "chain reaction."

Fissions → Heat

Rate of Fission → Rate of Heat Production

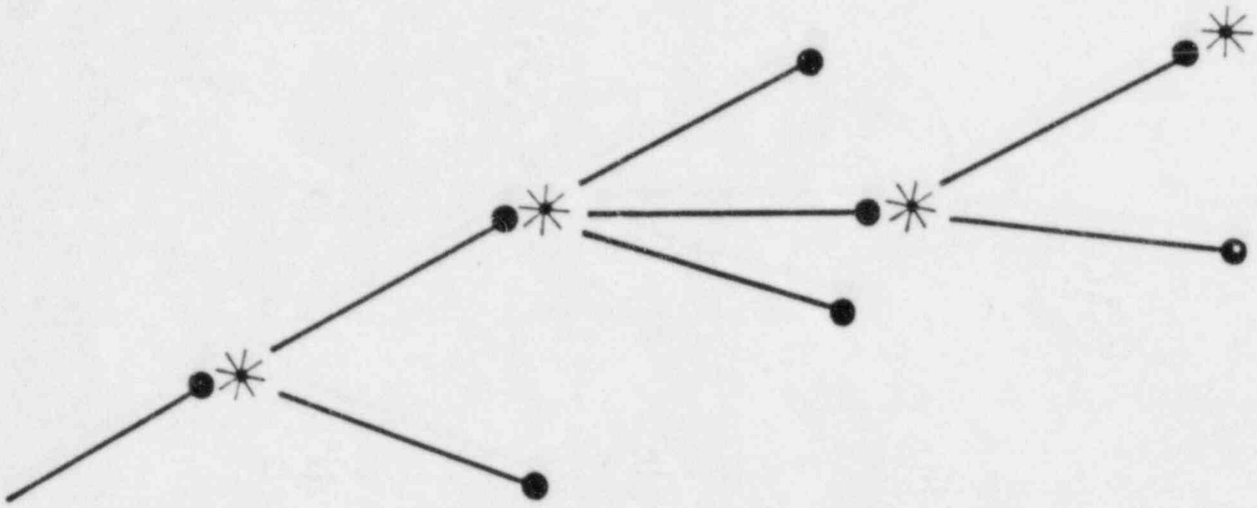
Every fission releases a tiny amount of heat. Trillions of fissions per second are necessary to produce high temperature, high pressure steam for electrical power production. The rate at which uranium atoms are fissioned determines the rate at which heat (and power) is produced.

Fission Chain Reaction



Since neutrons are necessary to cause the fission reaction and since each fission releases neutrons, there is the potential to set up a self-sustaining chain reaction (if there is a sufficient quantity of fissionable material and the material is shaped to decrease the chance of neutrons escaping).

Criticality



Steady Rate of Power Generation

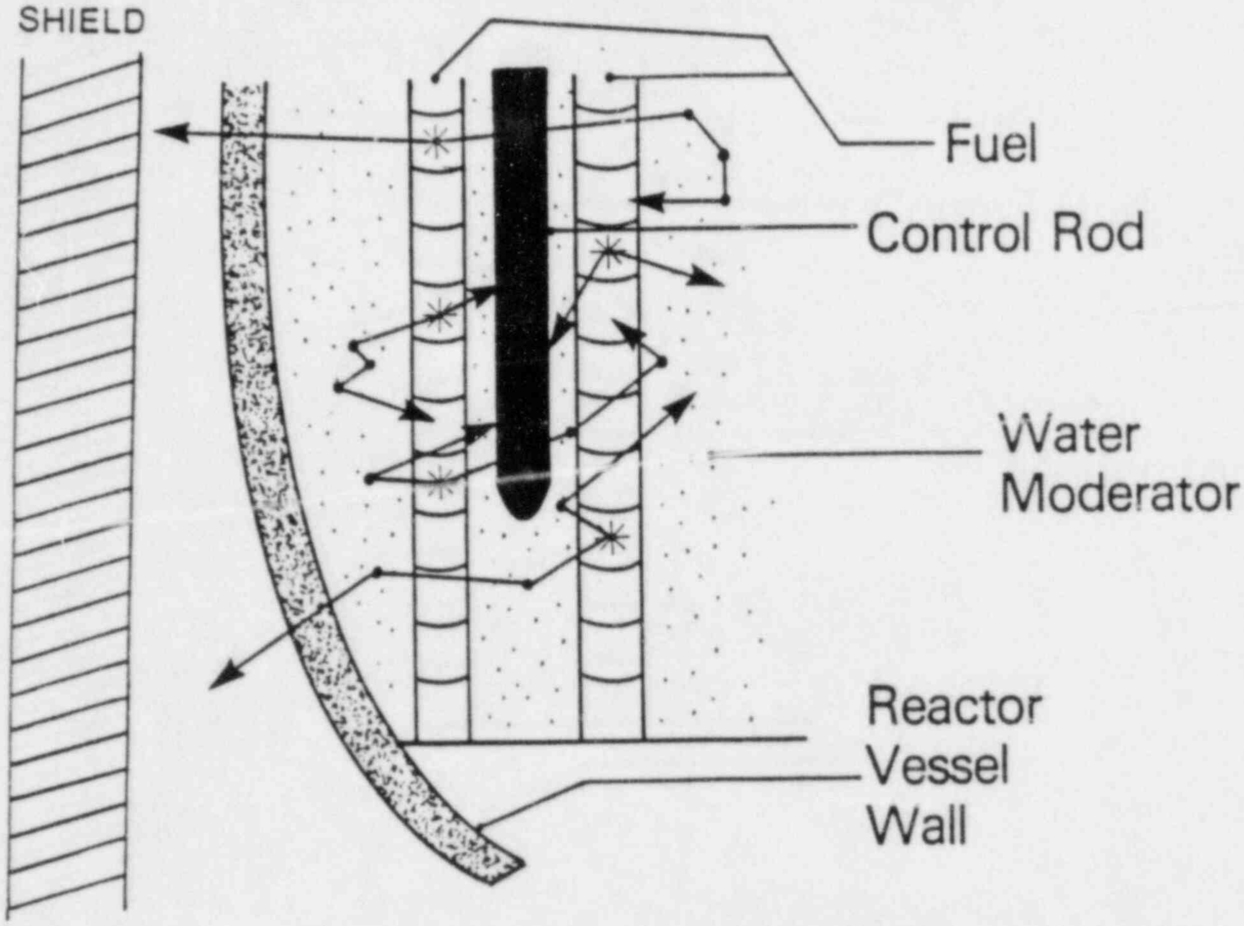
Criticality is the term used to describe the condition of "balance" in a reactor. When the number of neutrons being produced by fission exactly equals the number of neutrons being absorbed by all materials (uranium, structural components, shielding, etc.) the reactor is said to be "critical." In a critical reactor the number of neutrons present, the number of fissions occurring and the heat being produced are all steady over time.

For Criticality:

1. Neutrons Must Leak Out of the Core

2. Neutrons Must be Absorbed by Poisons

Because more neutrons are released by fission than are needed to produce a steady rate of fission, there is always a surplus of neutrons whenever the reactor is operating. To maintain the "critical" balance needed for a constant reactor power level, some of these excess neutrons must be allowed to "leak out" or escape the fuel area where they cannot cause further fission. The remaining surplus must be absorbed by non-fissionable materials in the reactor core. 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 dense concrete shielding around the reactor vessel. All the remaining neutrons in the reactor core area will be absorbed by some material (U-235, U-238, water, 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 absorb neutrons (especially xenon-135 and samarium-149). Uranium-238 sometimes fissions, but when it does not, it acts as a poison. Reactor operators can manipulate the total amount of poisons in the reactor by moving control rods and (in PWR's) changing the concentration of boron in the reactor coolant water.

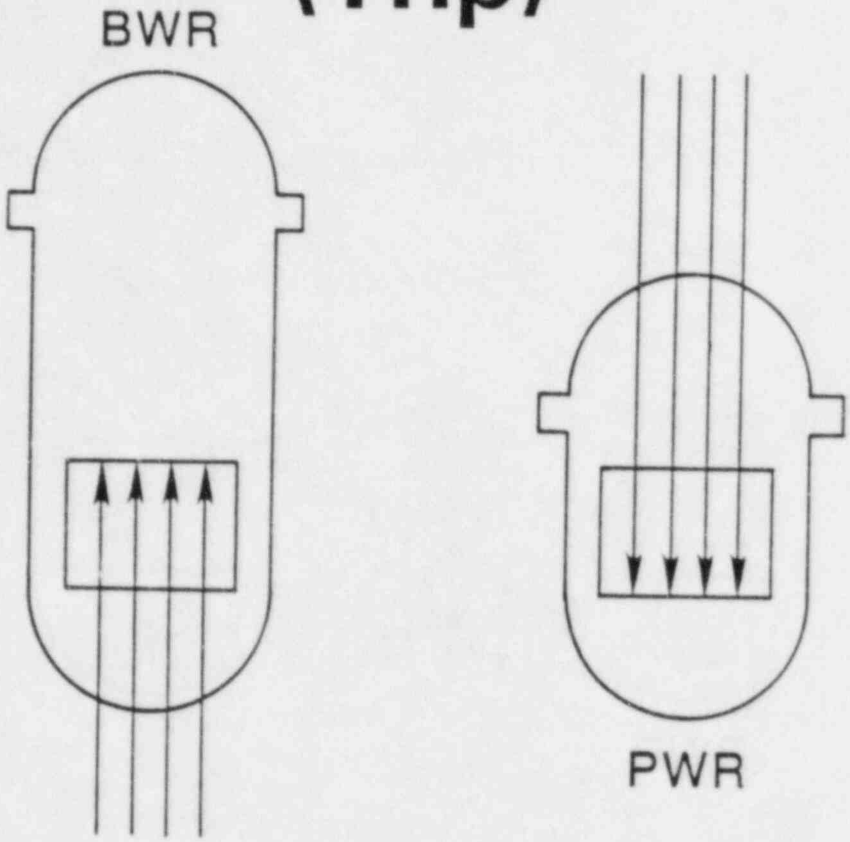
CONTROL RODS

IN - FEWER NEUTRONS
POWER DOWN

OUT - MORE NEUTRONS
POWER UP

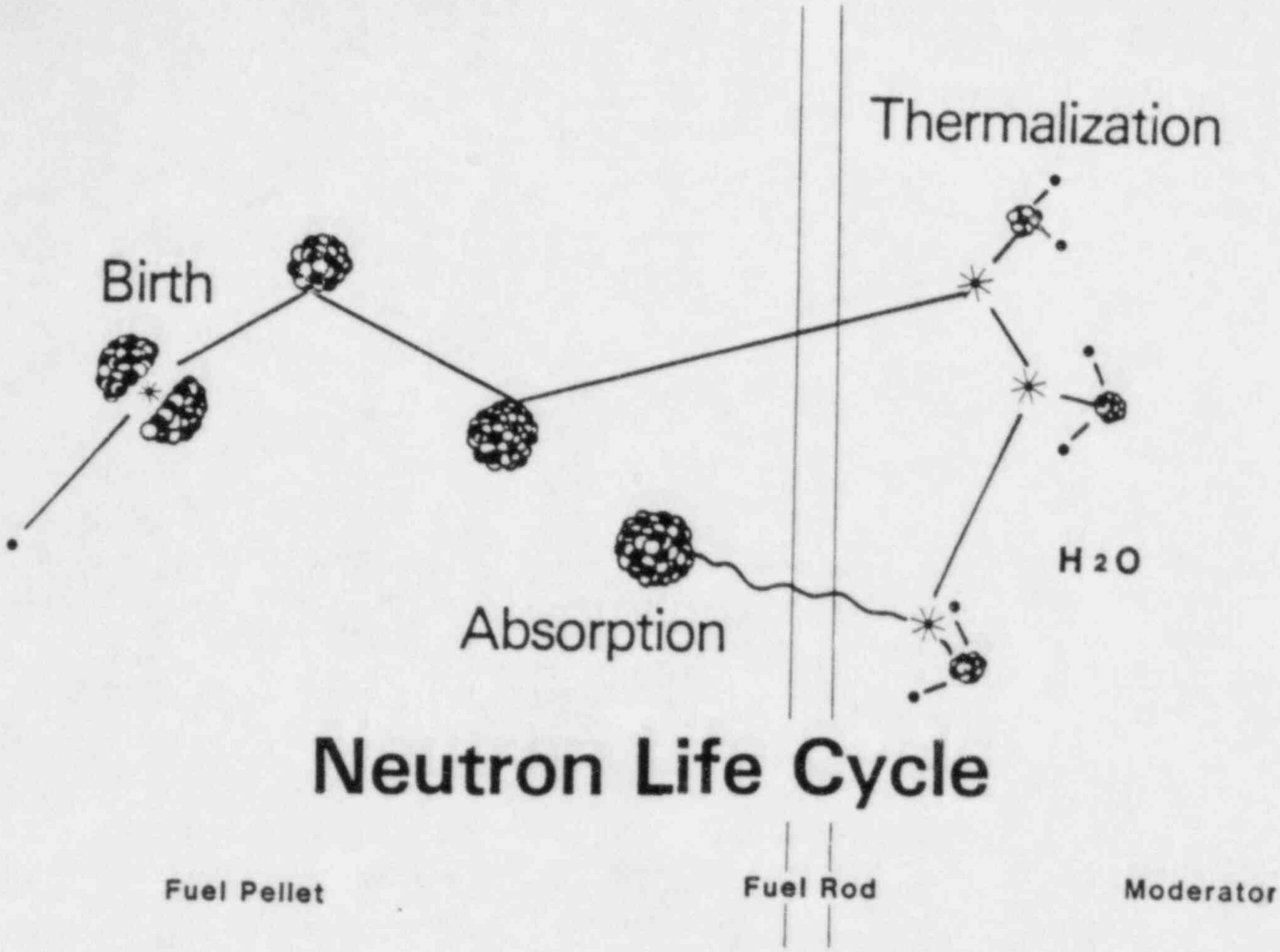
Control Rods are concentrated neutron absorbers (poisons) which can be moved into or out of the core to change the rate of fission in the reactor. Rod insertion adds neutron poison, thus fewer neutrons are available to cause fission, fission rate decreases, heat production decreases and reactor power goes down. Pulling control rods out of the core removes poison, thus more neutrons are available for fission and reactor power goes up.

Reactor Scram (Trip)



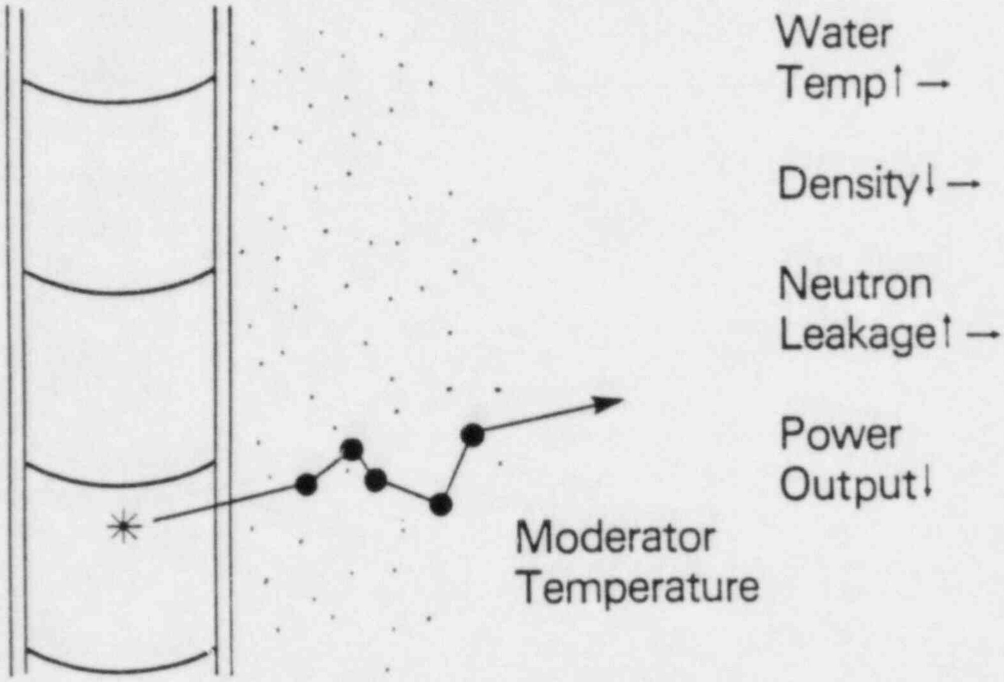
Rapid Insertion of Control Rods to Shutdown the Fission Chain Reaction

A reactor "scram" (or "trip") is the rapid (two-four seconds) insertion of control rods to stop the fission chain reaction. In a boiling water reactor, control rods are inserted from below the core. In a pressurized water reactor, control rods are inserted from above the core. Although a reactor scram does not stop all fission in the core, the "chain reaction" is immediately broken causing a significant decrease in reactor power in a few seconds.

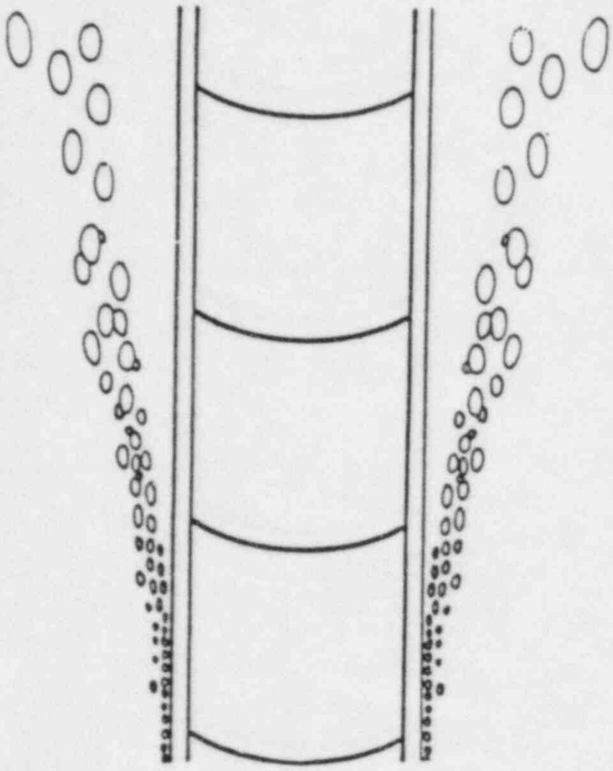


The water used in a BWR or PWR reactor coolant system has two important functions. As a coolant, water carries away heat from the reactor fuel rods (maintaining temperatures in the core within specified limits). Water's other major function is to control the fission process by slowing down and reflecting back high energy neutrons so that more fissions can occur. This "slowing down" process is called "thermalization" or "moderation."

TEMPERATURE—DENSITY RELATIONSHIP OF WATER



The use of water as a neutron moderator helps produce a steady rate of reactor power. If the reactor coolant temperature increases, the water becomes less dense and less effective as a neutron moderator. This tends to reduce the power level of the reactor. Conversely, if the reactor coolant temperature decreases, it becomes a better moderator, thus tending to increase the number of fissions that occur in the fuel. This temperature - density relationship is a major factor in controlling the fission process and heat production of the reactor.



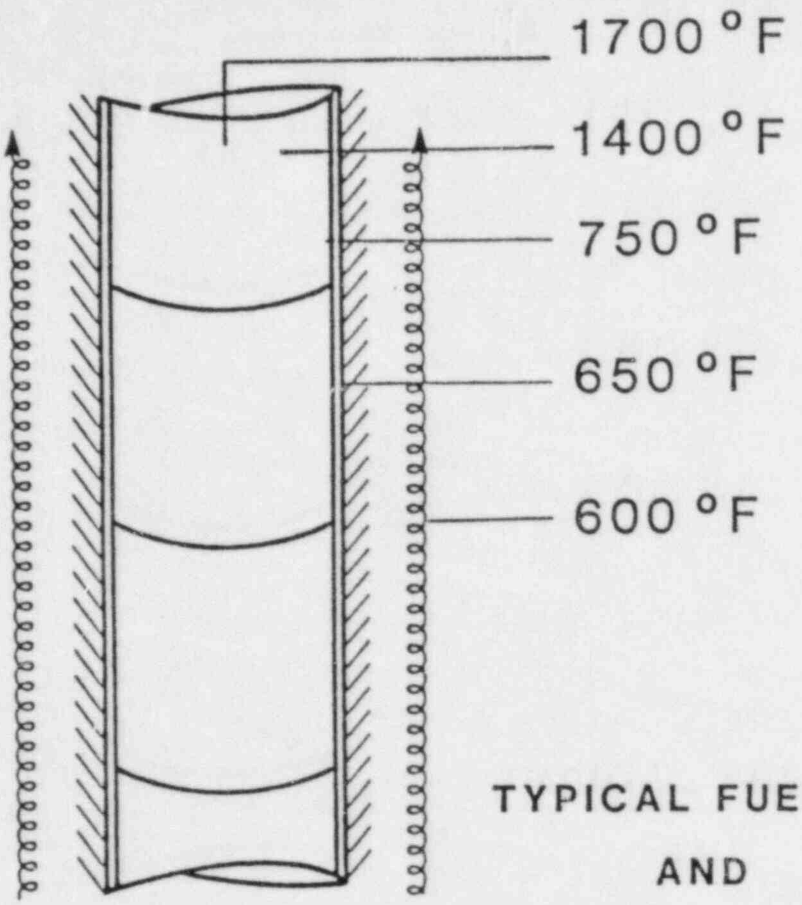
Voids

(Steam Bubbles)

(Very Low Density)

More Voids →
More Leakage →
Power ↓

Moderator density changes are important factors in controlling the fission rate and power production of a reactor. In boiling water reactors, the conversion of water into steam produces a dramatic change in moderator density from the bottom to the top of the core. Water at the bottom of the core is far more dense (and moderates neutrons far better) than does the water-steam mixture at the top.

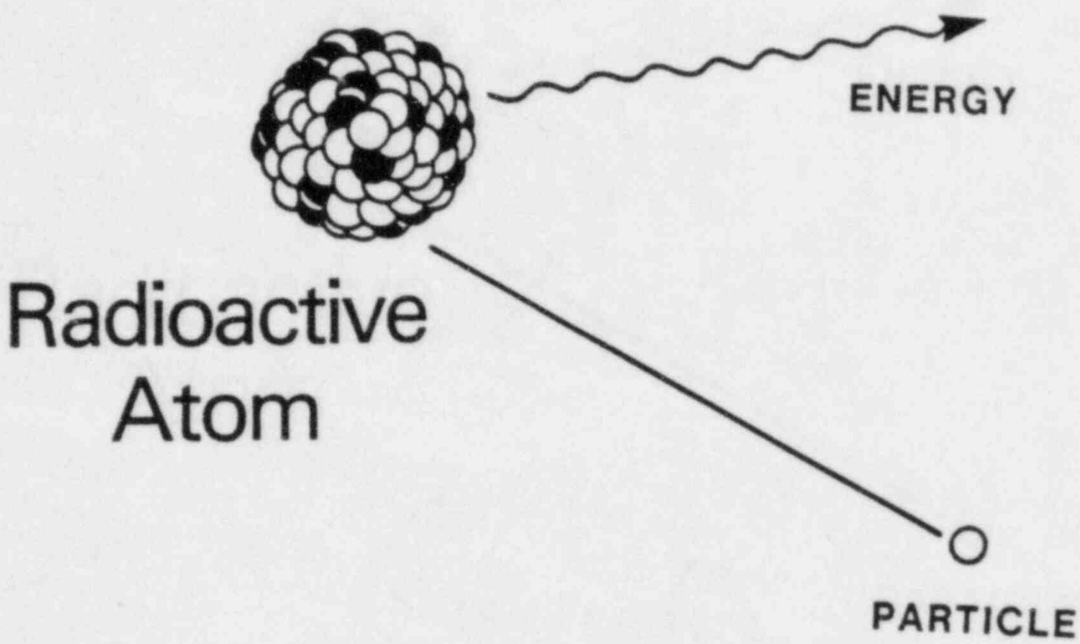


TYPICAL FUEL ROD AND COOLANT TEMPERATURES

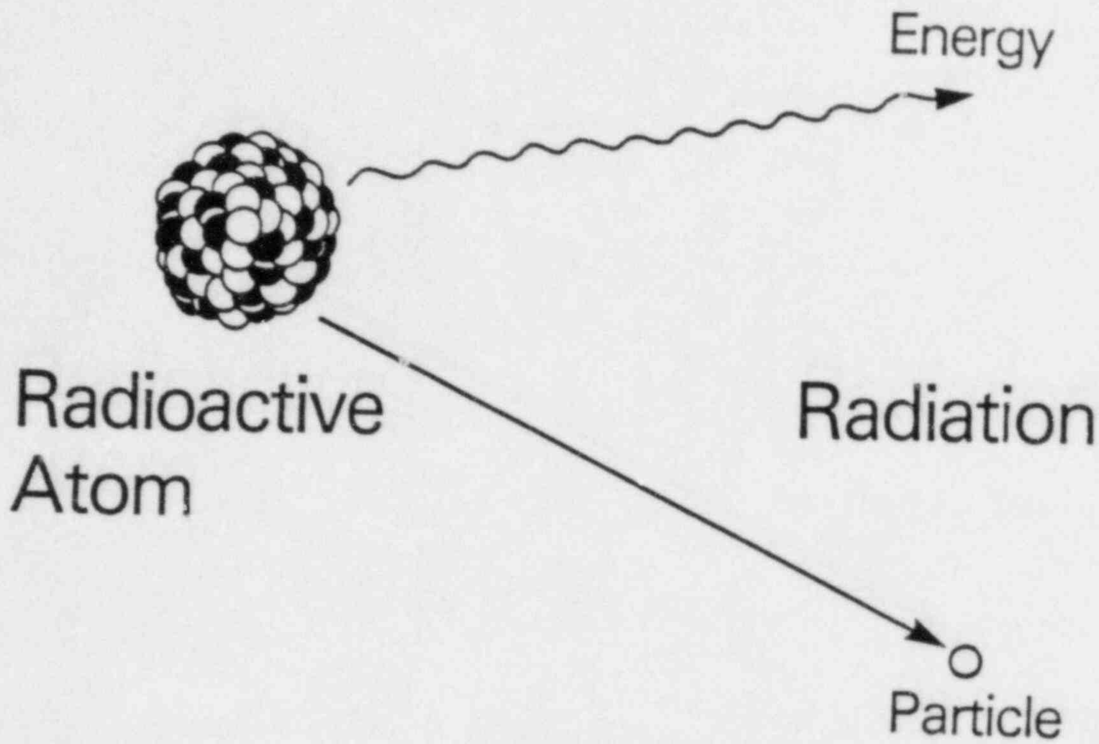
When a power reactor is operating, these are the approximate normal temperatures in the reactor core and reactor coolant system: 1700 degrees F in the center of the fuel pellets where many of the fissions occur, 750 degrees F at the outer surface of the fuel pellets, 650 degrees F at the cladding tube and 600 degrees F in the coolant water. The average fuel pellet temperature under normal operating conditions is about 1400 degrees F. Melt temperature for the ceramic fuel pellet material is about 5200 degrees F. Fuel clad damage will start to occur above about 1800 degrees F. Significant fuel damage can be expected at sustained temperatures above 2200 degrees F. Reactor emergencies and their consequences are discussed in section eleven of this manual.

RADIATION TERMINOLOGY

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

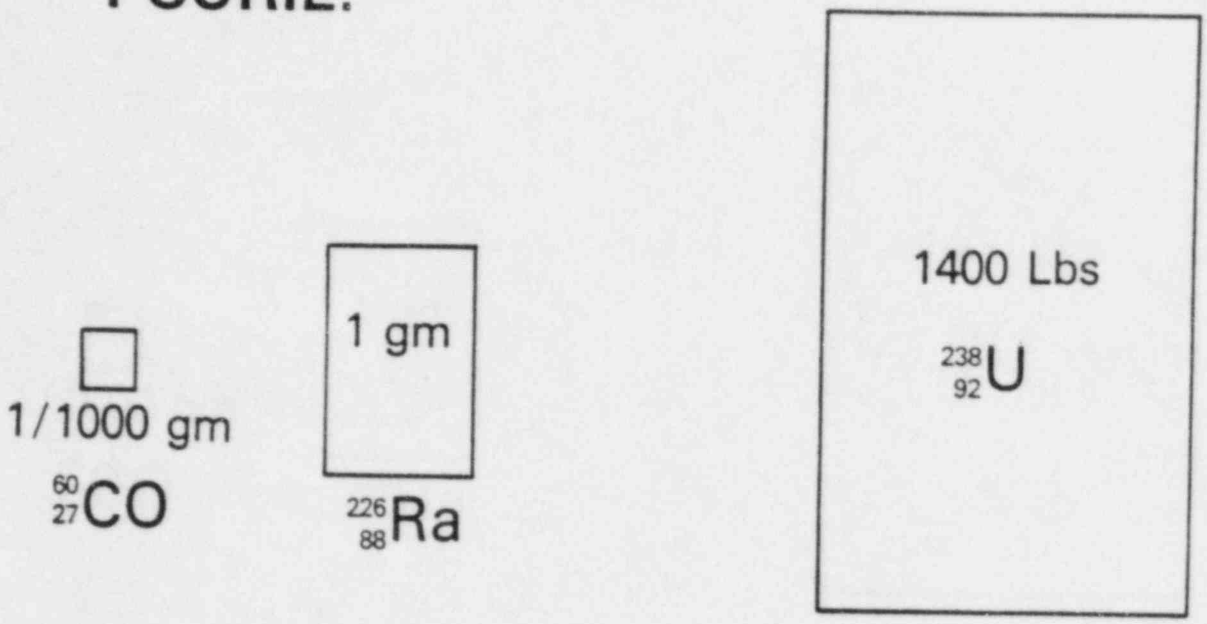


A "radioactive material" contains atoms which are unstable due to some excess of energy in their nuclei. In an attempt to become more stable, a radioactive atom disintegrates (or decays) by ejecting particles or electromagnetic energy (photons).



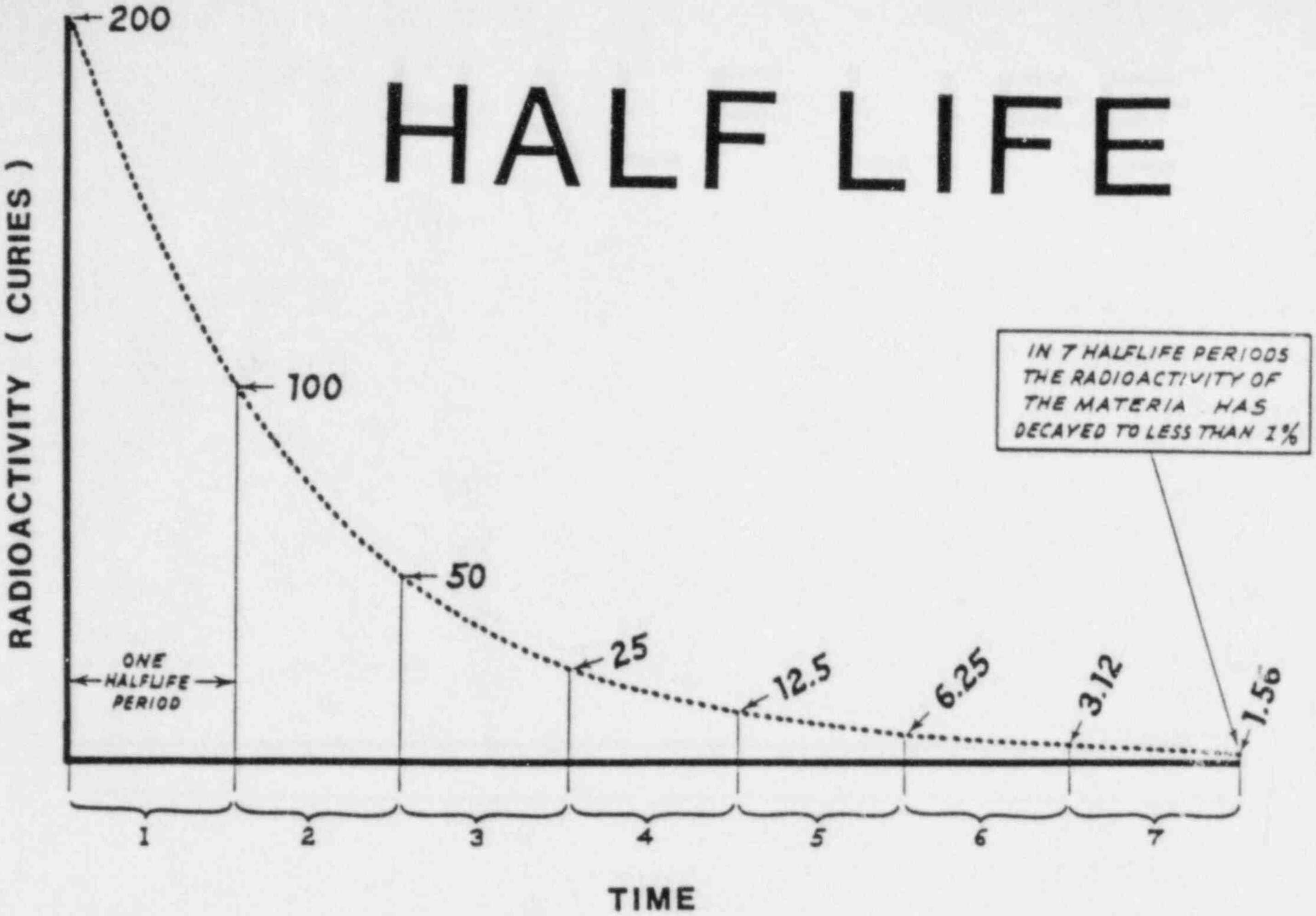
Radioactive material ejects particles and/or photon energy as it decays. The particles and/or energy emitted are "radiation."

1 CURIE:



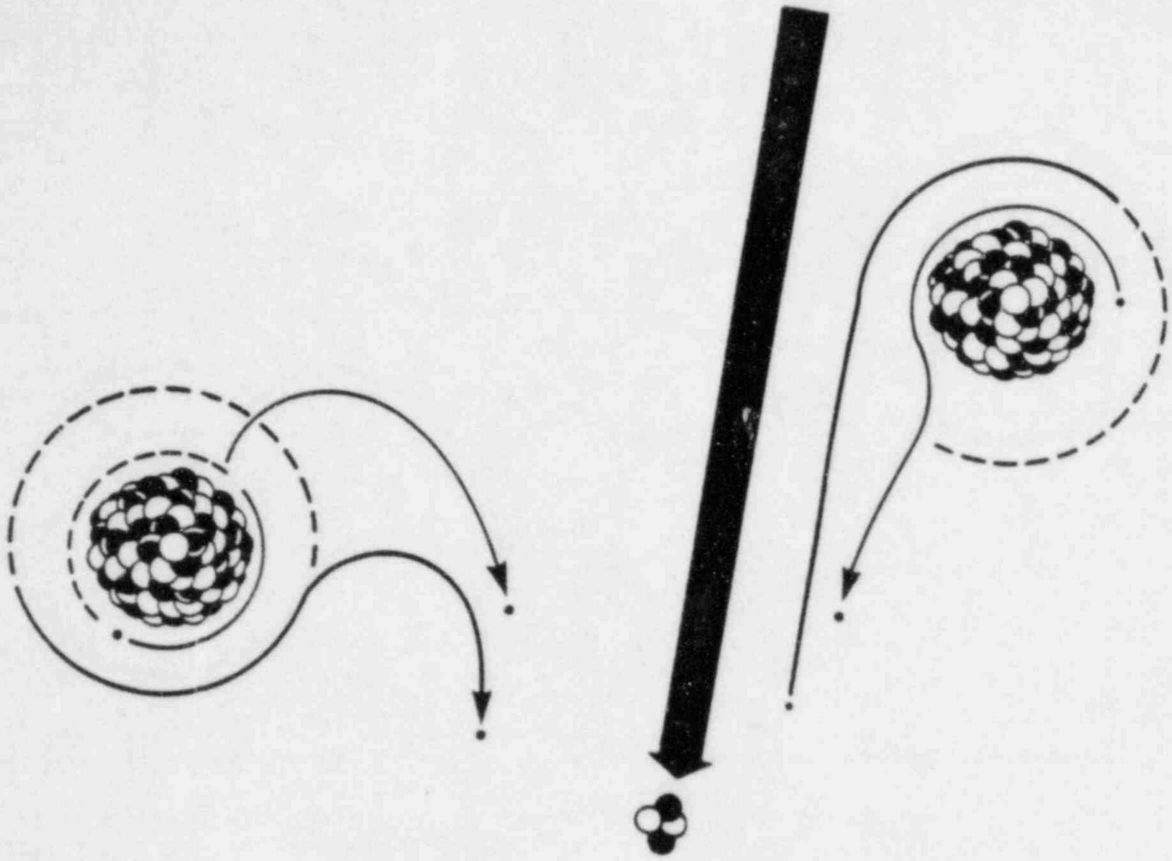
3.7×10^{10} Disintegrations per second

Radioactivity is measured in "curies." One curie is defined as the amount of any radioactive material (radioisotope) that will decay at a rate of 37 billion disintegrations per second (the rate of 1 gram of Radium-226).



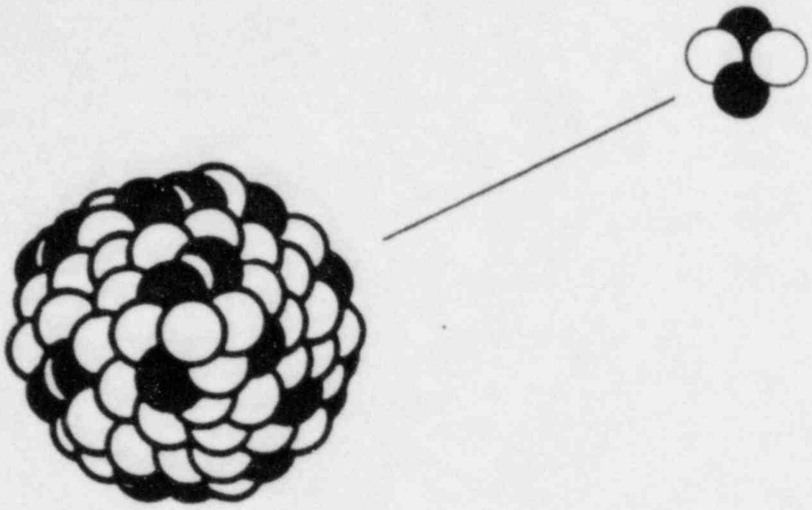
The rate of nuclear decay is measured in "half lives." The half life of any radioactive material is the length of time necessary for one half of the atoms of that material to decay to some other material.

Half lives range from millionths of a second (for highly radioactive fission products) to millions of years (for long lived materials such as naturally occurring uranium).



IONIZATION

Nuclear power plants produce ionizing radiations. "Ionization" is the process of stripping or knocking electrons away from their orbital paths creating chemically active ions. This process can cause chemical changes in the material where it occurs. If chemical changes occur in the cells of our bodies some cellular damage may result. The biological effects of radiation exposure are discussed in section six of this manual.



ALPHA

Alpha radiation is a particle made up of two protons and two neutrons. Alphas are low speed, low penetrating particles which can only travel one or two inches in air. Alphas are easily shielded (stopped) by thin sheets of paper or the body's outer layer of skin. Alphas are considered to be an "internal hazard" due to their ability to cause a large number of ionizations in a small area if the radioactive atom can get inside the body. Outside the body, alphas present little or no hazard.

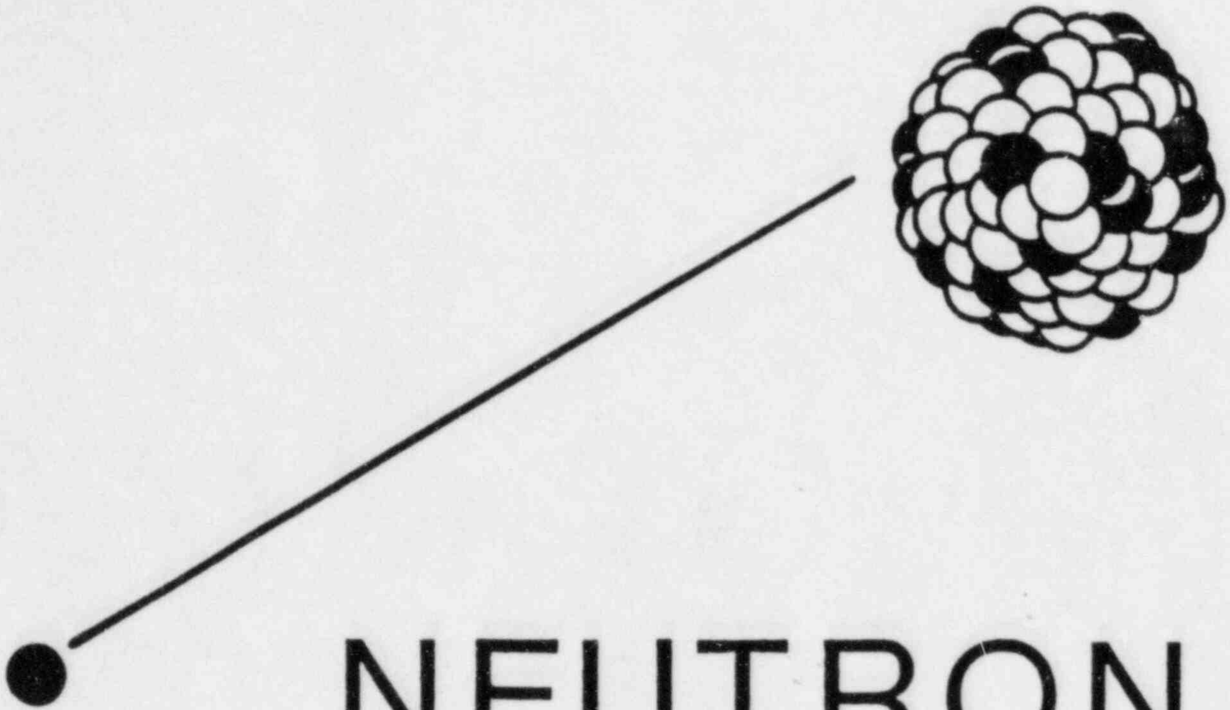
BETA

Betas are high speed, high penetrating particles which are usually negatively charged. About 1/1800 the mass of a proton or neutron, the beta can easily penetrate the skin and is considered both an "internal" and an "external" hazard. Betas are best shielded by thick metals and plastics.

GAMMA

Gamma radiation is electromagnetic energy (no mass, no charge) similar in many respects to visable light (but far more energetic). Gammas can travel thousands of feet in air and can easily pass through the human body. Gammas are best shielded by very dense materials such as lead, concrete, and uranium.

Note: X-rays are similar to gammas but are produced by changes in electron position rather than nuclear decay or fission.



NEUTRON

Neutron radiation is the high speed, high energy neutrons emitted by nuclear fission and by the decay of some radioactive atoms. Neutrons can travel hundreds of feet in the air, can easily penetrate the human body and are best shielded by materials such as water, polyethylene and concrete.

EXPOSURE AND DOSE MEASUREMENTS

ROENTGEN

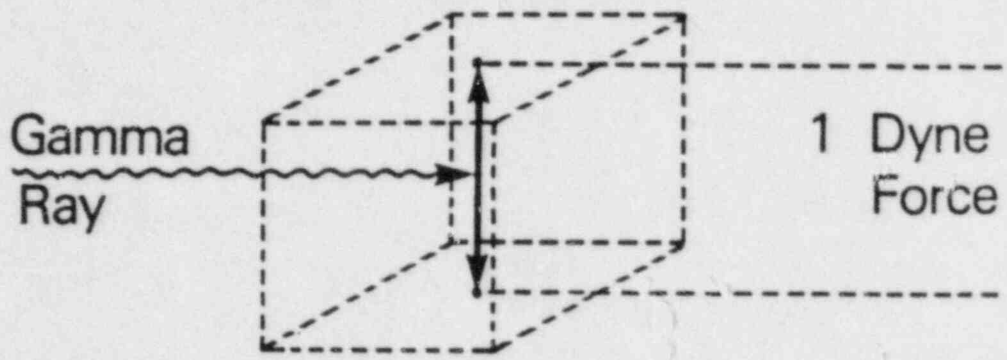
RAD

REM

When radiation interacts with a material it causes ionizations. These ionizations can be measured and their effects estimated.

The commonly used units for radiation exposure and dose measurements in the U.S. are the roentgen, the rad and the rem.

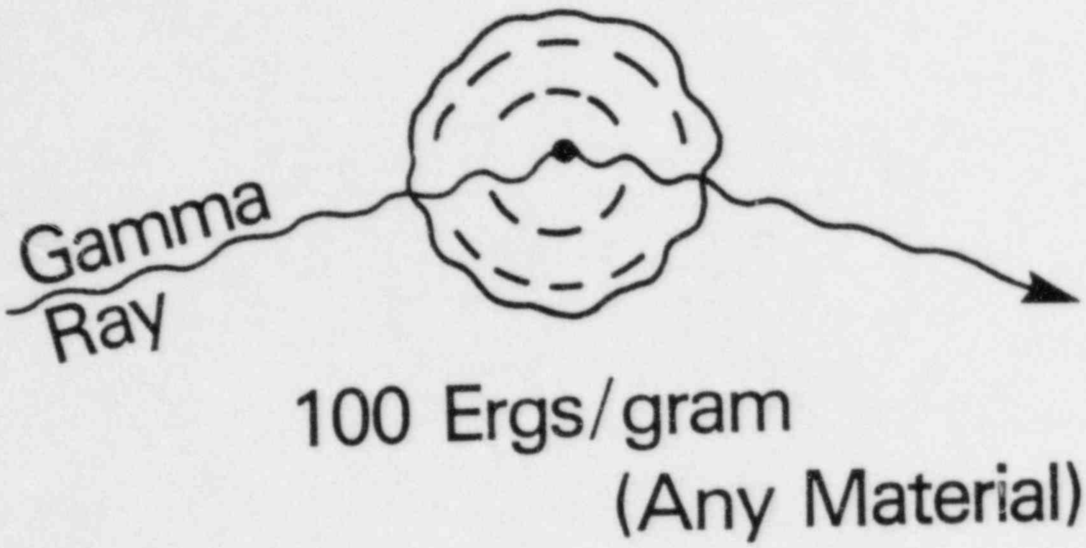
ROENTGEN



1 Esu/Cm^3 Dry Air

The roentgen is a measure of exposure to X or gamma radiation. One roentgen will deposit enough energy to strip about two billion electrons out of their orbits in a cubic centimeter of dry air.

1 RAD



The rad is a measure of absorbed dose (the energy deposited in a material). One rad is the deposition of one hundred ergs of energy in one gram of any material due to ionization from any type of radiation. (One erg is about one ten billionth of a btu). Rad is an acronym for "Radiation Absorbed Dose."

Rem

Damage Equal To 1 Rad of Gamma Radiation in Body Tissue

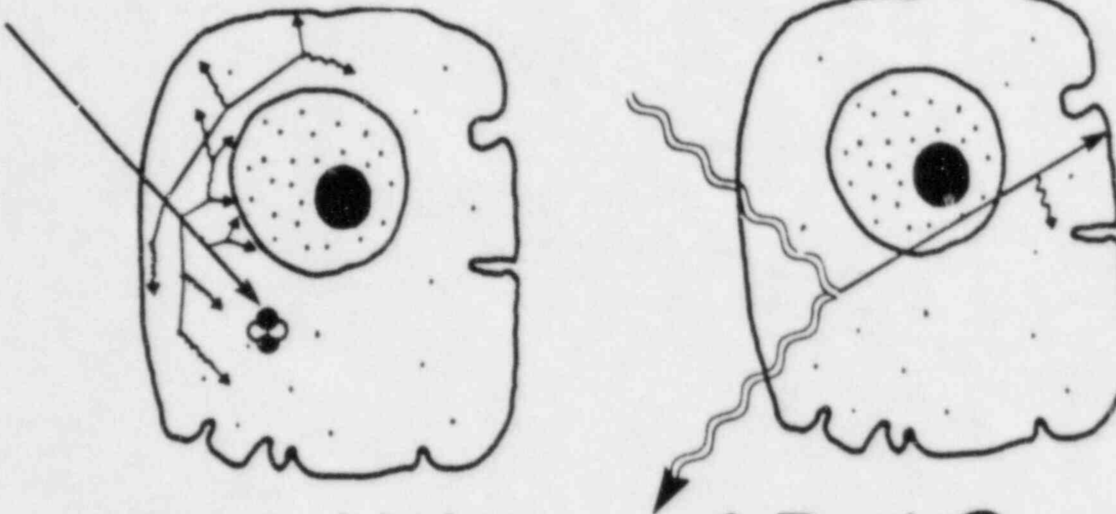
The rem is a measure of biological damage caused by ionization in human tissue. One rem equals the biological damage that would be caused by one rad of exposure to gamma radiation in the body. Rem is an acronym for "Roentgen Equivalent Man."

FOR GAMMA

(AND X-RAYS)

1 Roentgen =
1 Rad =
1 Rem.

For gamma and X radiations, one roentgen of exposure is (about) equal to one rad of absorbed energy which equals one rem of biological damage in humans.



1 Rad Alpha 1 Rad Gamma

Particulate radiations such as alphas and neutrons have been found to cause more biological damage than do gamma or X-rays for the same energy deposited. For example, 100 ergs deposited by alpha can be expected to cause about twenty times the damage caused by 100 ergs deposited by gamma. This difference in ability to cause damage is called the "Relative Biological Effectiveness" (RBE).

DOSE

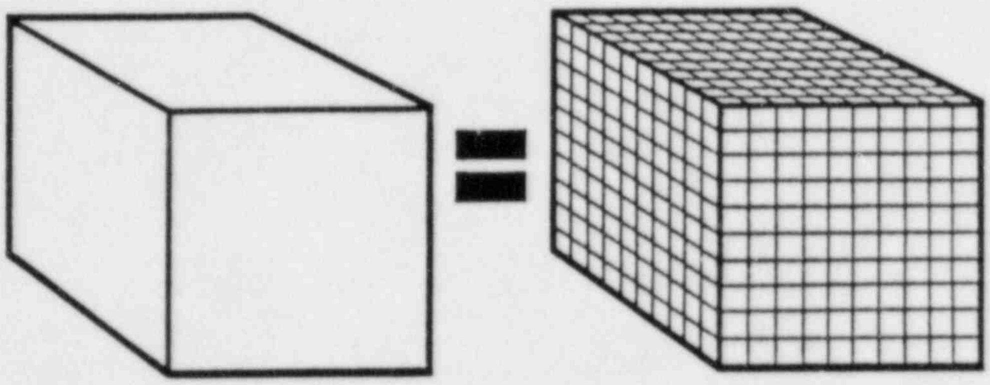
Energy vs. Damage

1 Rad Gamma	= 1 Rem
1 Rad Beta	= 1 Rem
1 Rad Neutron	= 10 Rem
1 Rad Alpha	= 20 Rem

REM = Rad × Quality Factor

To account for Relative Biological Effectiveness, a group of "Quality Factors" has been developed which convert the energy deposited (rads) into an equivalent biological damage in rems.

REM VS. MILLIREM



1 Rem = 1000 m Rem

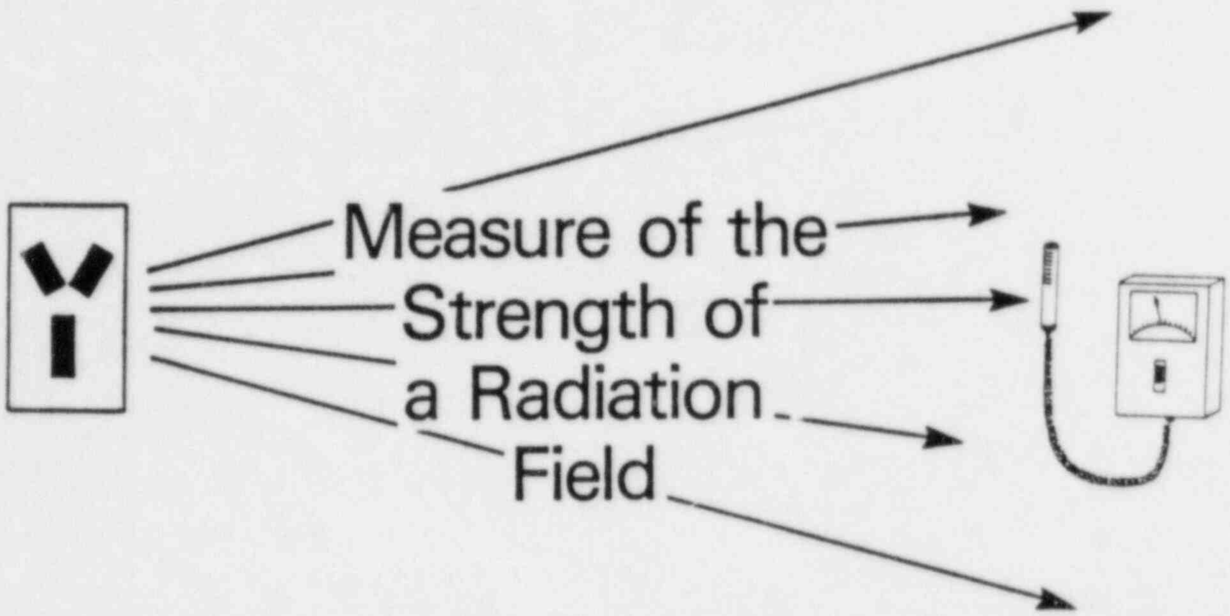
1 m Rem = 1/1000 Rem

All 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 most common prefixes for scientific use.

PREFIXES

d	deci	(= 10^{-1})	da	deka	(= 10)
c	centi	(= 10^{-2})	h	kecto	(= 10^{2})
m	milli	(= 10^{-3})	k	kilo	(= 10^{3})
μ	micro	(= 10^{-6})	M	mega	(= 10^{6})
n	nano	(= 10^{-9})	G	giga	(= 10^{9})
p	pico	(= 10^{-12})	T	tera	(= 10^{12})
f	femto	(= 10^{-15})			
a	atto	(= 10^{-18})			

DOSE RATE



The dose rate is the amount of radiation exposure (or equivalent biological damage) that a person would receive in a particular length of time. It is a measure of radiation intensity (or field strength). Commonly used dose rates are:

mrem/hr, rem/hr, mrem/wk, rem/wk, rem/quarter, rem/yr

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

$$25 \text{ m Rem} = \frac{50\text{mRem}}{\text{HR}} \times 1/2 \text{ Hour}$$

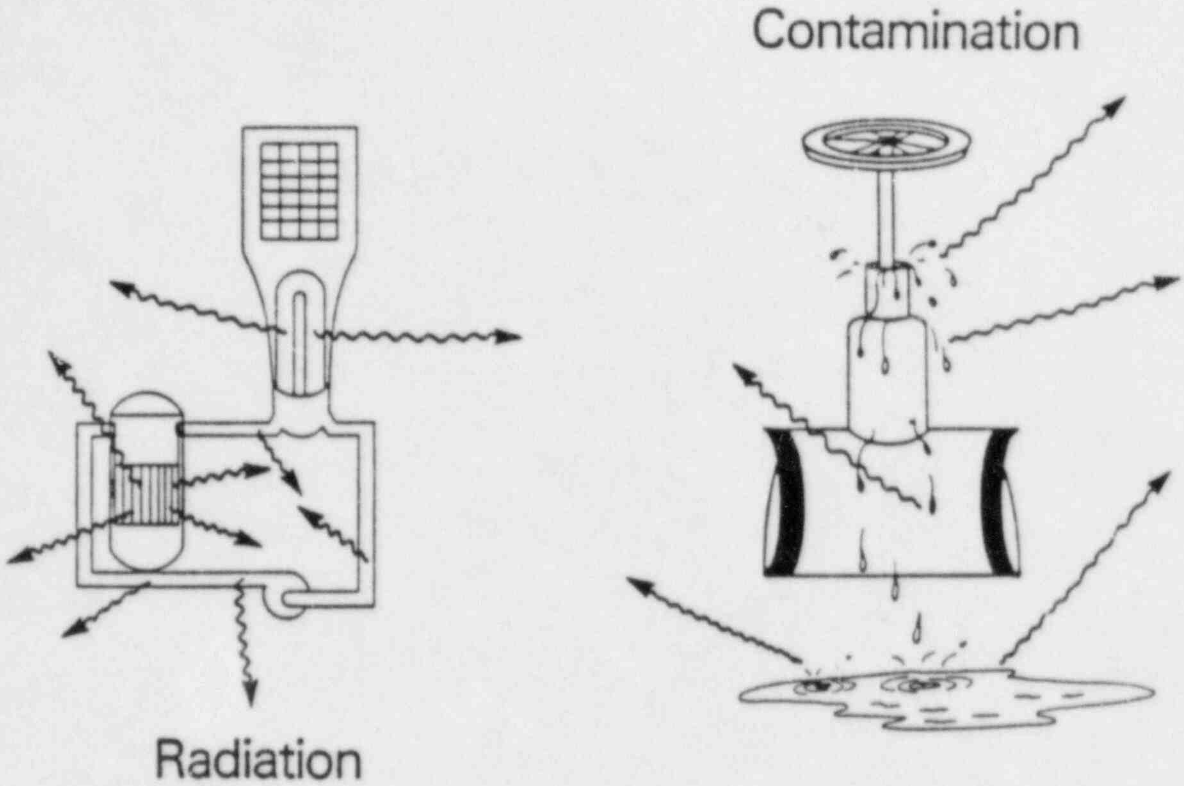
The dose is equal to the strength of the radiation field (dose rate) multiplied by the length of time spent in that field. The example above indicates a person could expect to receive a dose of 25 mrems by staying in a 50 mrem/hr field for thirty minutes.

STAY TIME

Dose Limit/Dose Rate

100 m Rem/50 m Rem/Hr = 2 Hour Stay Time

The "stay time" is 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 mrems has been established. The dose rate is 50 mrem/hr. The stay time is calculated by dividing the dose limit by the dose rate.



Contamination is generally referred to as some material in a location where it is not intended or desired to be. Radioactive contamination is radioactive atoms that have escaped the systems or structures that normally would contain them.

Additionally, if a worker must enter a "container" (for example, to perform steam generator repair on a PWR or turbine repair on a BWR) we say that worker will enter a "contaminated area." Methods of protection against radiation and contamination are discussed in section seven of this manual.

INTERNATIONAL SYSTEM OF UNITS (SI)

OLD UNIT	SI UNIT
CURIE	BECQUEREL
ROENTGEN	COULOMB / KILOGRAM
RAD	GRAY
REM	SIEVERT

The United States has yet to fully implement the use of the internationally accepted system of units and measures (SI). The SI units shown above are expected to gradually replace the curie, roentgen, rad and rem in technical literature.

1 CURIE	=	3.7×10^{10} DIS./SEC.
1 Bq.	=	1 DIS./SEC.
1 Bq.	=	2.7×10^{-11} Ci.

One curie is defined as the amount of any radioactive material that decays at the rate of 37 billion disintegrations per second. One becquerel equals one reciprocal second (sec^{-1}). Therefore, we can say that one curie equals 37 billion becquerel.

$$1 \text{ ROENTGEN} = 2.58 \times 10^{-4} \text{ COULOMB/KILOGRAM}$$

$$1 \text{ COULOMB/KILOGRAM} = 3876 \text{ ROENTGEN}$$

The roentgen will not have a designated SI equivalent unit, but the force produced by a roentgen can still be expressed. The correct representation of coulomb/kilogram is coulomb kilogram $^{-1}$.

$$1\ \text{RAD} = \frac{1}{100}\ \text{GRAY}$$

$$1\ \text{GRAY} = 100\ \text{RAD}$$

The gray will replace the rad as the unit of absorbed dose.

One rad equals 1/100 of a gray.

One gray equals 100 rad.

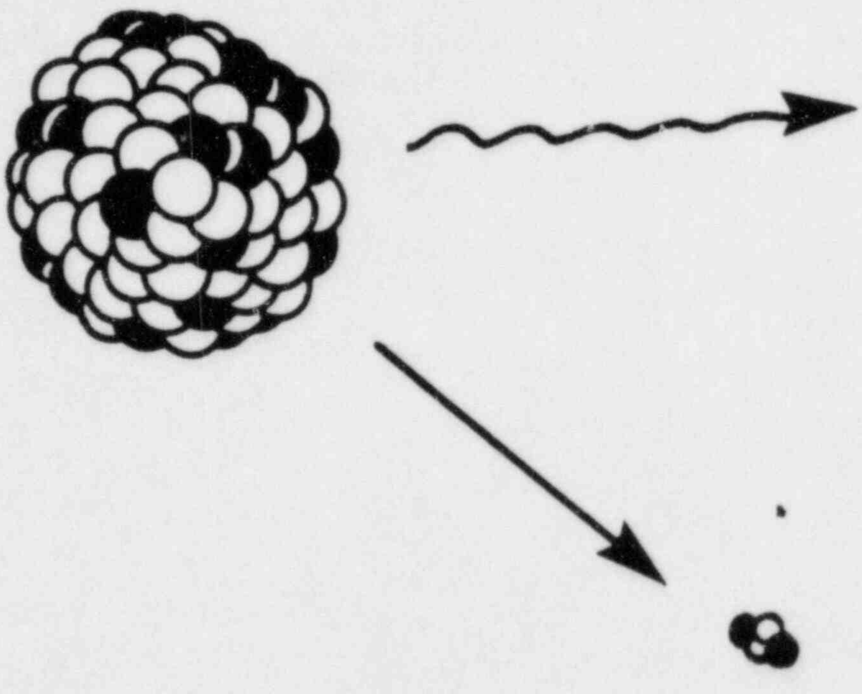
1 REM = $\frac{1}{100}$ SIEVERT

1 SIEVERT = 100 REM

The sievert will replace the rem as the unit of biological damage to human tissue.

One rem equals 1/100 sievert.
One sievert equals 100 rem.

Radiation Sources



This section discusses the sources of radiation exposure to the general U.S. population. Both naturally occurring and man made radiation sources are discussed.

NATURAL BACKGROUND RADIATION SOURCES

OUTER SPACE
AIR
WATER
GROUND MINERALS
FOOD / TOBACCO PRODUCTS
BODY TISSUES

Our bodies are penetrated thousands of times each second by naturally occurring radiations. Natural Background Radiation comes from the Sun and other stars and the decay of naturally occurring radioactive elements in the ground, air, water, plants, and animals and inside our own bodies.

BACKGROUND SOURCES

COSMIC RADIATION

PROTONS

NEUTRONS

BETAS

GAMMAS

X - RAYS

38 – 75 m REM / YEAR

Activity on our Sun (and other stars) and the Earth's magnetic fields cause the upper atmosphere to be bombarded with high speed particles and photons. While the Earth's atmosphere shields us from much of this direct radiation, we are still exposed to some of this "primary" radiation. Interactions in the upper atmosphere release "secondary radiations" which are the source of most of the cosmic radiation which reaches the earth.

TERRESTRIAL RADIATION

Granite, Soil, Minerals, Ground Water, Etc.

$^{3}_{1}H$, $^{14}_{6}C$, $^{40}_{19}K$, $^{222}_{86}Rn$, $^{226}_{88}Ra$, $^{232}_{90}Th$, $^{238}_{92}U$

15 -140 mRem/Year

Terrestrial radiation comes from the decay of naturally occurring radioactive materials which can be found in varied amounts throughout the world. Some of the most abundant natural radioisotopes are listed above.

INTERNAL SOURCES

$^{14}_{6}C$, $^{40}_{19}K$, $^{226}_{88}Ra$

15-20 m Rem/Year

All of us have some radioactive material inside our bodies. Three of the most abundant internal radiation sources are listed above.

NATURAL BACKGROUND RADIATION

COSMIC	38 - 75 m REM / YEAR
TERRESTRIAL	15 - 140 m REM / YEAR
INTERNAL	15 -20 m REM / YEAR

AVERAGE = 100 m REM / YEAR

The average American receives a dose of about 100 m Rem each year due to background radiation.

MAN MADE RADIATION SOURCES

MEDICAL EXPOSURES	90 m REM / YEAR
BUILDING MATERIALS & CONSUMER PRODUCTS	5 m REM / YEAR
WEAPONS FALLOUT	5 m REM / YEAR

AVERAGE = 100 m REM / YEAR

Medical procedures (both diagnostic and therapeutic) are the largest source of man made radiation exposure to the general public. The use of building materials containing trace amounts of natural radioactivity, some consumer products, and fallout from nuclear weapons add slightly to the total man made radiation dose.

CONSUMER PRODUCTS

TV SETS

LUMINOUS WATCHES

SMOKE DETECTORS

AIRPORT X-RAYS

NATURAL GAS

INCANDESCENT MANTLES

FOOD/TOBACCO PRODUCTS

The consumer products listed above either contain small amounts of radioactive materials or generate high speed particles or photons in the course of their operation.

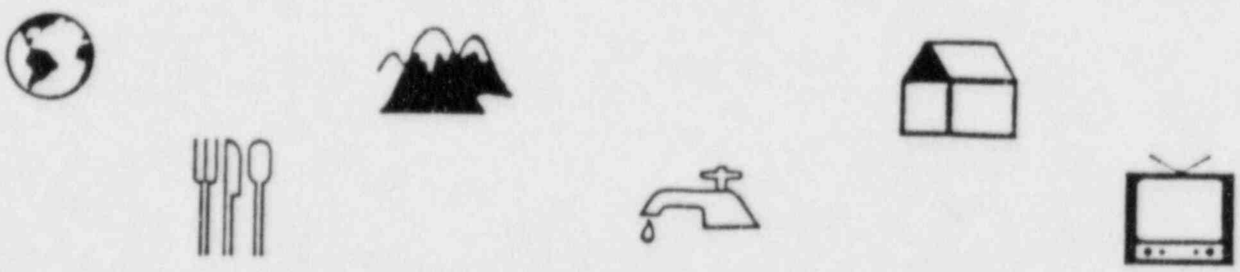
GENERAL U.S. POPULATION :

NATURAL BACKGROUND	100 m REM / YEAR
MAN MADE SOURCES	100 m REM / YEAR
AVERAGE =	200 m REM / YEAR

The average U. S. citizen receives a total annual dose of about 200 m Rem as a result of naturally occurring and man made radiations.

COMPUTE YOUR OWN RADIATION DOSE

	Common Source of Radiation	Your Annual Inventory
WHERE YOU LIVE	Location: Cosmic radiation at sea level	26
	For your elevation (in feet) — add this number of mrem	______
	Elevation — mrem: 1000-2, 2000-5, 3000-9, 4000-15, 5000-21, 6000-29, 7000-40, 8000-53, 9000-70	
	Elevation of some U.S. cities (in feet): Atlanta 1050, Chicago 595, Dallas 435, Denver 5280, Las Vegas 2000, Minneapolis 815, Pittsburgh 1200, St. Louis 455, Salt Lake City 4400, Spokane 1890.	
	(Coastal cities are assumed to be zero, or at sea level.)	
	Ground: U.S. average	26
	House Construction — For stone, concrete or masonry building, add 7	______
WHAT YOU EAT, DRINK, AND BREATHE	Food Water Air — U.S. average	24
	Weapons test fallout	4
HOW YOU LIVE	X ray and radio pharmaceutical diagnosis	
	Number of chest x rays ______ x 10	______
	Number of lower gastrointestinal tract x rays ______ x 500	______
	Number of radiopharmaceutical examinations ______ x 300	______
	(Average dose to total U.S. population = 92 mrem)	
	Jet plane travel: For each 2500 miles add 1 mrem	______
	TV viewing: For each hour per day ______ x 0.15	______
	My total annual dose in mrem =	______



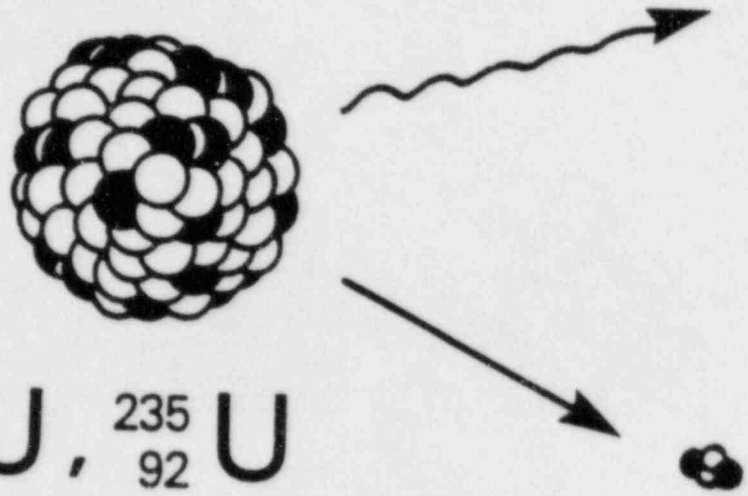
One mrem per year is equal to: **Moving to an elevation 100 feet higher.**
Increasing your diet by 4%.
Taking a 4- to 5-day vacation in the Sierra Nevada Mountains.

RADIATION SOURCES AT NUCLEAR PLANTS

Nuclear Fuel Decay
Fission Process
Fission Product Decay
Activation Products
Calibration Sources

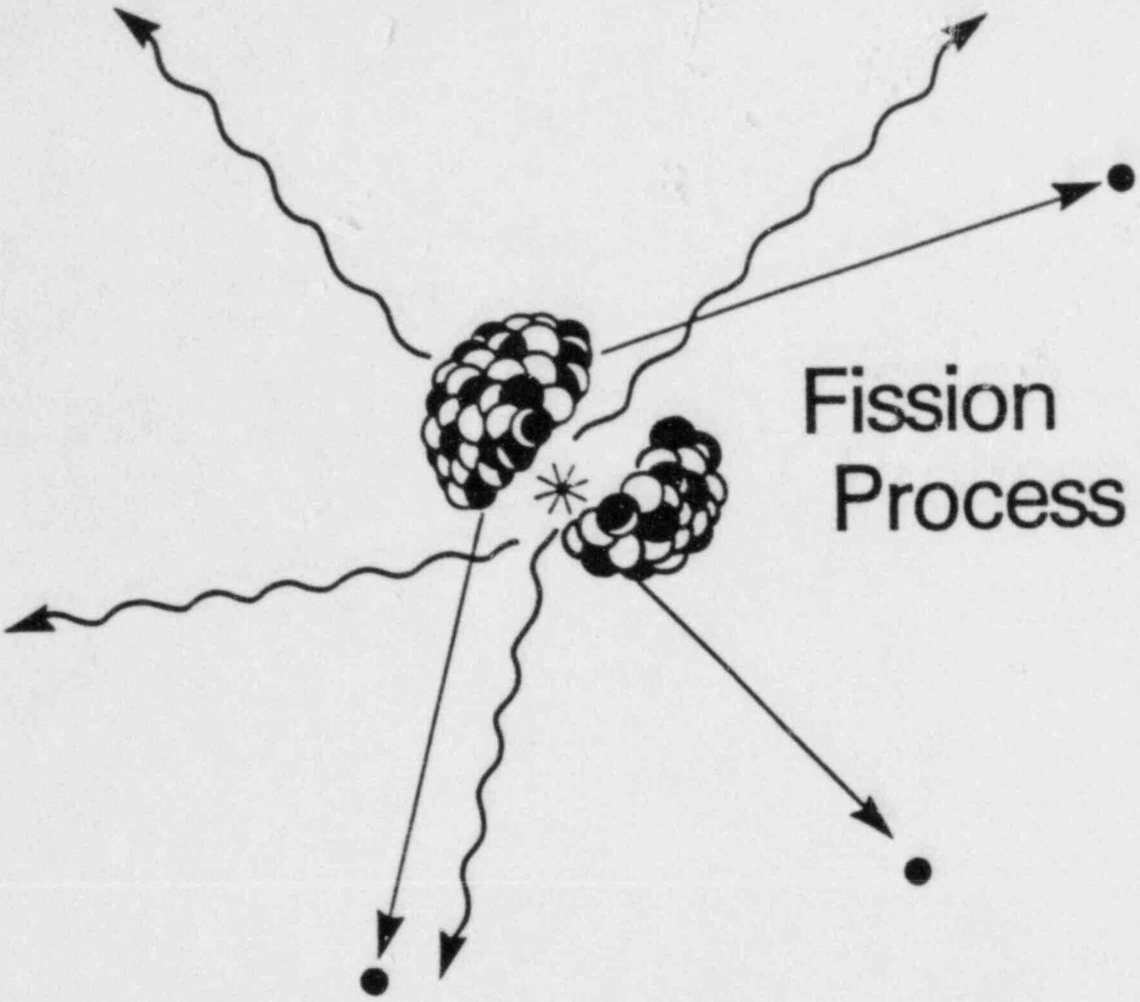
This section discusses the sources of radiation found at power reactors.

Nuclear Fuel Natural Decay Process



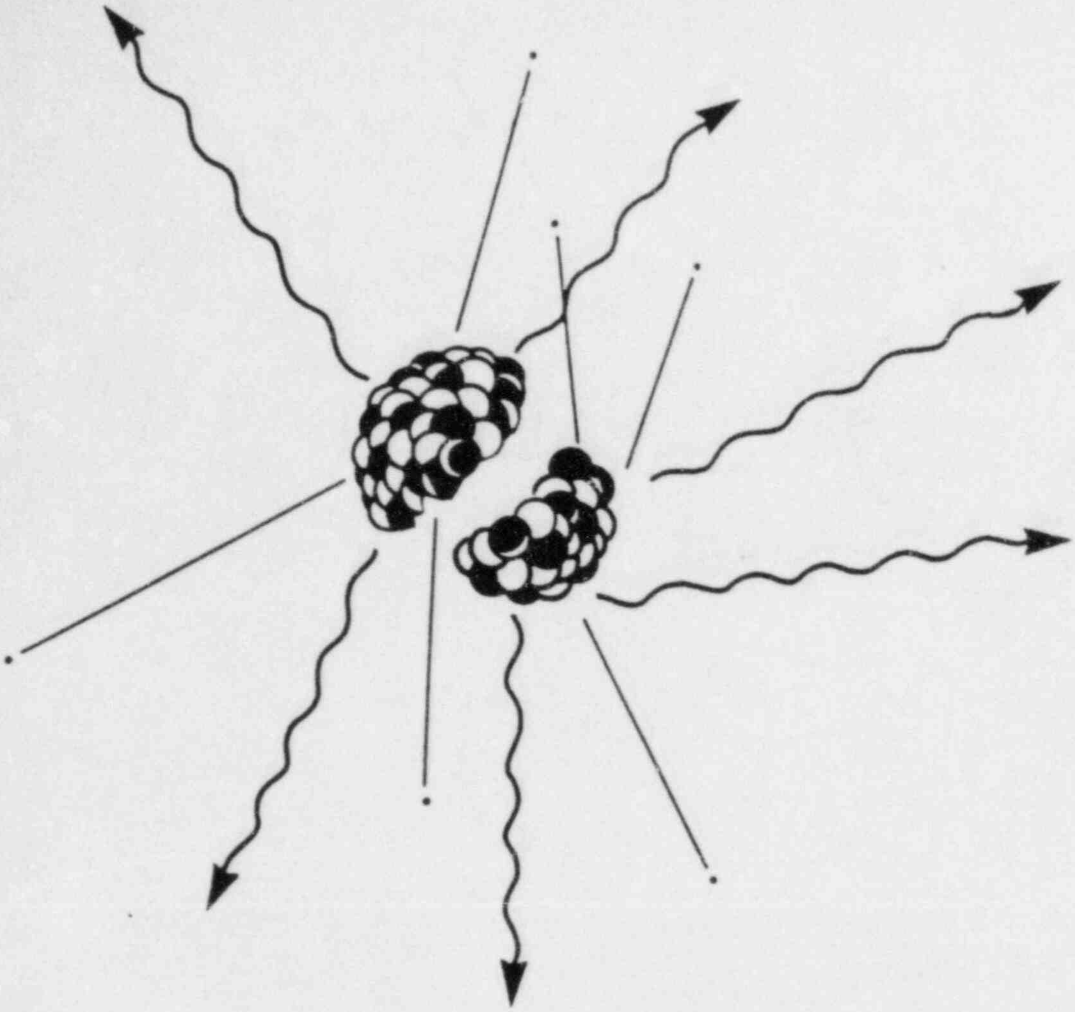
$^{238}_{92}U$, $^{235}_{92}U$

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



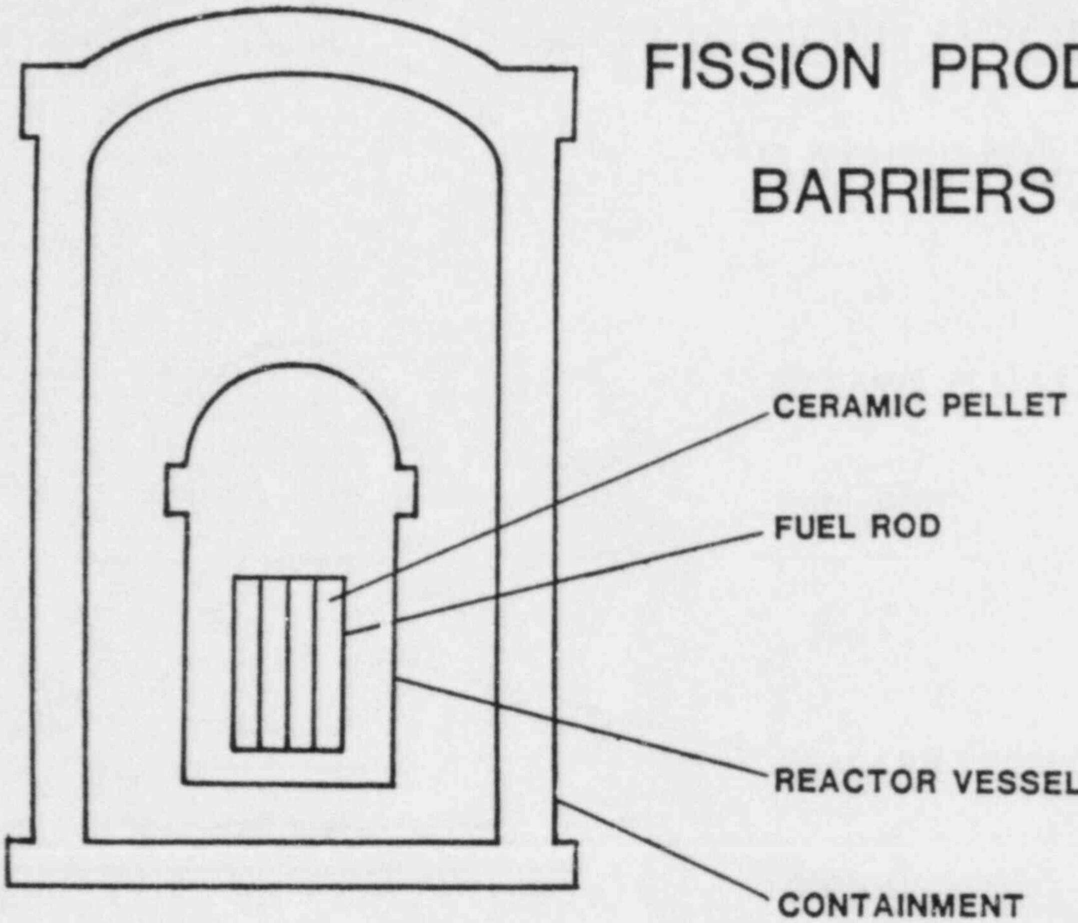
During the fission process uranium atoms split into two or three smaller atoms (called fission products). Powerful gamma rays and high speed neutrons are released during (and immediately following) the fission process.

Fission Product Decay

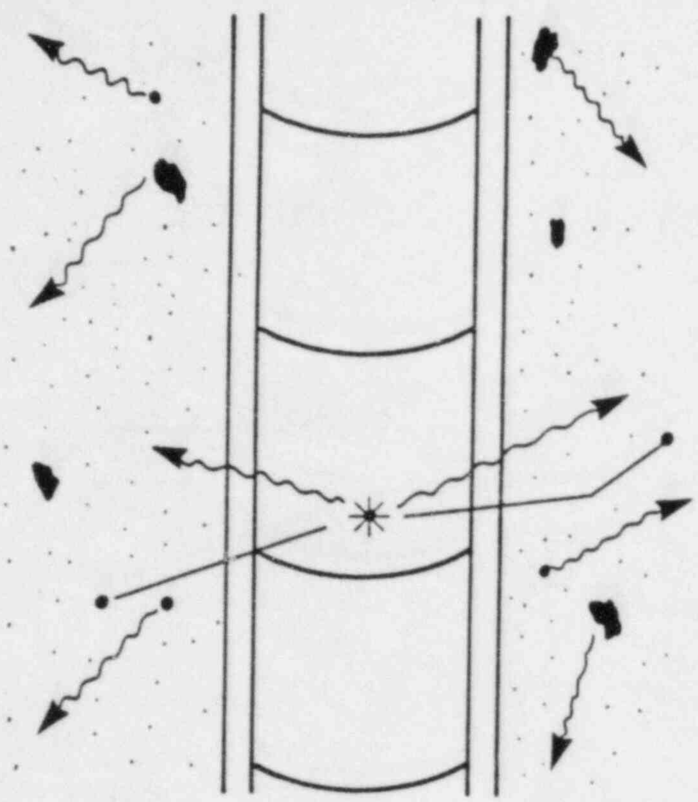


The new atoms produced by fission (fission products) are intensely radioactive. Most will decay rapidly but several decay very slowly. Fission products generally decay by beta and gamma emission.

FISSION PRODUCT BARRIERS



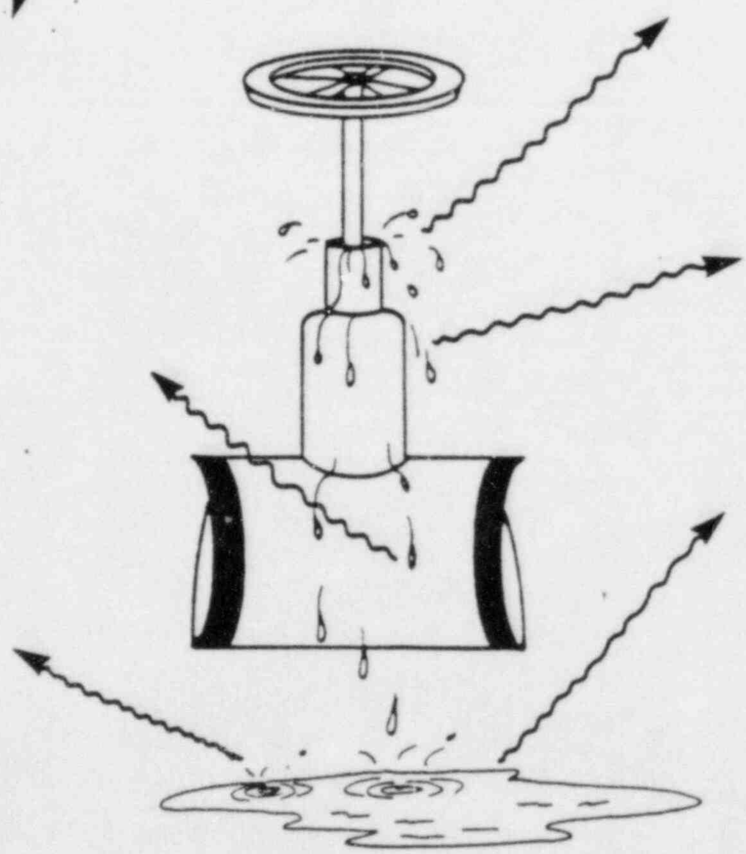
Since a significant fission product release could seriously jeopardize public health and safety (and the environment) a system of fission product barriers is a part of every power reactor design.



Activation of Water and Corrosion Products

(CRUD)

Contamination



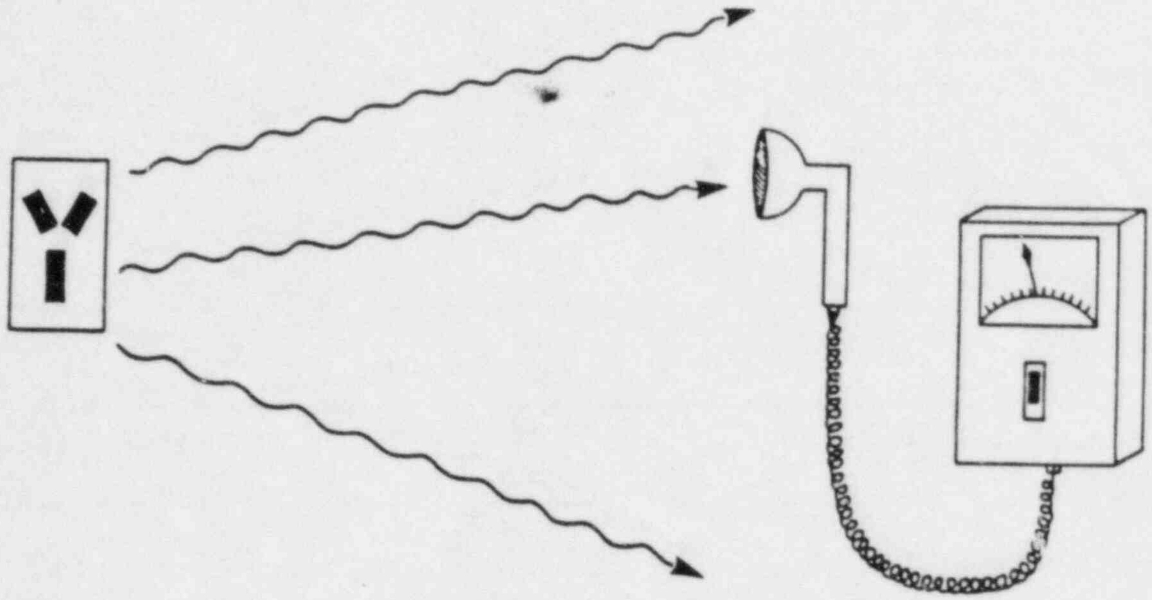
During the fission process, some of the materials in the vicinity of the reactor core will absorb neutrons and be changed from a stable form to a non-stable (radioactive) form. These materials (called activation products or "crud") are not contained inside the fuel rods (as are most fission products) and are easily transported by the reactor coolant system. Crud is the source of most radioactive contamination at nuclear power plants.

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

Above is a partial list of radioactive materials produced either by fission (fission products) or neutron absorption (activation products). These materials are of particular interest because of:

1. Their relatively long half-lives
2. Their relative abundance in the reactor (or)
3. Their ability to chemically interact in biological systems

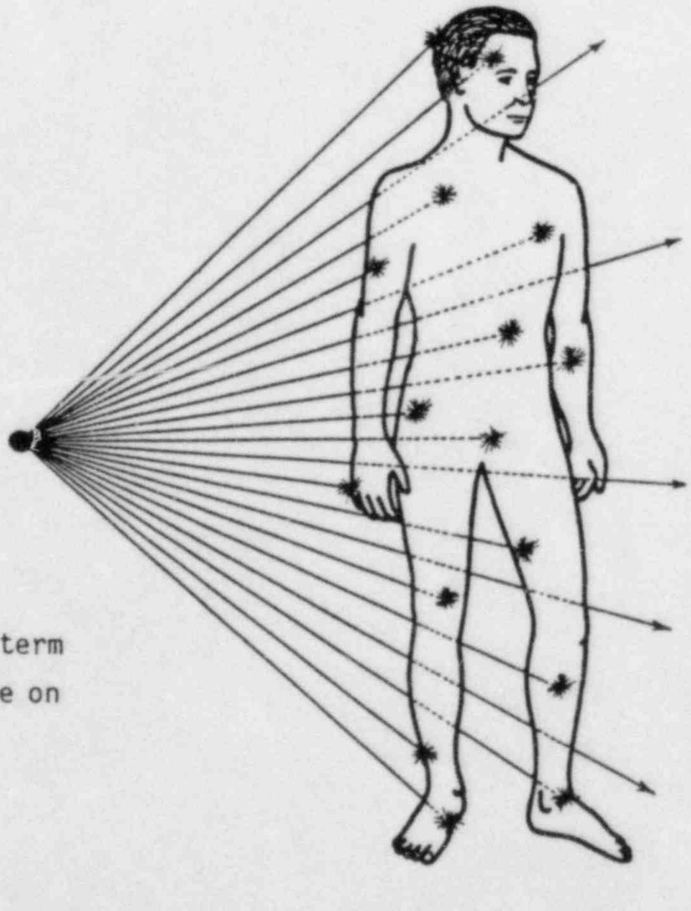
INSTRUMENT CALIBRATION



SOURCES

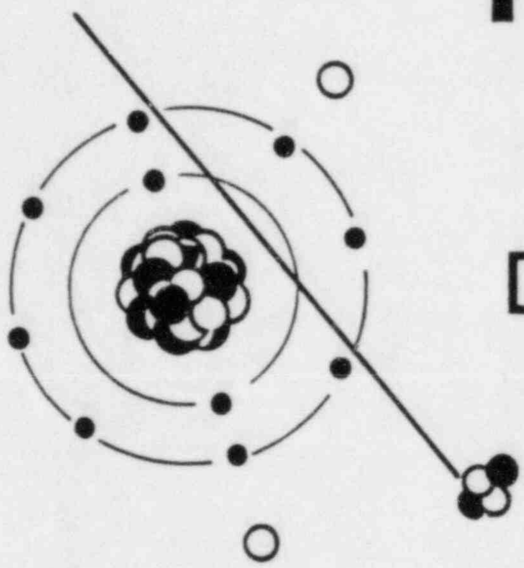
Small quantities of radioactive material (sources) are stored on the plant site to allow instrument technicians to properly test and calibrate radiation detection devices. These sources are completely sealed and are stored in isolated areas when not in use.

Biological Effects of Radiation



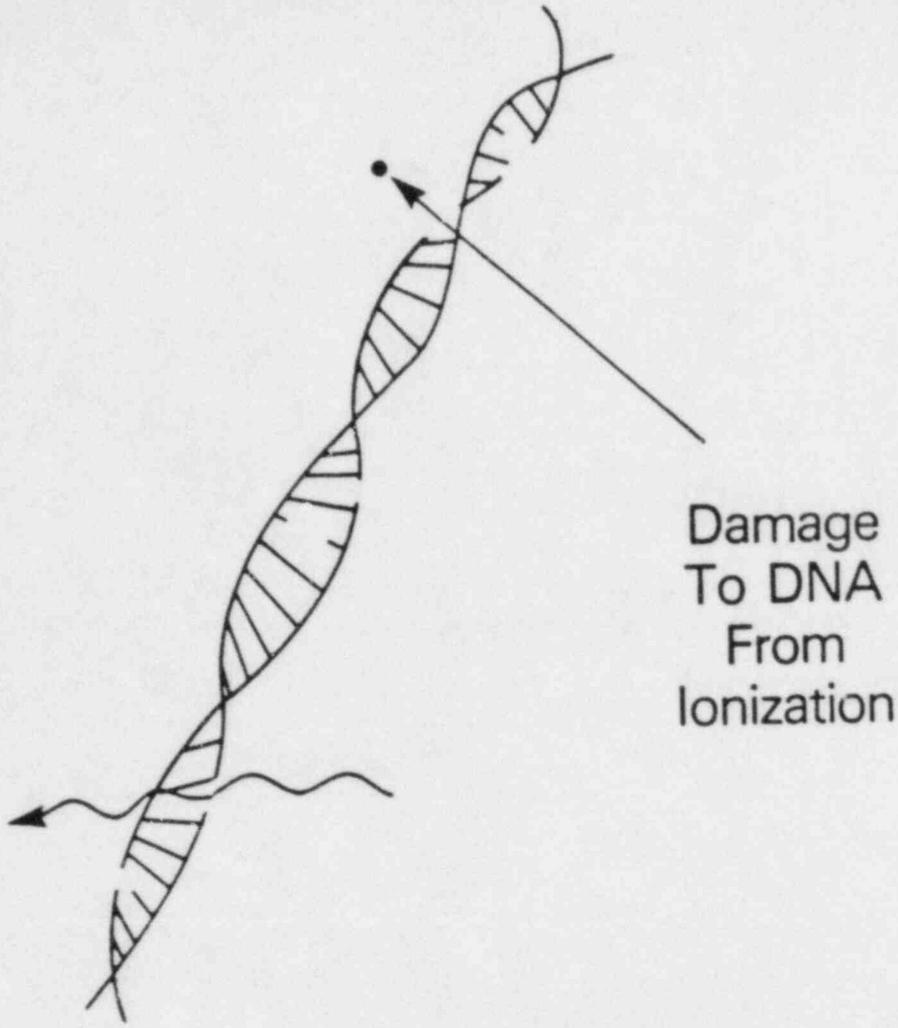
This section discusses the expected short term and long term effects of radiation exposure on biological systems.

Radiation Causes Ionization



Decomposition of H_2O In Cell

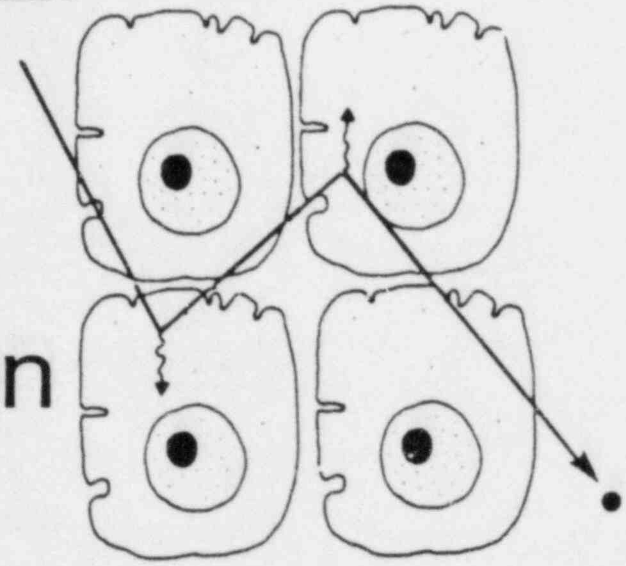
Radiations such as alpha, beta, gamma, x-ray and neutron can deposit enough energy inside human tissue to knock or strip electrons away from their nuclei. Since a large percentage of the body is water, most of the radiation induced ionizations will involve water molecules. Some of these molecules may be decomposed (hydrogen separated from oxygen). The water molecules involved may or may not recombine into H_2O. If a large number of water molecules are ionized, a certain number can be expected to form into other combinations. (Example: $2H_2O \rightarrow H_2 + H_2O_2$).



Inside the cell nucleus, the DNA molecules represent a relatively small (but very important) percentage of the whole body. Ionizations occurring in these molecules may result in the transfer of incomplete (or incorrect) genetic information to the cell's offspring during reproduction.

CELLULAR DAMAGE:

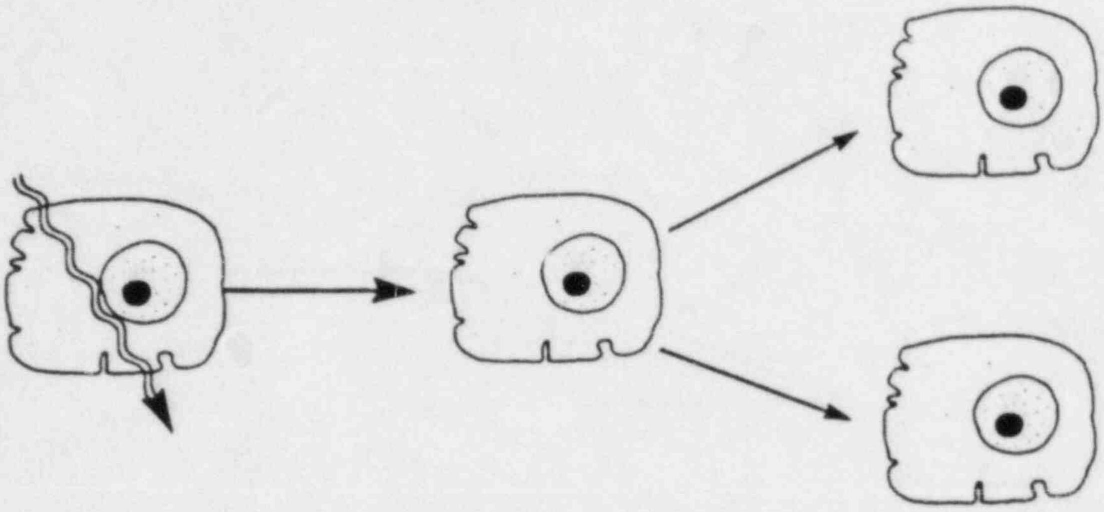
1. Ionization
2. Chemical Recombination



Radiation can cause cellular damage by ionization and by the potentially harmful effects of forming new chemical compounds as a result of the ionization process.

POSSIBLE CELLULAR PROCESSES

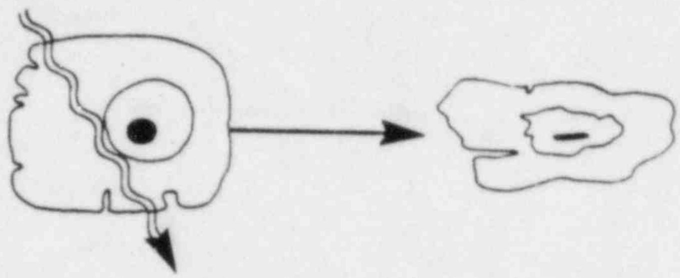
1. Normal Repair of Damage (Normal Reproduction)



At low levels of radiation (such as normal background) the affected cell can usually repair (overcome) any damage resulting from the exposure.

POSSIBLE CELLULAR PROCESSES

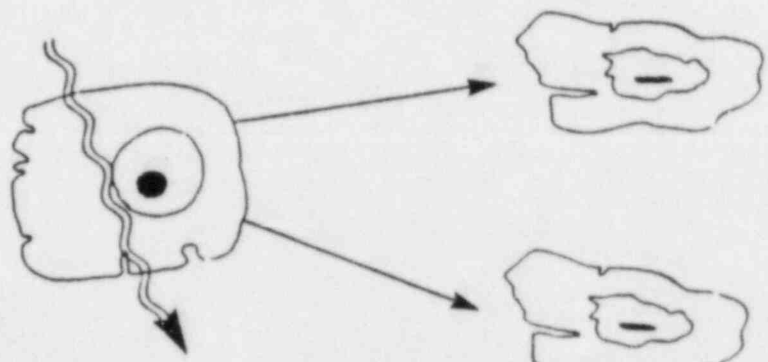
1. Normal Repair of Damage
2. Cell Dies From Damage



At high levels of radiation, cellular damage may ultimately result in the death of the affected cell or in the inability of the cell to reproduce.

POSSIBLE CELLULAR PROCESSES

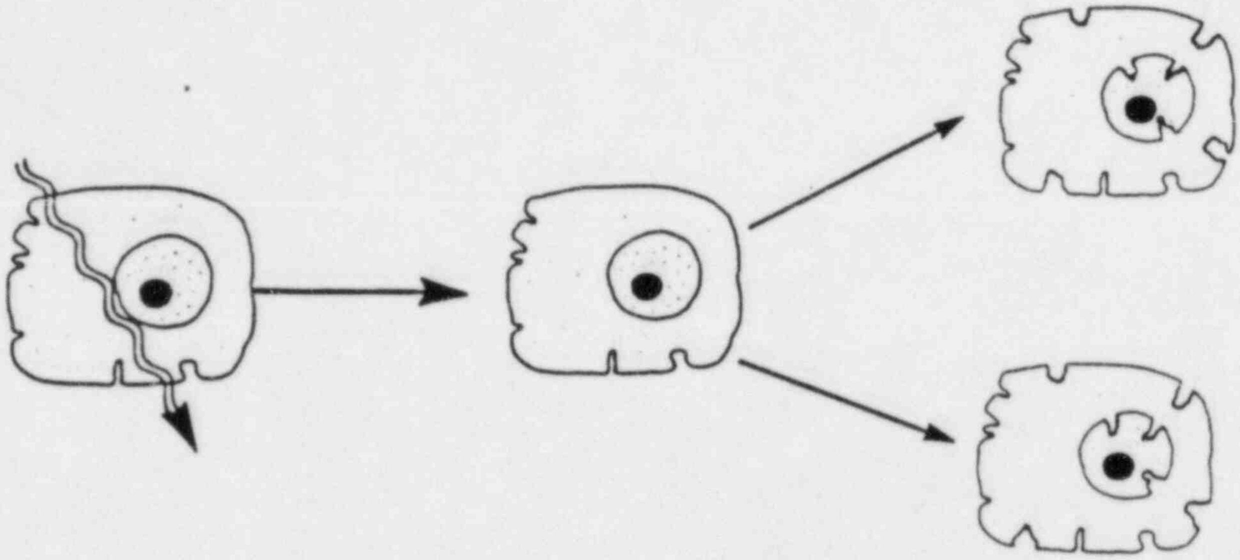
1. Normal Repair of Damage
2. Cell Dies From Damage
3. Daughter Cells Die



If genetic damage occurs, the cell may reproduce, but the resultant daughter cells may not live (or may live but be incapable of further reproduction).

POSSIBLE CELLULAR PROCESSES

1. Normal Repair of Damage
2. Cell Dies From Damage
3. Daughter Cells Die
4. No Repair or Non-Identical Repair Before Reproduction



A small portion of DNA changes are reproducible. The resultant changes, (or mutations) may range from non-detectable to life threatening.

RADIATION EFFECTS

ACUTE	CHRONIC
UNDETECTABLE AT DOSES BELOW 5 - 50 REMS	RISK IS LOW BUT INCREASES WITH EACH ADDITIONAL EXPOSURE

The effects of radiation exposure on living tissue can be short term (acute) and long term (chronic). Acute radiation exposures can cause sickness and even death at doses of 300 - 1000 Rems. Acute exposures below 5 - 50 Rems should cause no short term ill effects.*

The chronic effects of radiation exposure are considered to have no threshold for risk. Although very small (compared to the total cancer risk, a person faces) the risk of a radiation induced cancer increases with each additional exposure.

RADIATION SYNDROME

Nausea
Fatigue
Loss of Appetite
Vomiting

Acute radiation sickness (the radiation syndrome) can be expected if a person receives a dose of 50 - 200 Rems or more over a short period of time. The onset of symptoms and the severity of the illness are related to the total dose received, the duration of the exposure and several other factors. Most people exposed to radiation doses below about 300 Rems can be expected to ultimately recover from these short term effects.

RADIATION SYNDROME

Ultimate Effect Can Be Death

The ultimate effect of any exposure to a hazardous material can be death. The likelihood (risk) of death increases as the dose increases.

NRC DOSE LIMITS
10 CFR 20

DOSE STANDARDS IN RESTRICTED AREAS:

		QUARTERLY	YEARLY
WHOLE BODY	(REM)	1.25	5
HANDS & FEET	(REM)	18.75	75
SKIN OF WHOLE BODY	(REM)	7.5	30

3 REM/QUARTER IF
EXPOSURE HISTORY IS KNOWN
(NRC FORM 4)
AND
LIFETIME EXPOSURE DOES NOT
EXCEED 5(N-18)
N=AGE IN YEARS

The NRC radiation exposure limits shown above are designed such that no worker at a nuclear facility will receive an acute whole body radiation exposure sufficient to trigger the radiation syndrome. The risk of cancer (although not zero) should be no higher than the risk of cancer from other occupations.

NRC DOSE LIMITS 10 CFR 20

UNRESTRICTED AREA:

2 m Rem/HR

100 m Rem/7 Days

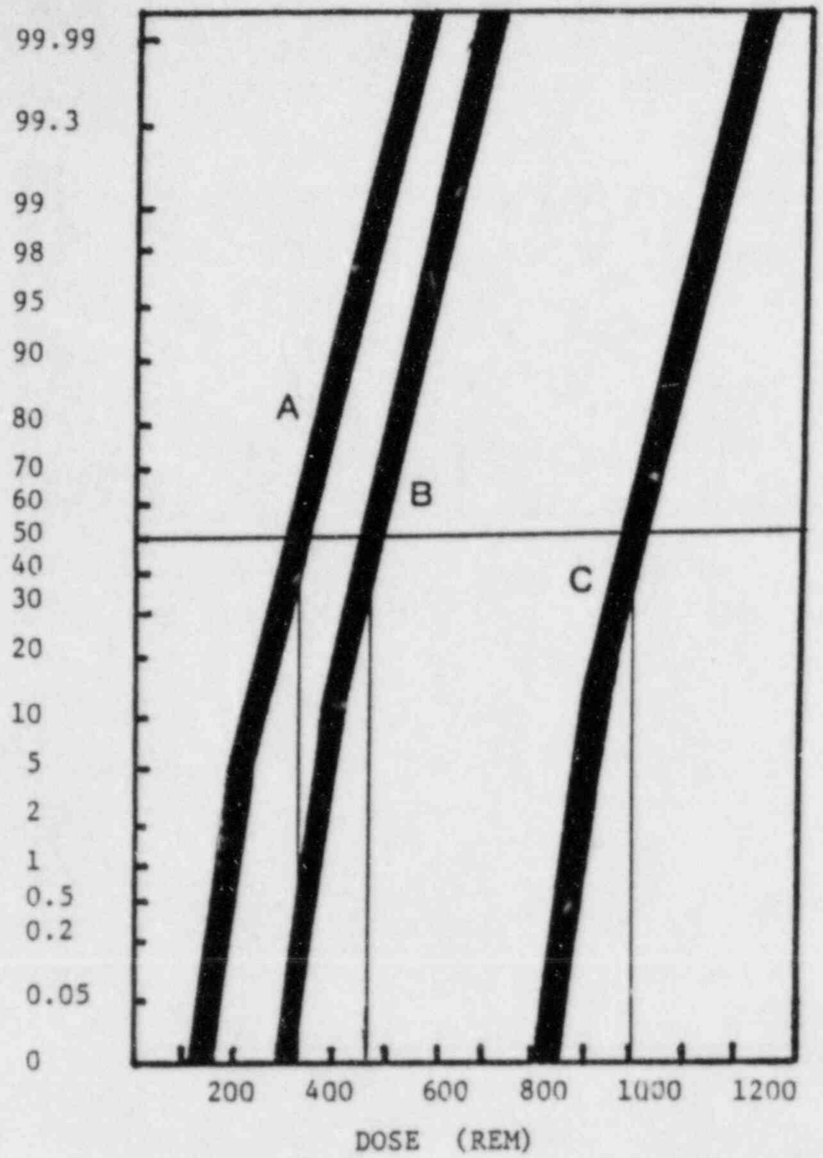
The NRC limits all licensees in the handling and use of radioactive materials such that no member of the public (or worker outside the restricted area) will receive a radiation dose of 2 millirems in any hour, or 100 millirems in any seven consecutive days. Additionally, the NRC has provided design objectives for power reactor licensees to keep off-site releases as far below the 10 CFR 20 limits as is reasonably achievable. These guidelines can be found in 10 CFR Part 50. See page 10-7 of this manual for more information on design objectives.

ACUTE RADIATION DOSE

0-5 Rem	No Detectable Effect
5-50 Rem	Slight Blood Changes
50-100 Rem	Blood Changes, Nausea, Fatigue
100-200 Rem	Above Plus Vomiting, 1% LED
200-450 Rem	Hair Loss, Severe Blood Changes, Some Deaths in 2-6 Weeks
450-700 Rem	Lethal to 50% of Those Exposed Within 1 Month
700-1000 Rem	Probable Death For 100% of Those Exposed in 1 Month
5000 Rem	Immediate Incapacitation Death Within 1 Week

The table above lists the expected effects from an acute whole body radiation exposure. The duration of the exposure is assumed to be short (24 hours or less). 1% LED is the lethal effective dose for one percent of a group of individuals exposed to a dose of 100 - 200 Rems.

PERCENT MORTALITY WITHIN 60 DAYS



Curve A - Minimal Medical Treatment
Curve B - Supportive Medical Treatment
Curve C - Heroic Medical Treatment

The grafts above indicate how supportive and heroic medical assistance can significantly reduce the effects of the acute radiation syndrome. The 50% mortality line lies at about 300 Rems for minimal assistance, about 450 Rems for supportive (normal) assistance and about 1000 Rems for heroic/extensive) assistance.

AS DOSE INCREASES:

Risk of Cancer Increases

The chronic effects of radiation exposure are considered to have no threshold for risk. In other words, there is no level of exposure which is completely safe. The risk of a radiation induced cancer is considered to be very low (but not zero) compared to the normal incidence of cancer in the population (one person in four).

CANCER RISK ESTIMATES

1. ADDITIONAL CANCERS

2. REDUCED LIFE EXPECTANCY

Two commonly used methods to evaluate risks are decreased life expectancy and increased probability of cancer related to certain activities. The National Academy of Sciences' Advisory Committee on the Biological Effects of Radiation (BEIR), the International Commission on Radiation Protection (ICRP), the National Council on Radiological Protection (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and many other national and international scientific bodies have studied and continue to study the risks of radiation exposure.

RADIATION INDUCED CANCERS

RISK INCREASES ABOUT .03 % FOR EACH REM

.016 - .045 %	**BEIR , 1980**
.02 %	**ICRP , 1977**
.015 - .035 %	**UNSCEAR , 1977**

The normal incidence of cancer in the U. S. is about 25% (one person in four). Out of 10,000 people, 2500 can be expected to develop a cancer. If all these people were to receive a dose of one additional rem we can estimate between 1 and 4 additional persons will develop a cancer.

RADIATION INDUCED CANCERS

DECREASED LIFE EXPECTANCY

SUBTRACT ONE DAY FOR EACH REM

Several stud.es have compared the projected decrease in life expectancy resulting from exposure to radiation and other health risks. The additional risk associated with radiation exposure has been calculated to be a reduction of life expectancy by about one day for each rem.

Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Natural background radiation, calculated	8
Medical diagnostic x-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose, calculated (industry average for the higher-dose job categories is 0.65 rem/yr)	1
1 rem/yr for 30 years, calculated	30

[a]Adapted from Cohen and Lee, "A Catalogue of Risks," *Health Physics*, Vol. 36, June 1979.

RISK OF CANCER

A RADIATION EXPOSURE IS NOT
A GUARANTY OF CANCER

MOST PERSONS EXPOSED WILL
NOT DEVELOP A CANCER

BUT

EVERY EXPOSURE SLIGHTLY INCREASES
THE RISK OF A CANCER

The risk of cancer related to radiation exposure is under continuing study. The statements above can be used to summarize the results of most of the scientific findings in this area.

NATIONAL CANCER INSTITUTE'S SEVEN STEPS TO AVOID CANCER

1. DON'T SMOKE OR USE TOBACCO AT ALL
2. EAT LESS FAT
3. DRINK LESS ALCOHOL
4. FOLLOW INDUSTRIAL SAFETY RULES
5. AVOID UNNECESSARY X-RAYS
6. PROTECT YOUR SKIN FROM THE SUN
7. AVOID UNNECESSARY ESTROGEN TREATMENTS

The National Cancer Institute recommends the above precautions to markedly reduce the risk of cancer.

SENSITIVITY FACTORS

1. Type of Radiation
2. Amount of Radiation
3. Type of Cell Involved
4. Stage of Cell Division
5. Age of Individual
6. General State of Health
7. Part of Body Exposed
8. Percentage of Body Exposed
9. Duration of Exposure

Different individuals exhibit different sensitivity to radiation. Some of the factors affecting radiosensitivity are listed above.

MOST SENSITIVE	LEAST SENSITIVE
Blood Cells	Bone Cells
Bone Marrow	Muscle Cells
Eye Lens	Nerve Cells
Reproductive Cells	

The different cells of the body exhibit a wide range of sensitivity to radiation. Some of the most and least sensitive cells are listed above.

Methods For Protection Against Radiation and Contamination

CAUTION
RADIOACTIVE
MATERIAL

This section discusses the methods used to protect individuals from the harmful effects of radiation and contamination.

PROTECTION AGAINST RADIATION

1. Time

2. Distance

3. Shielding

Reducing the dose from any external source of radiation involves the use of three protective measures:

Reduced time
Increased distance
Use of shielding

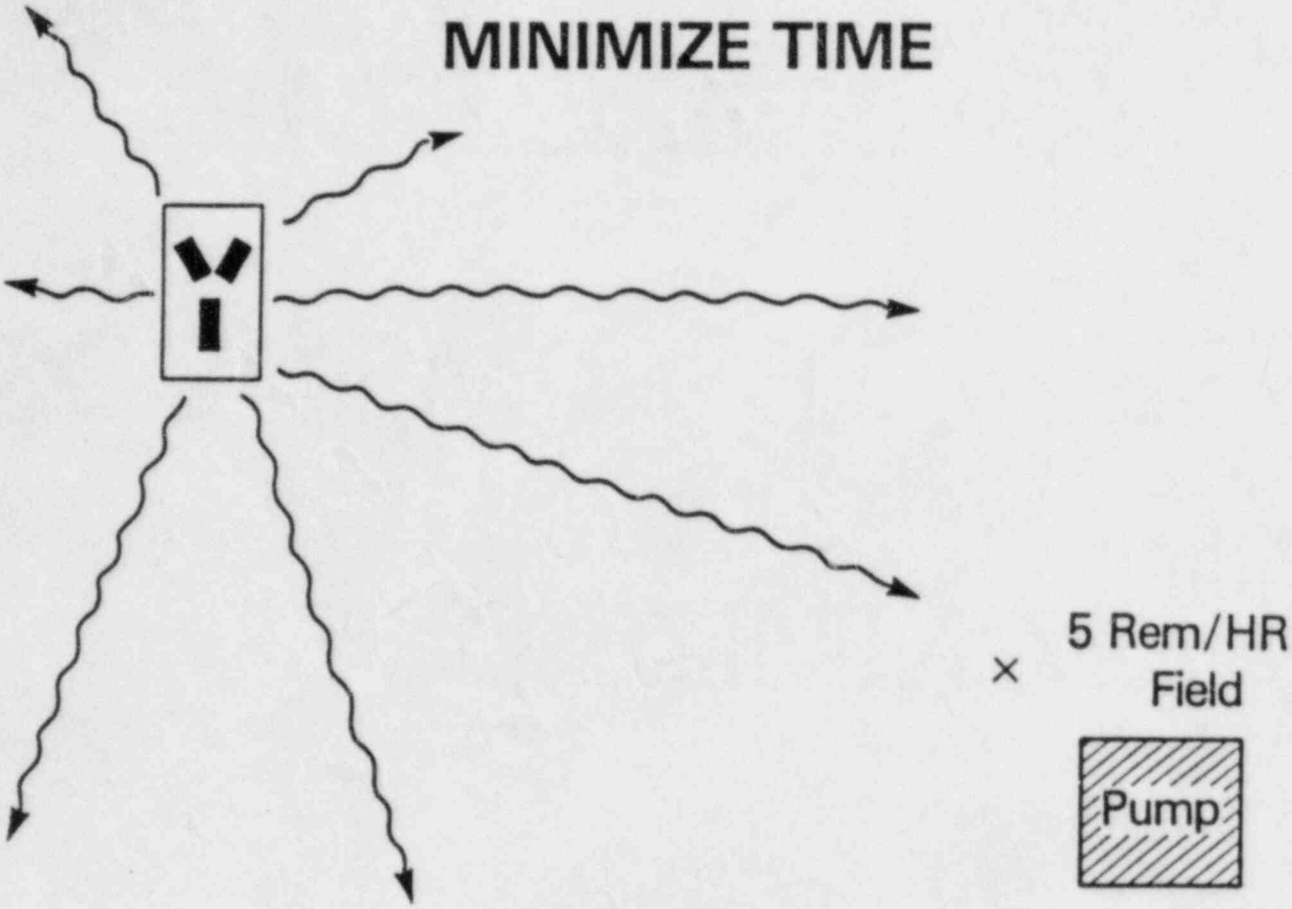
MINIMIZE TIME

DOSE RATE × TIME = DOSE

MINIMIZE DOSE

The length of time spent in a radiation field is directly related to the dose received.

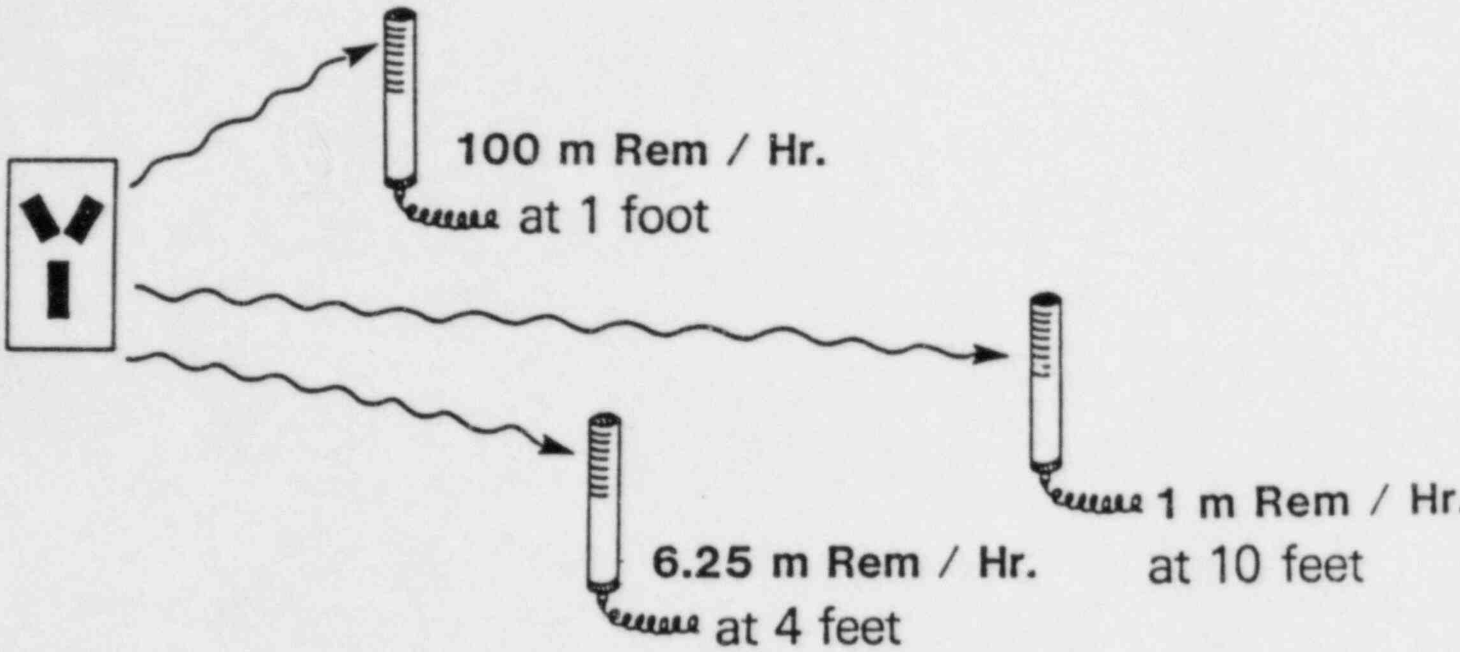
MINIMIZE TIME



In a five Rem/Hr field an individual would receive a dose of:

100 mRems in 1.2 min.
1.25 Rems in 15 min.
3 Rems in 36 min.
5 Rems in 60 min.

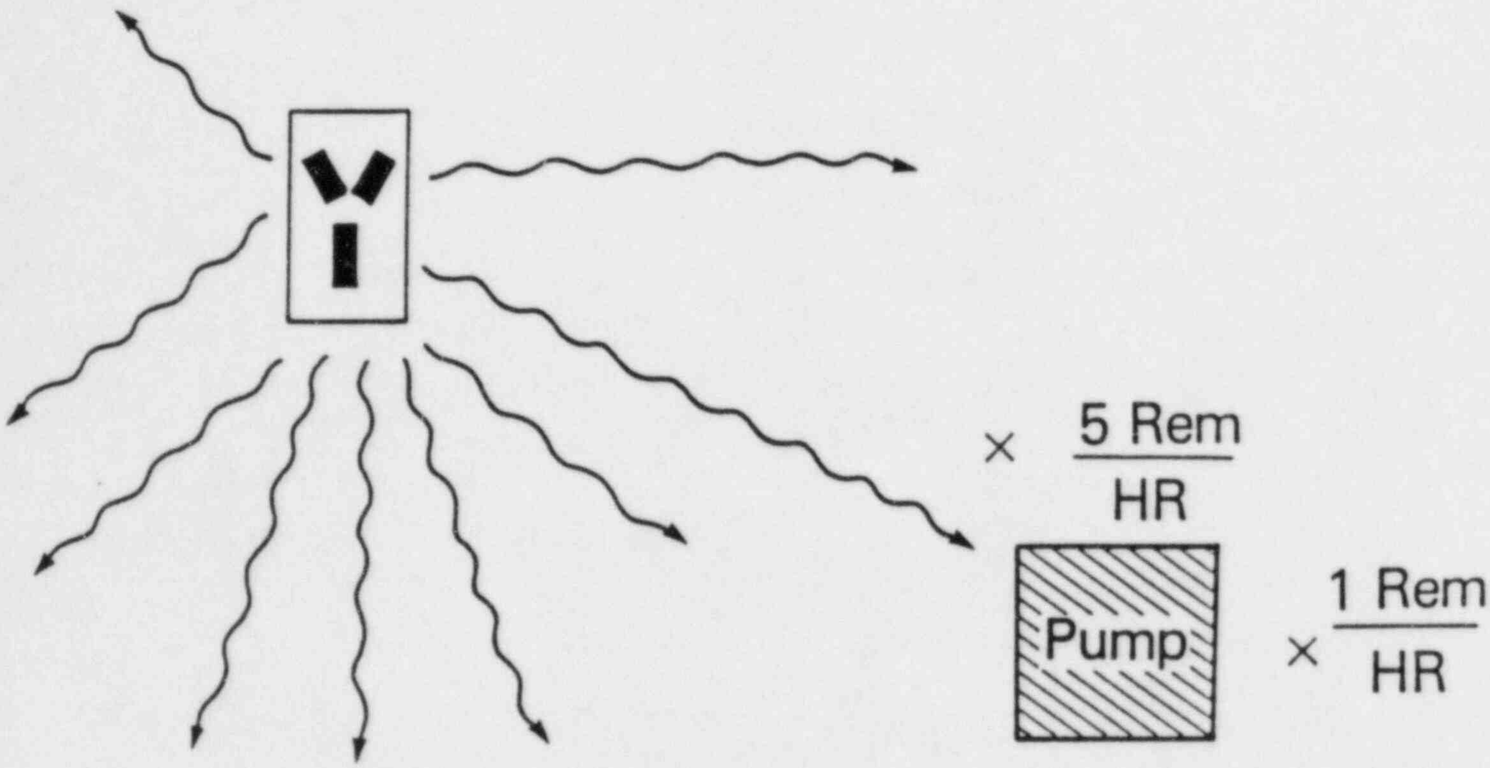
MAXIMIZE DISTANCE



MINIMIZE DOSE

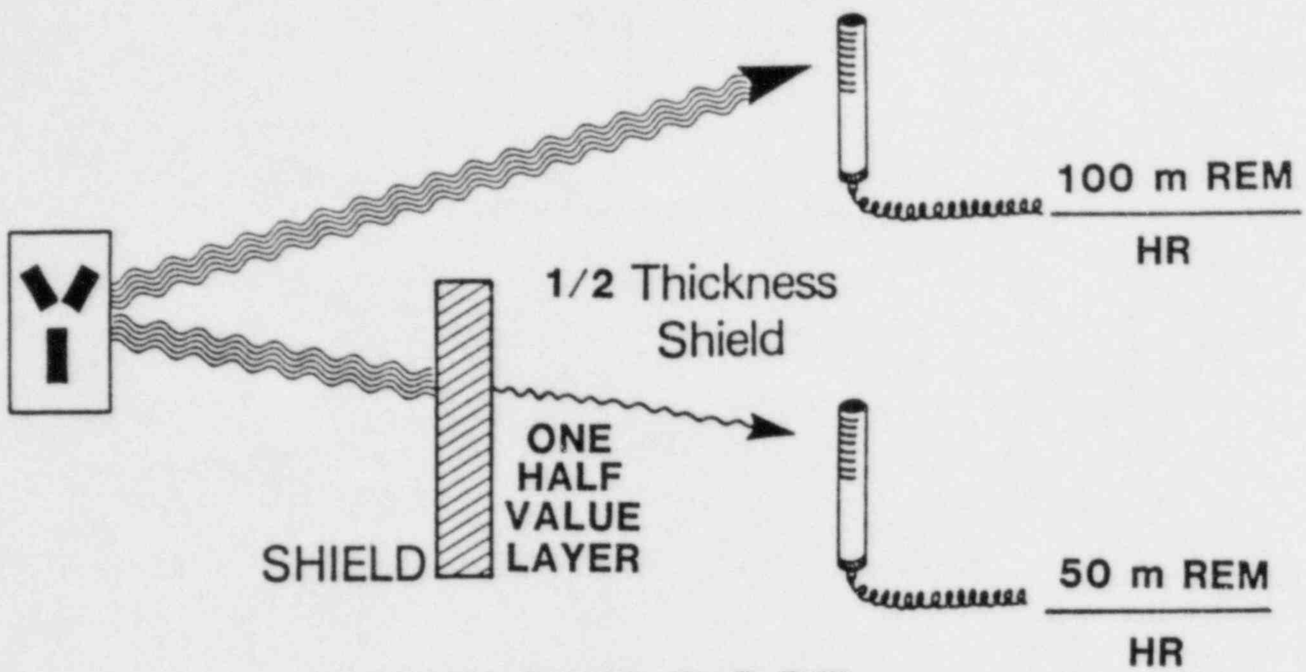
Many radiation sources are "point sources" (appear to come from one spot some distance away). The radiation dose from these sources can be significantly reduced by applying the protective measure of "distance" as demonstrated above.

MAXIMIZE DISTANCE



Moving a few feet further away from a source of radiation can significantly reduce the dose rate and significantly increase an individual's stay time in a radiation area.

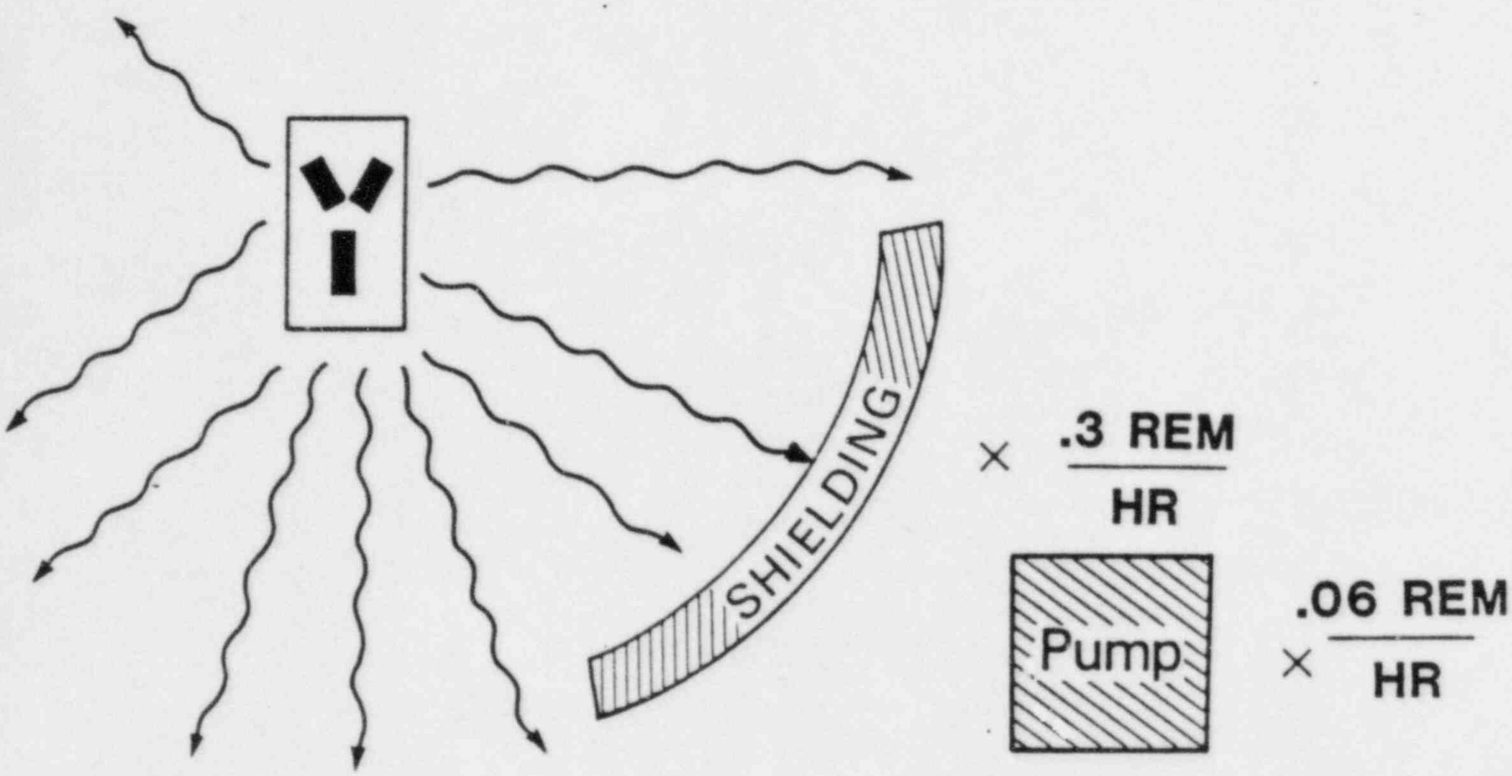
MAXIMIZE SHIELDING



MINIMIZE DOSE

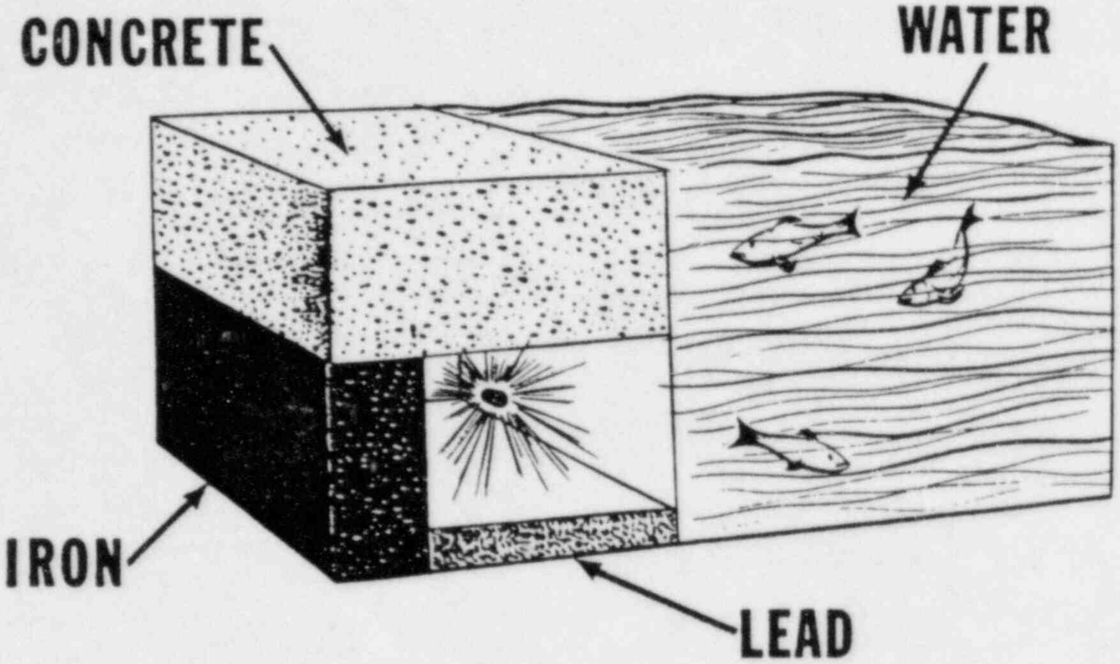
Shielding is another effective way to reduce radiation exposure. The example above shows that the installation of a one half-value layer (half-thickness) of shielding will reduce the dose rate by a factor of two at a set distance from the source of radiation.

MAXIMIZE USE OF SHIELDING



Installing several half-value layers of shielding can significantly lower radiation dose rates and allow much longer stay times than could otherwise be possible.

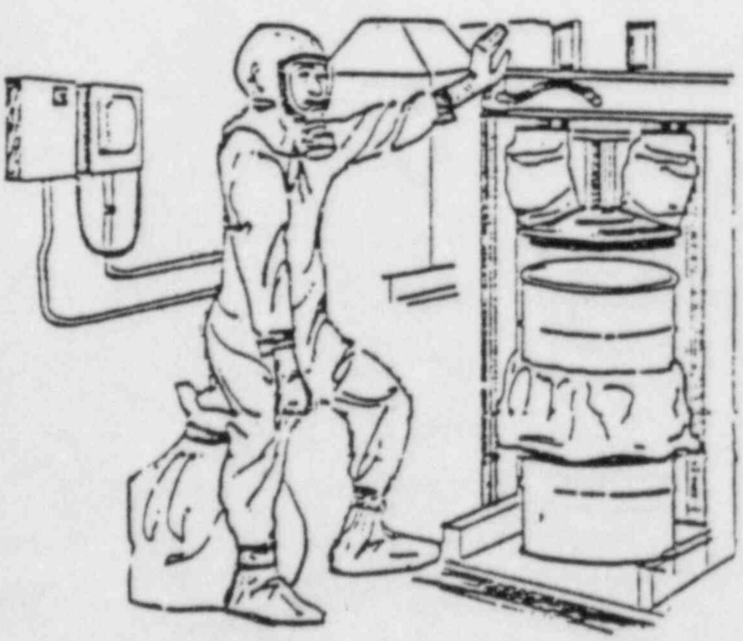
Relative Efficiency Of Various Shielding Materials



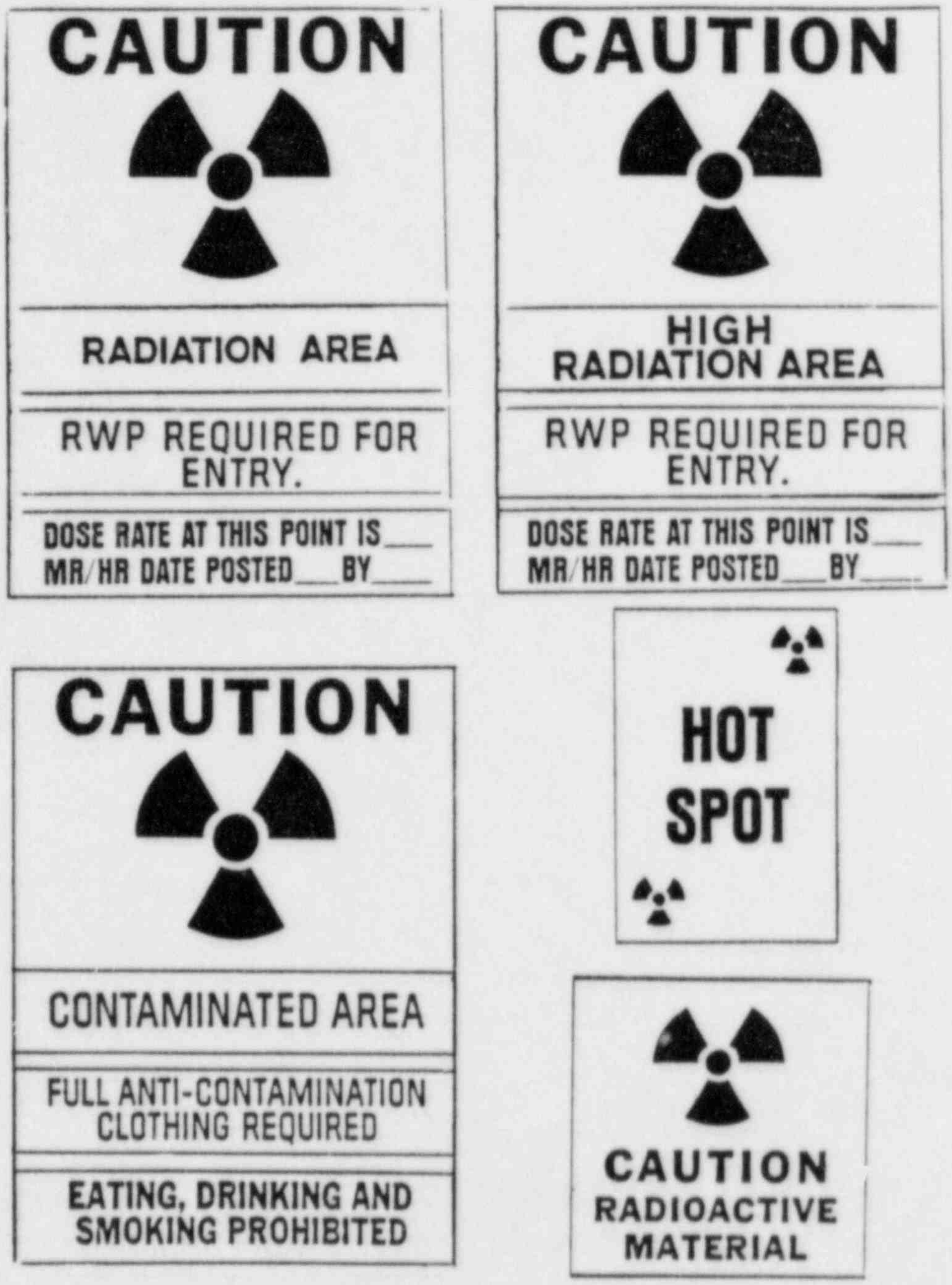
Materials differ greatly in their ability to shield (absorb radiation). The example above shows the relative efficiency of four common shield materials for gamma radiation.

PROTECTION AGAINST CONTAMINATION

1. Minimize Leakage
2. Frequent Surveys
3. Good Housekeeping
4. Access Control
5. Protective Clothing
6. Respiratory Protection
7. Bioassays



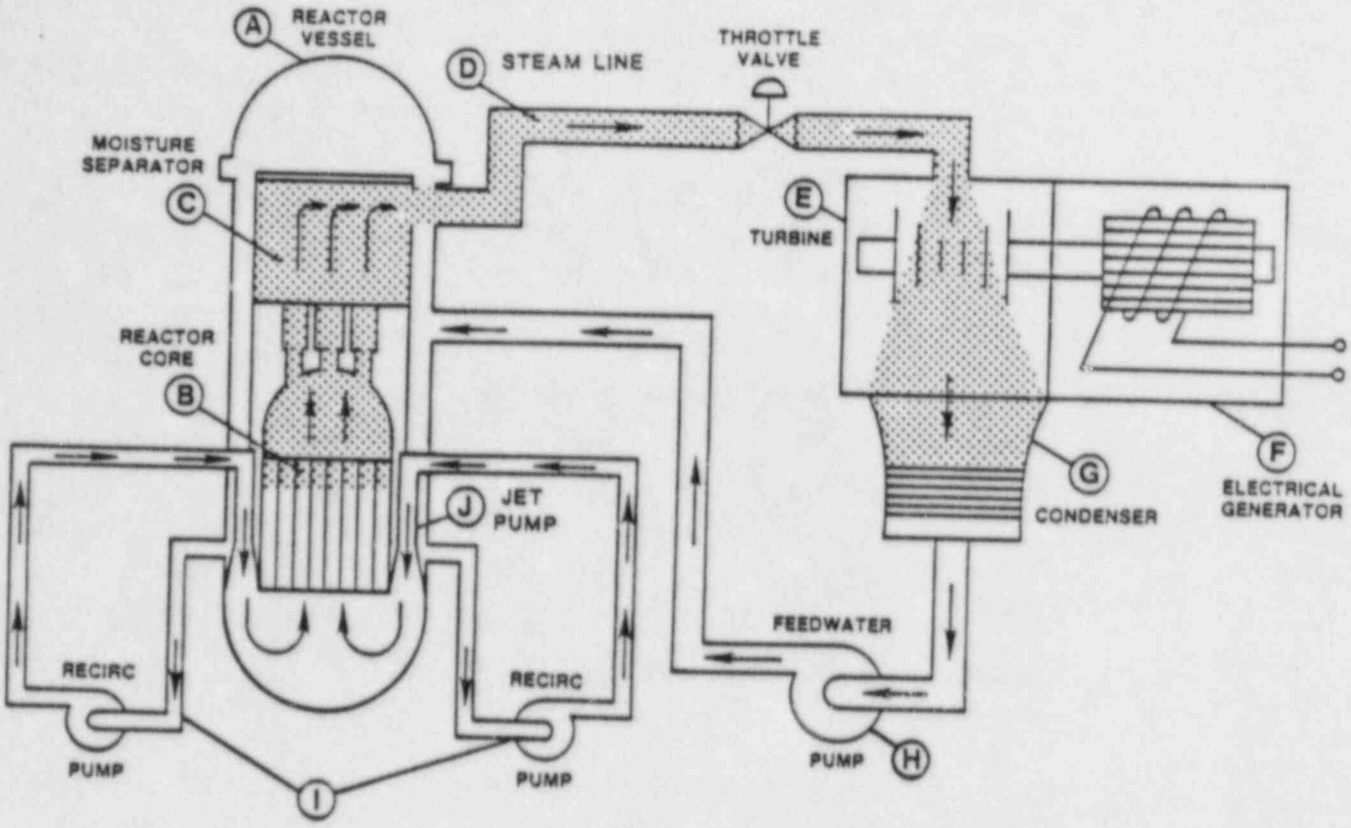
The protective measures listed above are used to prevent, detect or contain radioactive contamination.



Some commonly used radiation/contamination warning signs and labels are shown above. The international symbol for radioactive material is a magenta or purple three bladed design on a yellow background.

BWR SYSTEMS

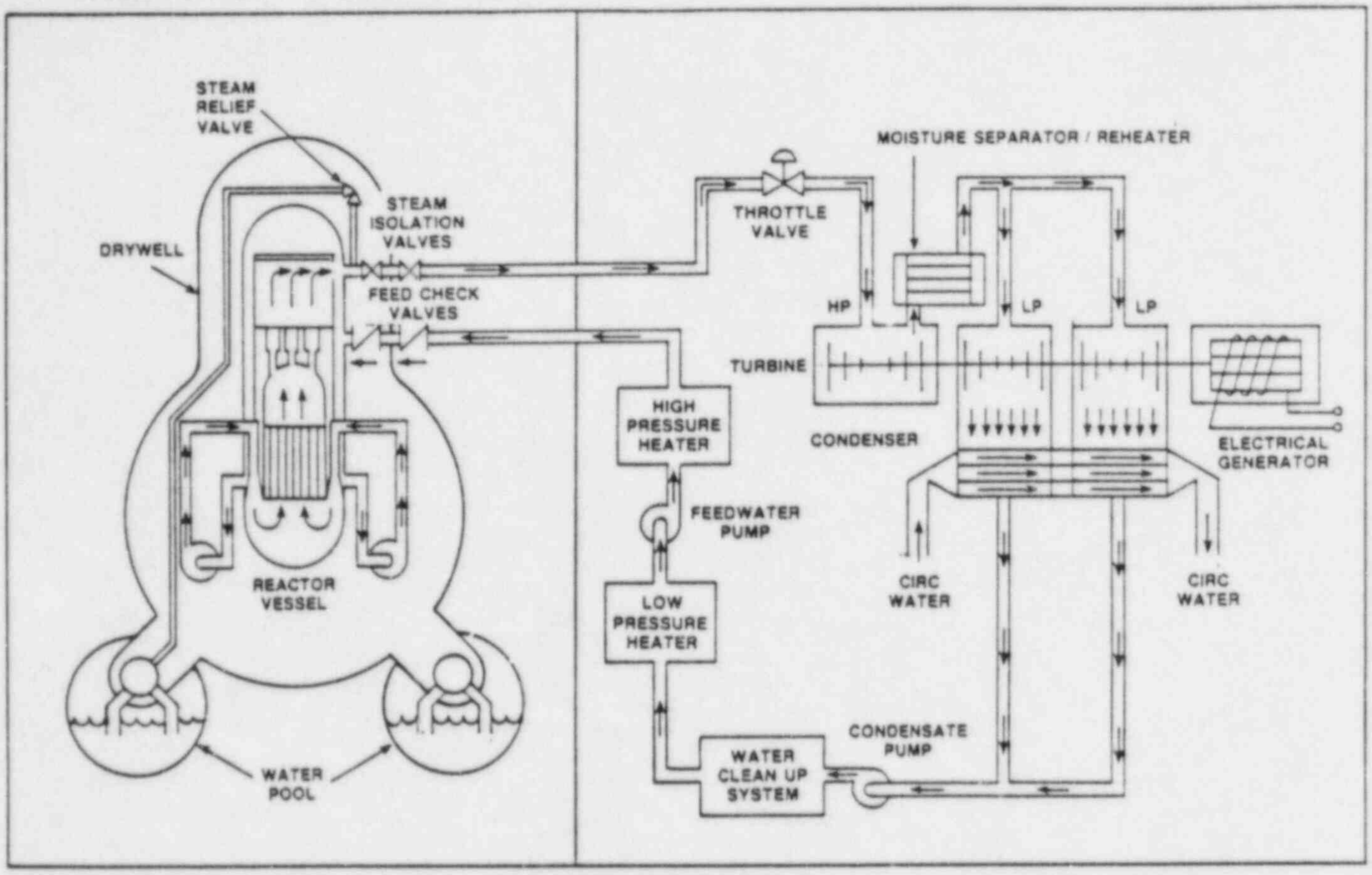
This section discusses the purposes of the major systems and components of Boiling Water Reactors.



BOILING WATER REACTOR PLANT
(BWR)

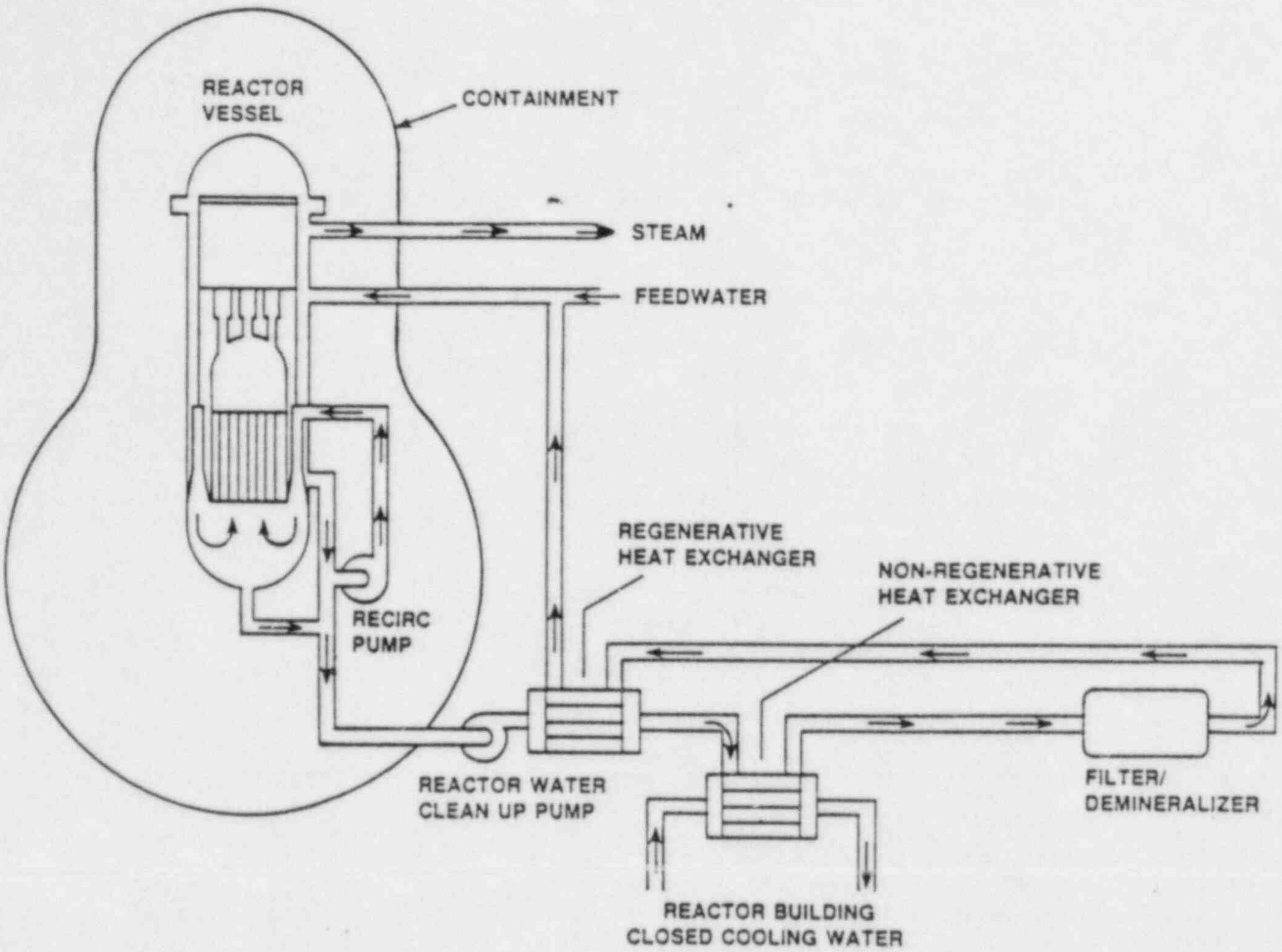
Inside the Boiling Water Reactor Vessel (A) a steam-water mixture is produced as coolant water removes heat from the reactor core (B). The steam-water mixtures moves upward and into the moisture separator (C), where water droplets are removed before the steam is allowed to enter the steam line (D). The steam turns the turbine (E), which turns the electrical generator (F). The steam than enters the condenser (G), where it is condensed into water. The water is pumped by the feedwater pump (H) from the condenser back into the reactor vessel. The recirculation pump (I) and jet pump (J) allow the operator to vary the coolant flow rate (and thus change reactor power).

REACTOR BUILDING TURBINE BUILDING



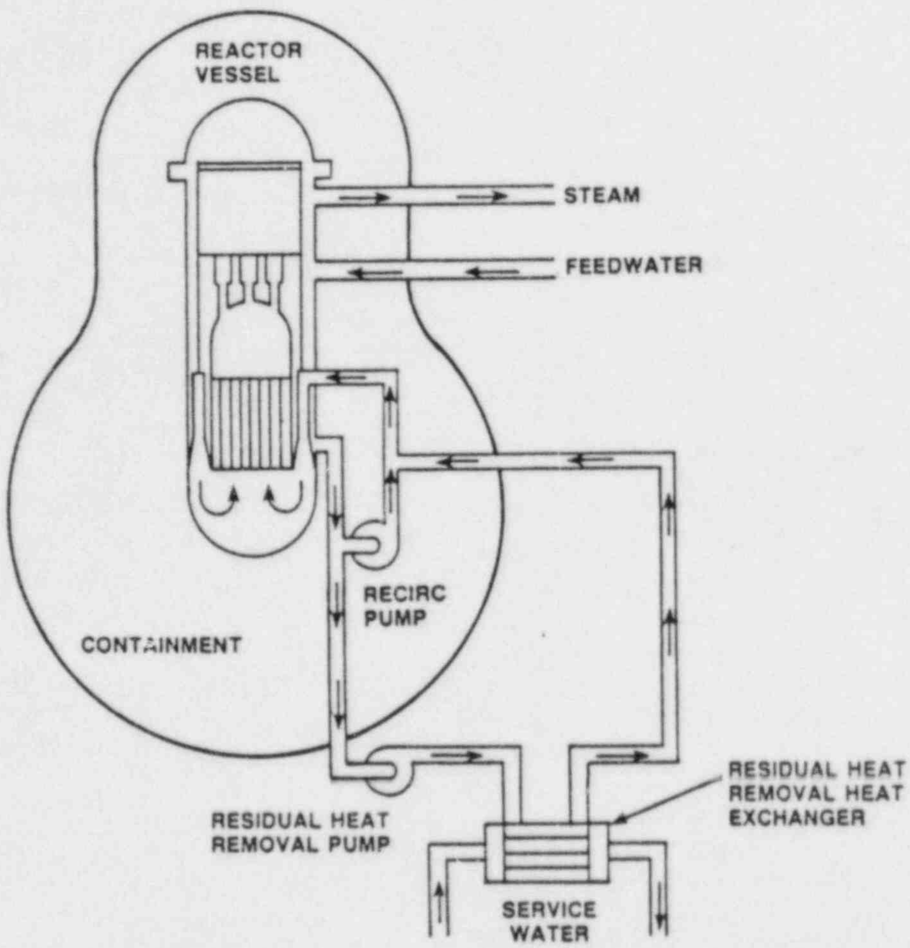
A boiling water reactor's coolant system consists of the reactor vessel, steam turbines, condensers, condensate and feedwater pumps, the reactor's recirc system and the pipes linking these components.

BWR REACTOR WATER CLEAN UP SYSTEM



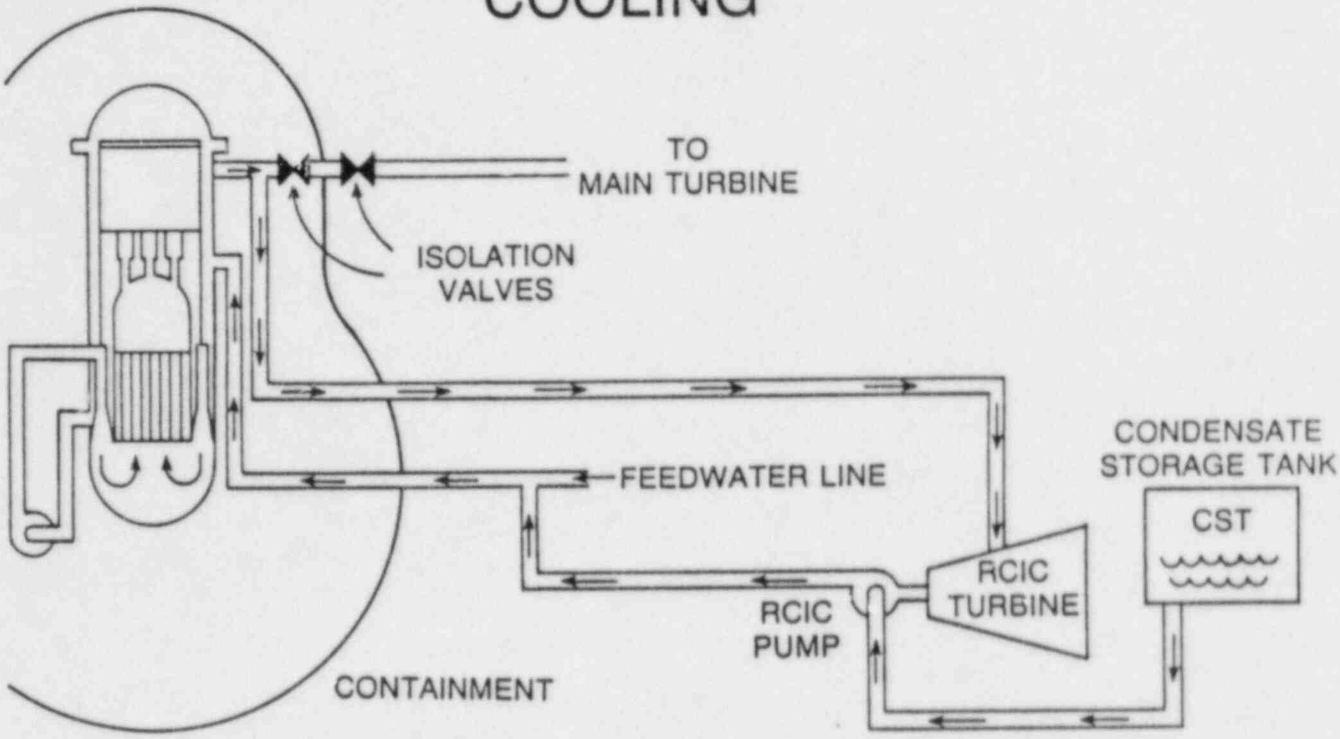
The reactor water cleanup system provides a means for the removal of corrosion and wear products and chemical impurities from the recirc system and the bottom of the BWR vessel.

BWR RESIDUAL HEAT REMOVAL SYSTEM (SHUTDOWN COOLING)



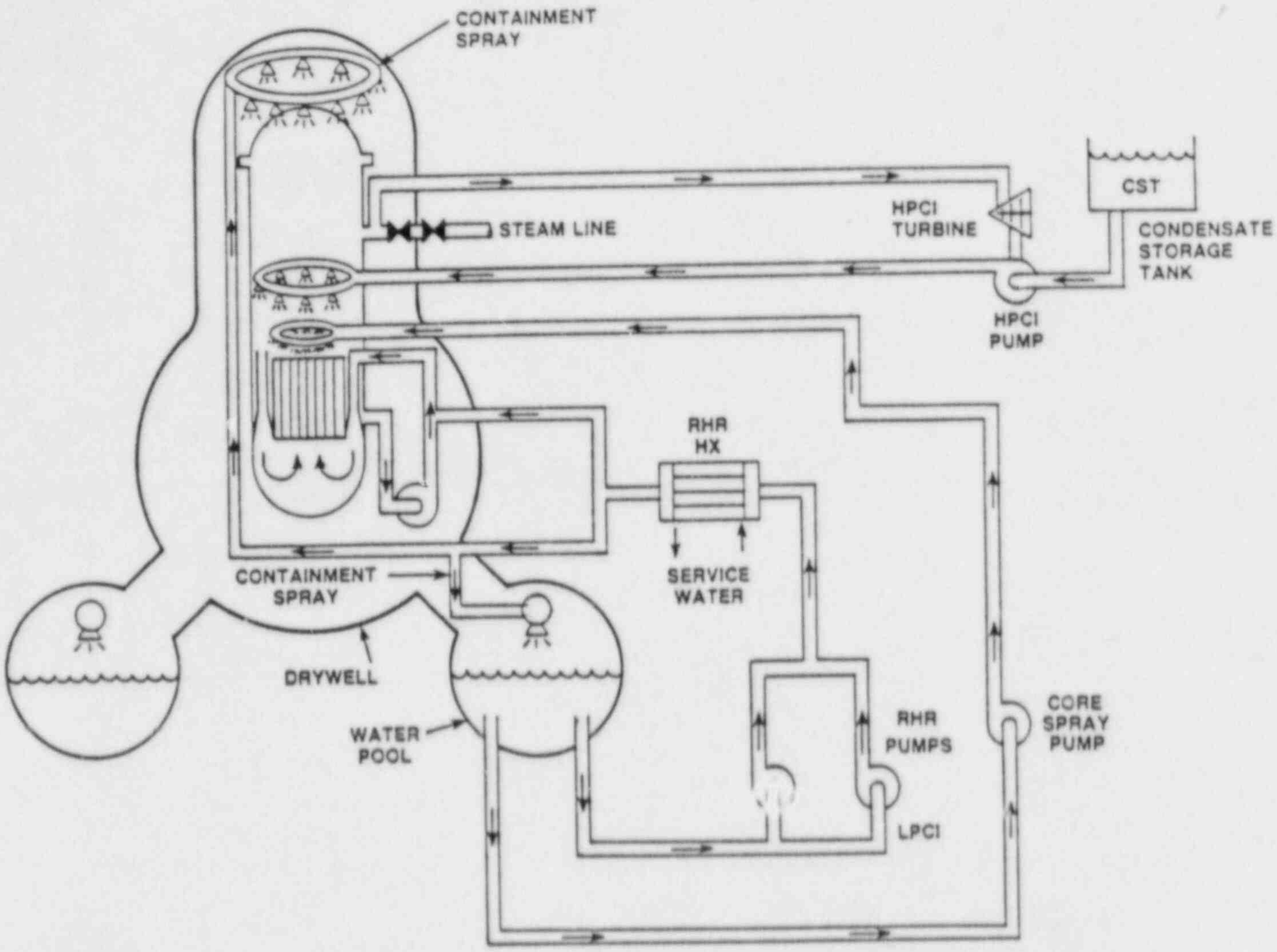
The BWR's Residual Heat Removal System is used during reactor shutdown to transfer the core's decay heat away from the fuel to the environment.

BWR
REACTOR CORE ISOLATION COOLING



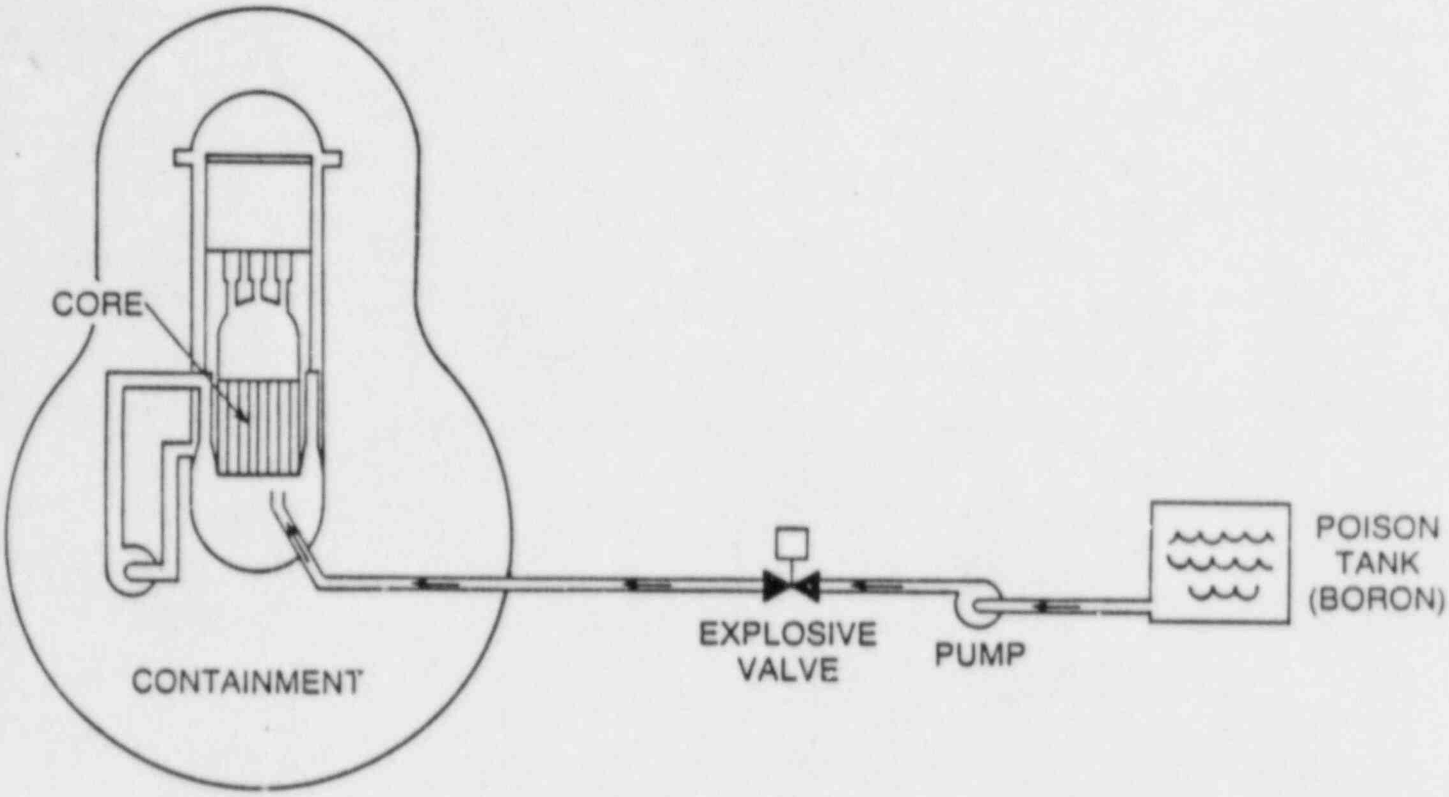
The BWR's Reactor Core Isolation Cooling System is used to supply water for decay heat removal when the normal source of coolant (feedwater) is not available.

BWR EMERGENCY COOLING SYSTEMS

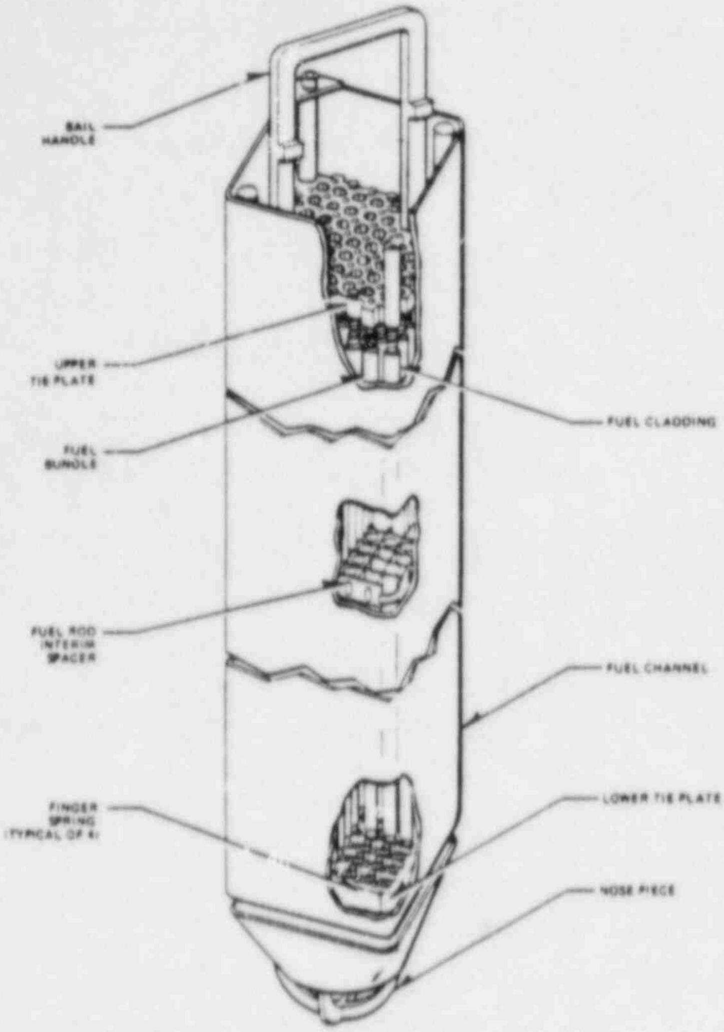


The BWR Emergency Cooling Systems are designed to supply water to cool the reactor core and the containment in the event of a loss of coolant accident (LOCA).

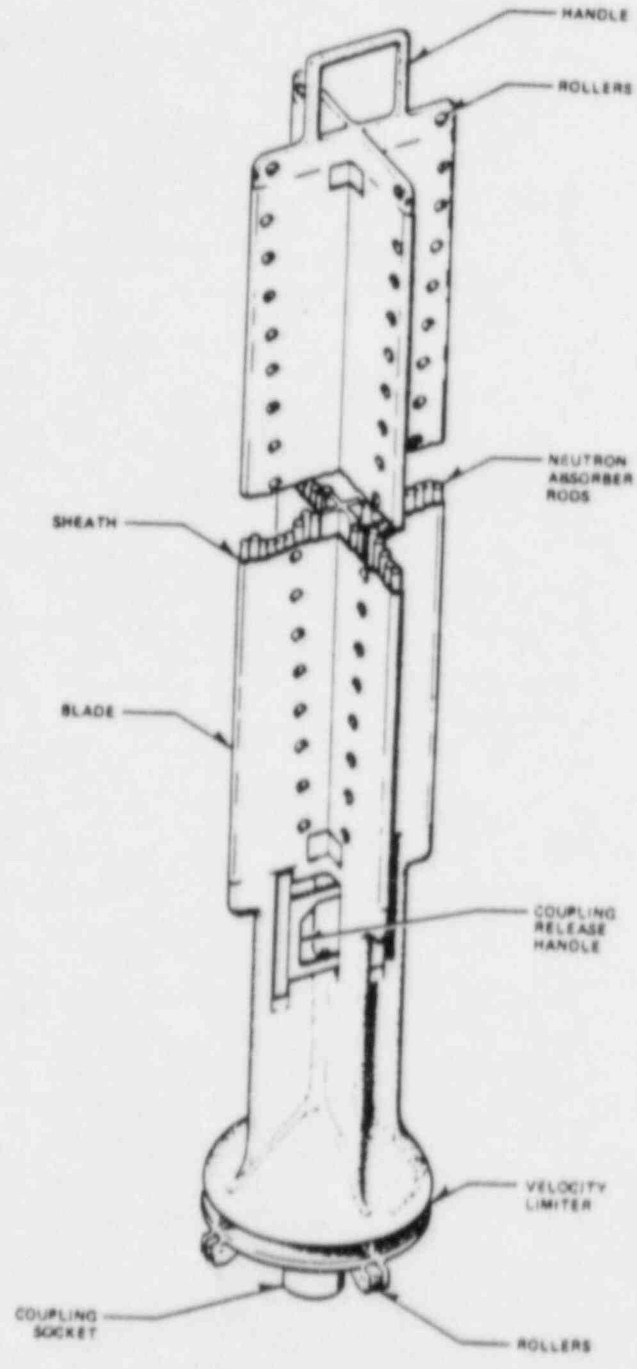
BWR STANDBY LIQUID CONTROL SYSTEM



The BWR's Standby Liquid Control System provides a method to stop the fission process and maintain the reactor in a shutdown condition even if there is no control rod movement.



GENERAL ELECTRIC

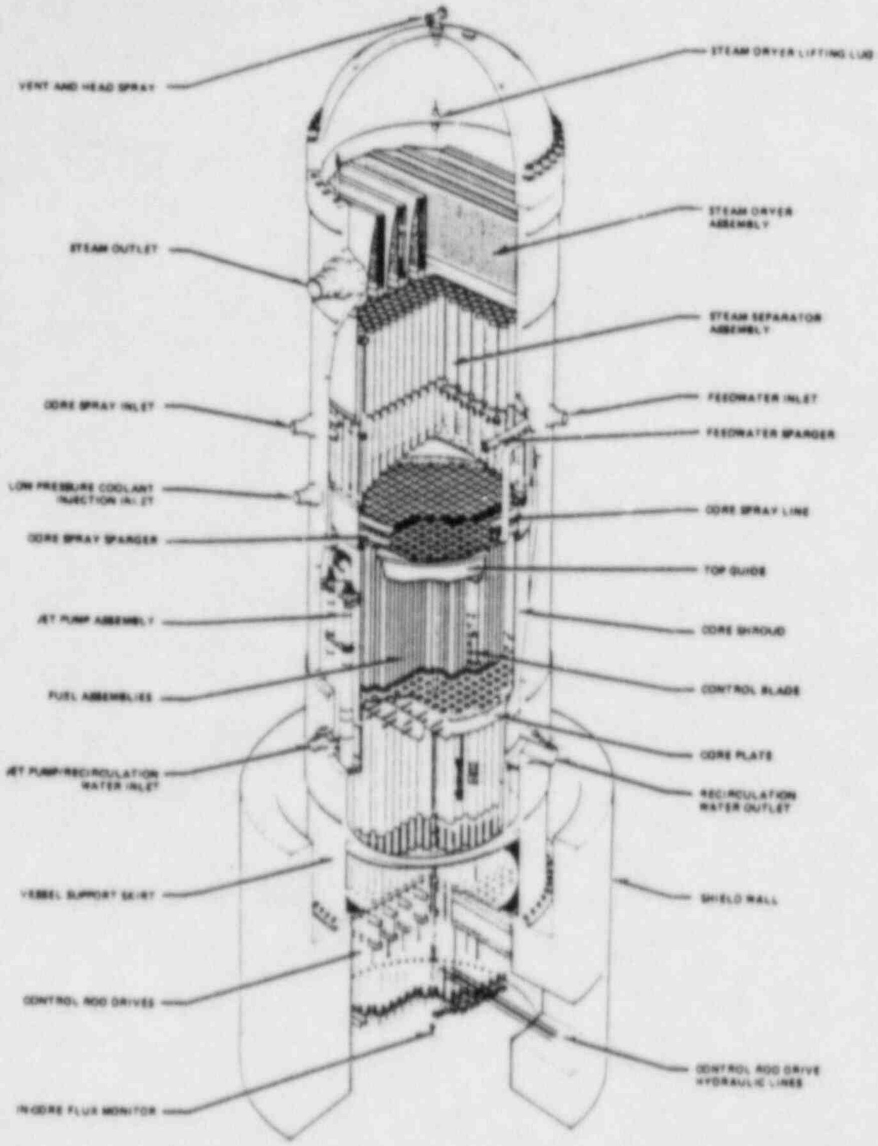


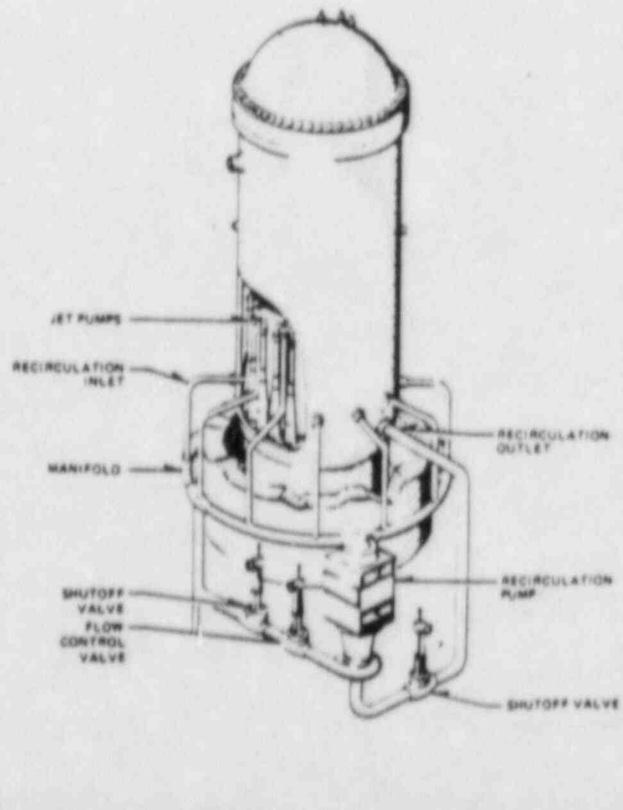
These cutaway drawings show the major components of a BWR fuel assembly and control blade (rod).

BWR/6

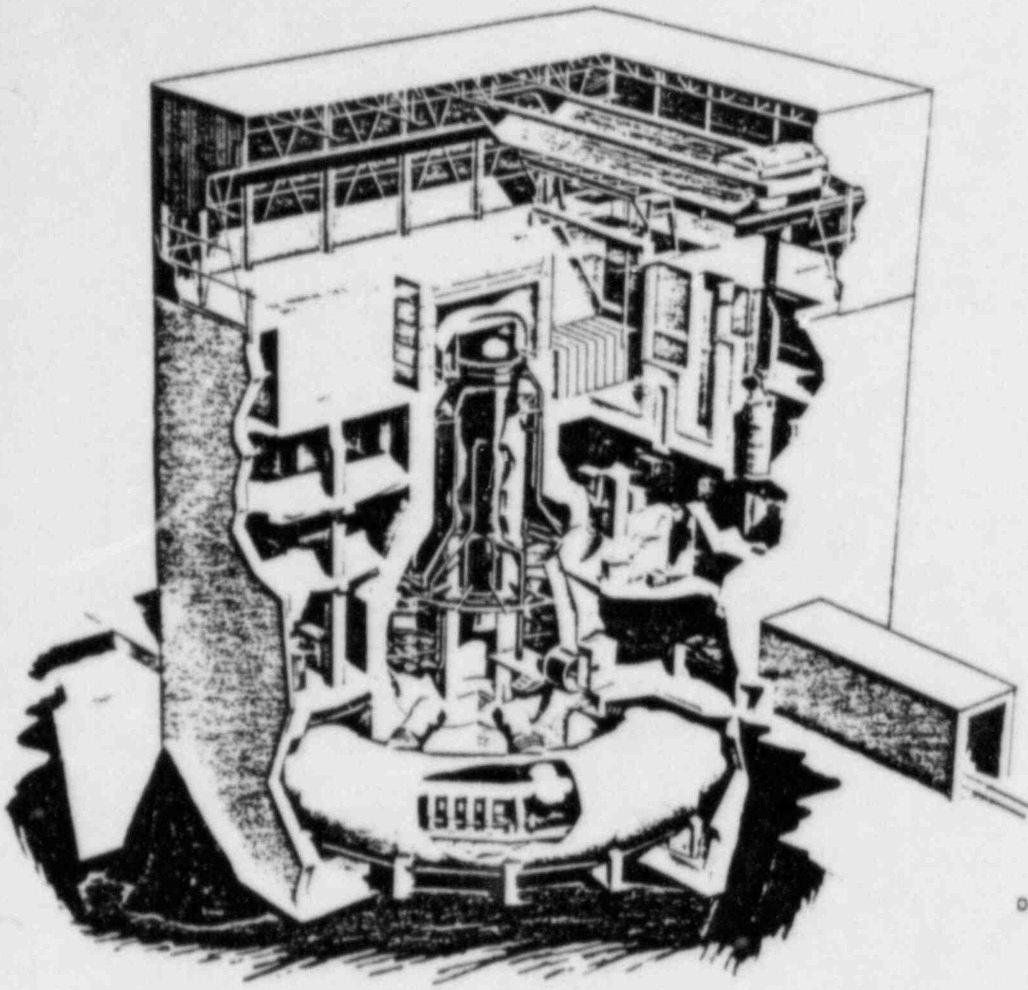
REACTOR ASSEMBLY

GENERAL ELECTRIC



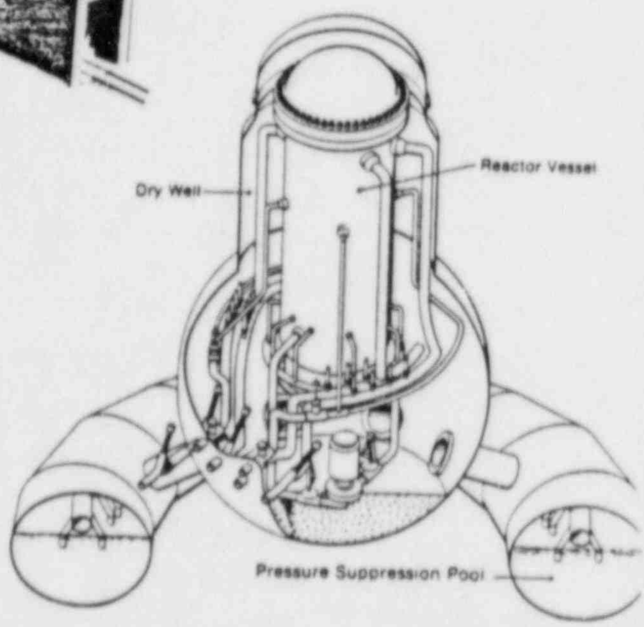


These cutaway drawings show the major components of a BWR's reactor vessel and recirculation system.

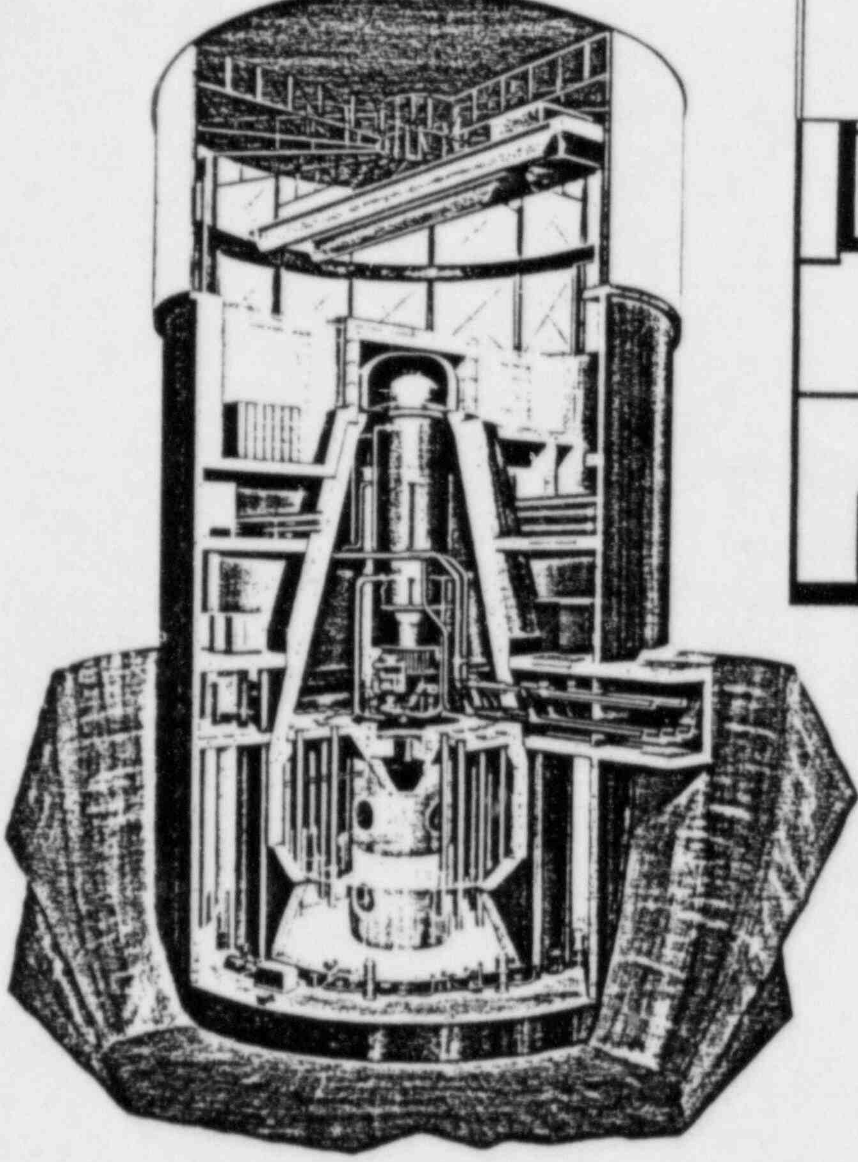


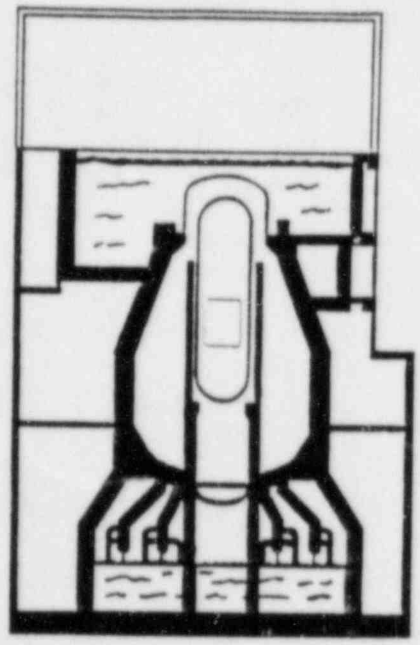
DRYWELL TORUS

GENERAL ELECTRIC



These drawings show the layout and major components of a Mark I (Drywell - Torus) Containment.

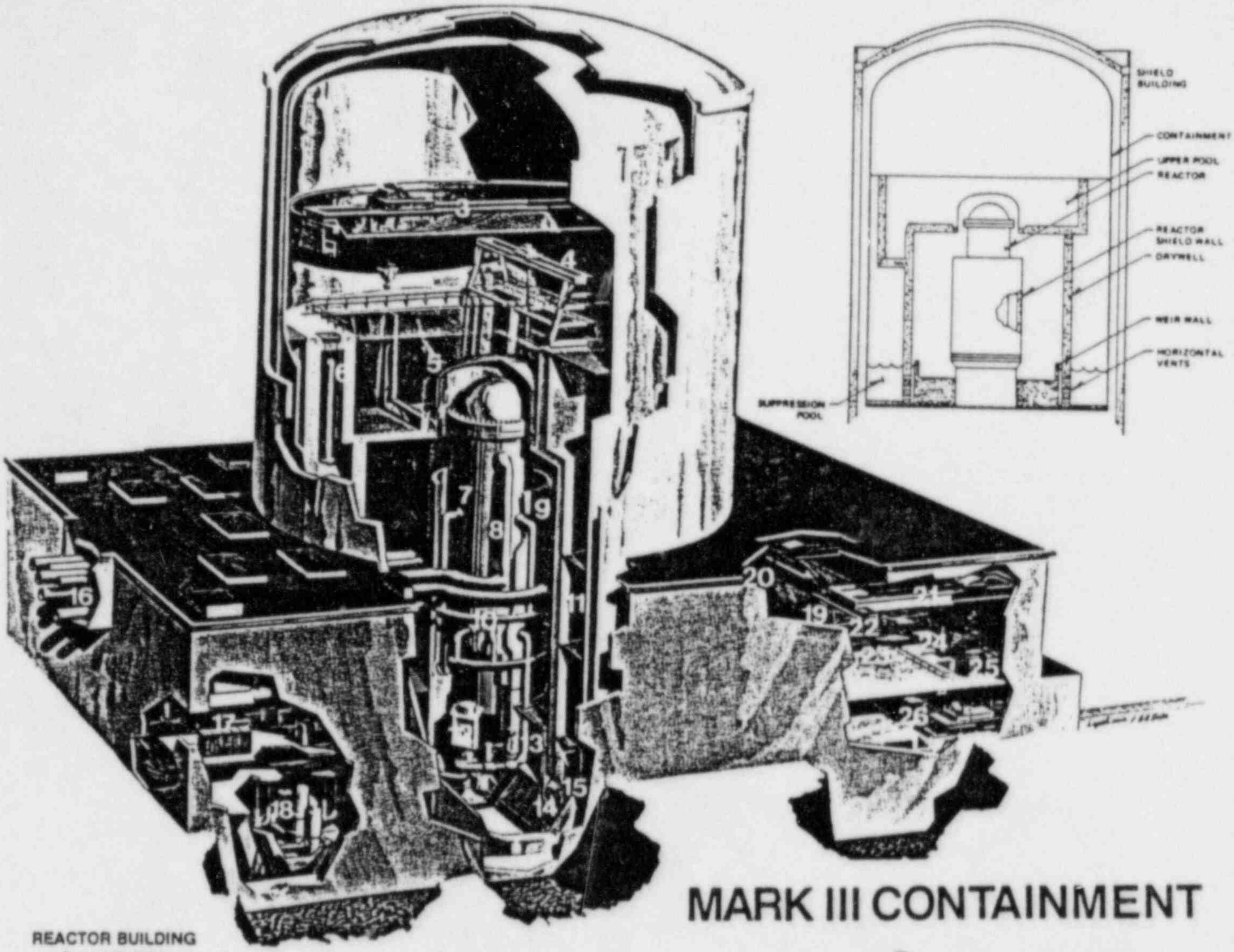




BWR CONCRETE CONTAINMENT

GENERAL ELECTRIC

These drawings show the layout and major components of a Mark II Containment.



MARK III CONTAINMENT

GENERAL ELECTRIC

REACTOR BUILDING

1. Shield Building
2. Free-Standing Steel Containment
3. Polar Crane
4. Refueling Platform
5. Upper Pool
6. Reactor Water Cleanup
7. Reactor Vessel
8. Steam Line
9. Shield Wall
10. Feedwater Line
11. Drywell
12. Recirculation Loop
13. Weir Wall
14. Horizontal Vent
15. Suppression Pool

AUXILIARY BUILDING

16. Steam Line Tunnel
17. Motor Control Centers
18. RHR System

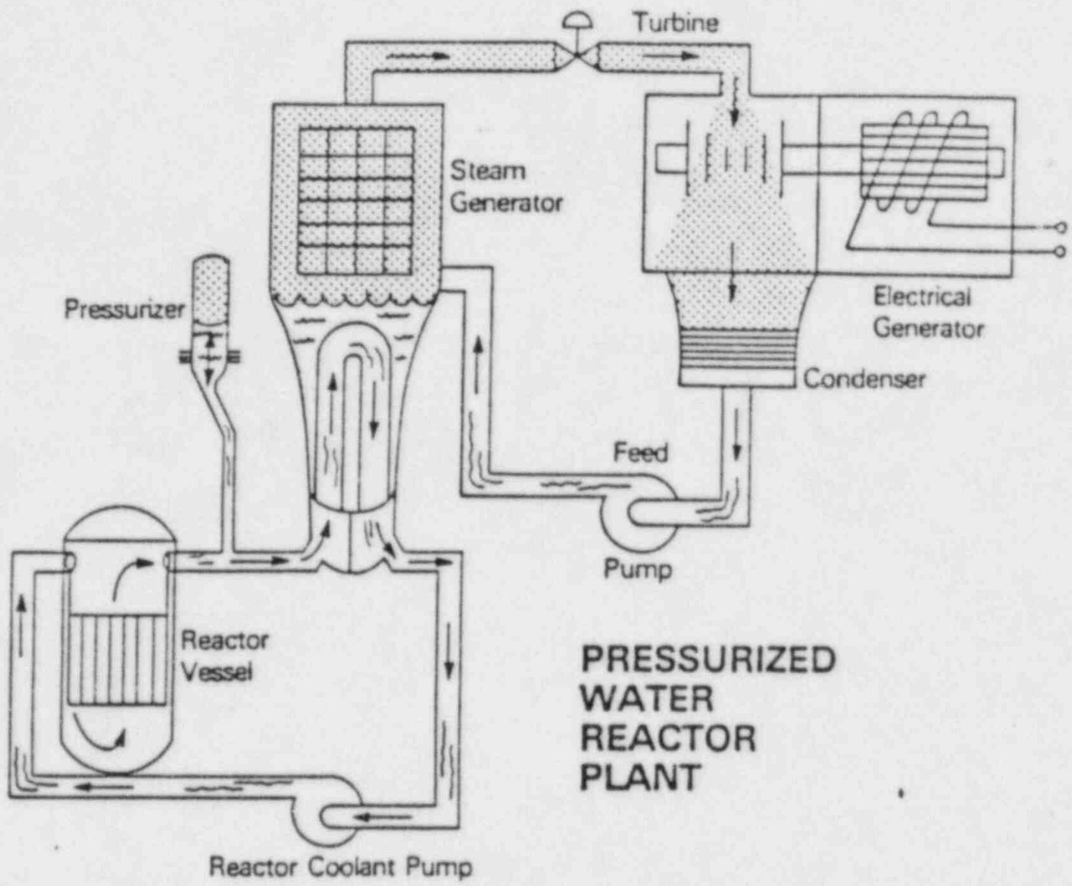
FUEL BUILDING

19. Fuel Transfer Bridge
20. Fuel Transfer Tube
21. Cask Handling Crane
22. Fuel Storage Pool
23. New Fuel Vault
24. Cask Loading Pool
25. Spent Fuel Shipping Cask
26. Fuel Cask Skid

These drawings show the layout and major components of a Mark III Containment.

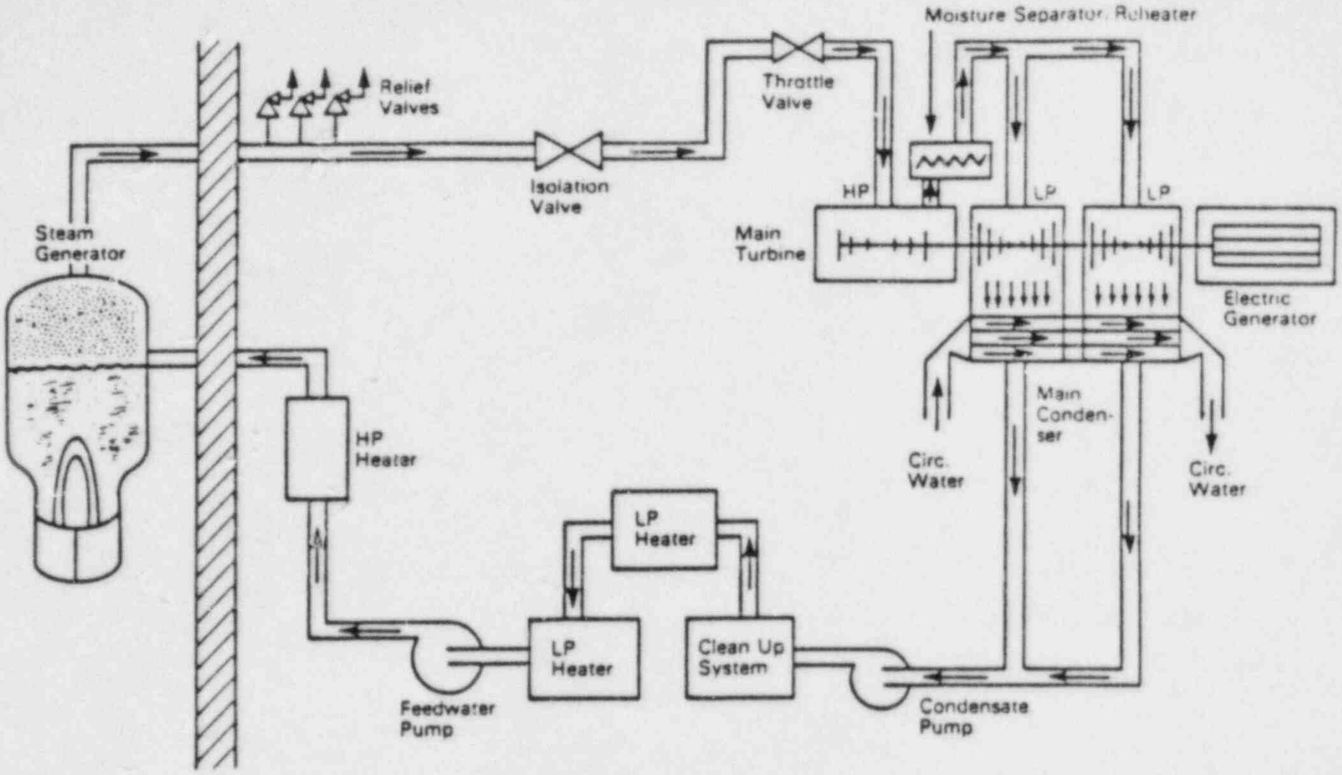
PWR SYSTEMS

This section discusses the purposes of the major systems and components of Pressurized Water Reactors.



PRESSURIZED
WATER
REACTOR
PLANT

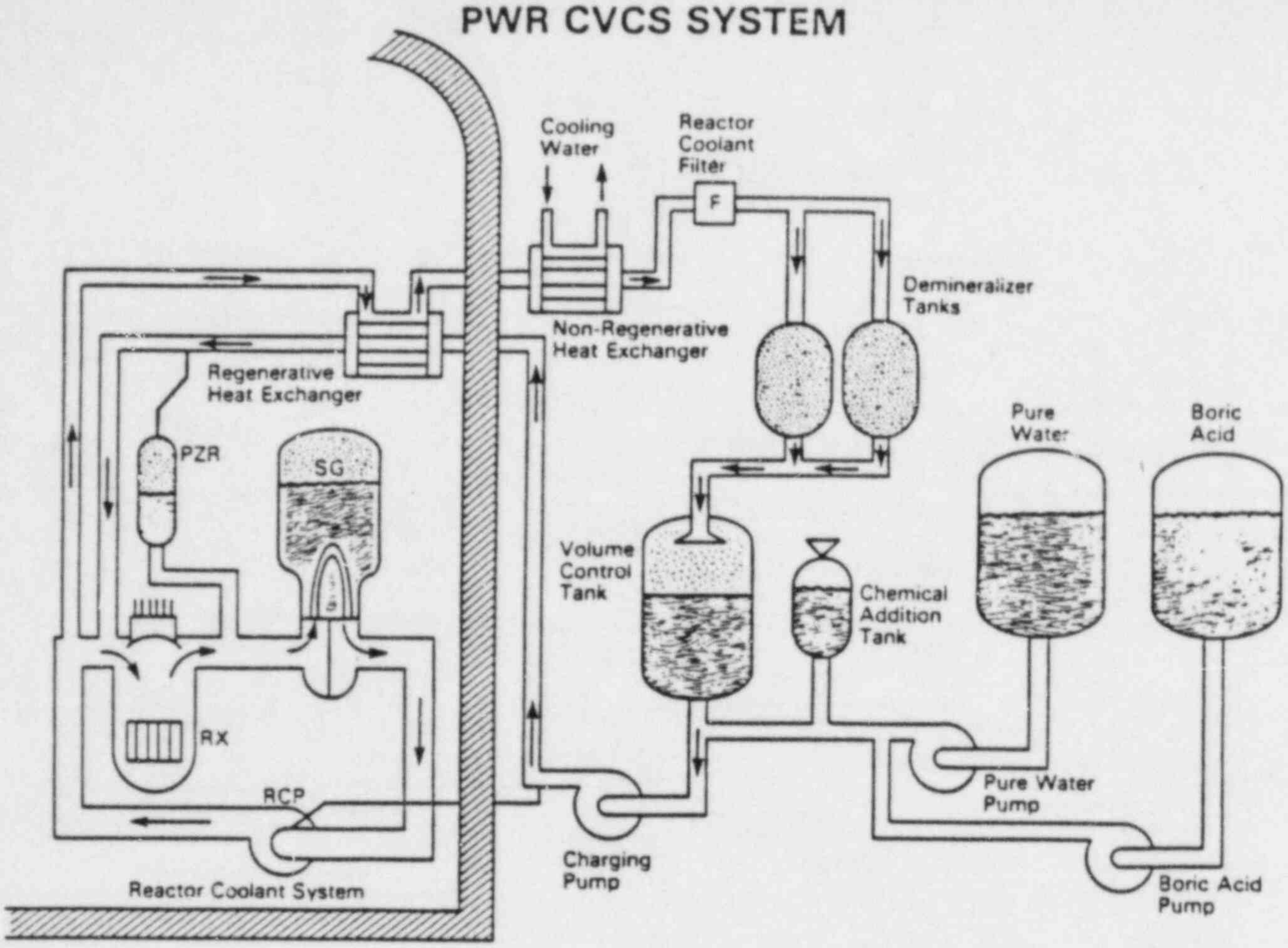
The pressurized water nuclear steam supply system consists of two closed loop water systems. The primary system transfers heated water from the reactor vessel through the steam generator tubes (where heat is removed) to the reactor coolant pump, which forces the water back into the reactor vessel to remove more heat. The secondary system is the steam that exits the steam generator, turns the turbine and electrical generator, and enters the condenser. The secondary system also includes the condensed water pumped by the feedwater pump back to the steam generator.



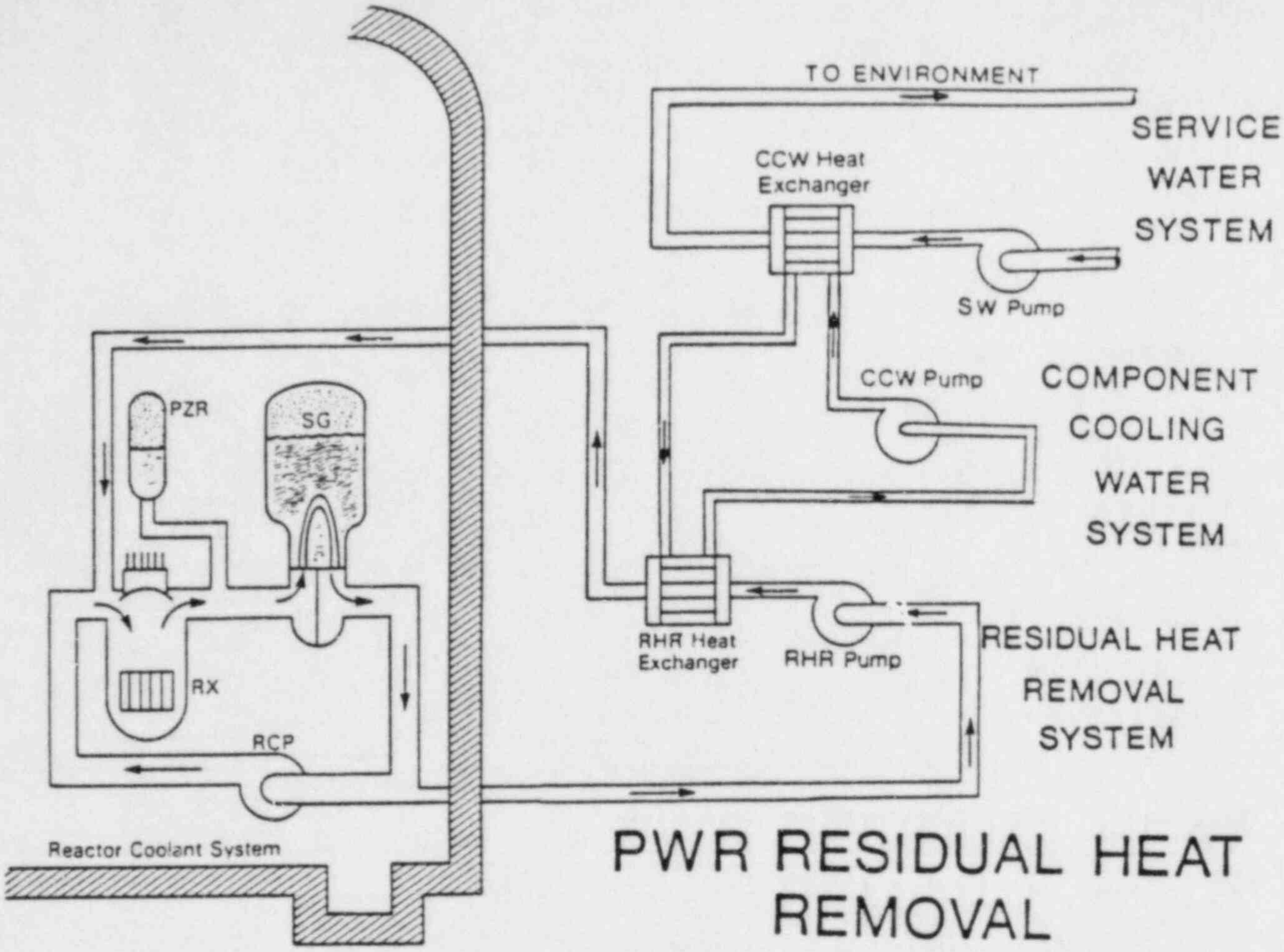
PWR SECONDARY SYSTEM (STEAM/CONDENSATE/FEEDWATER)

A pressurized water reactor's secondary system consists of the steam, condensate and feedwater systems. Since physically separate from the contaminated primary system (by the steam generator tubes) the secondary system water should contain little or no radioactive material.

PWR CVCS SYSTEM



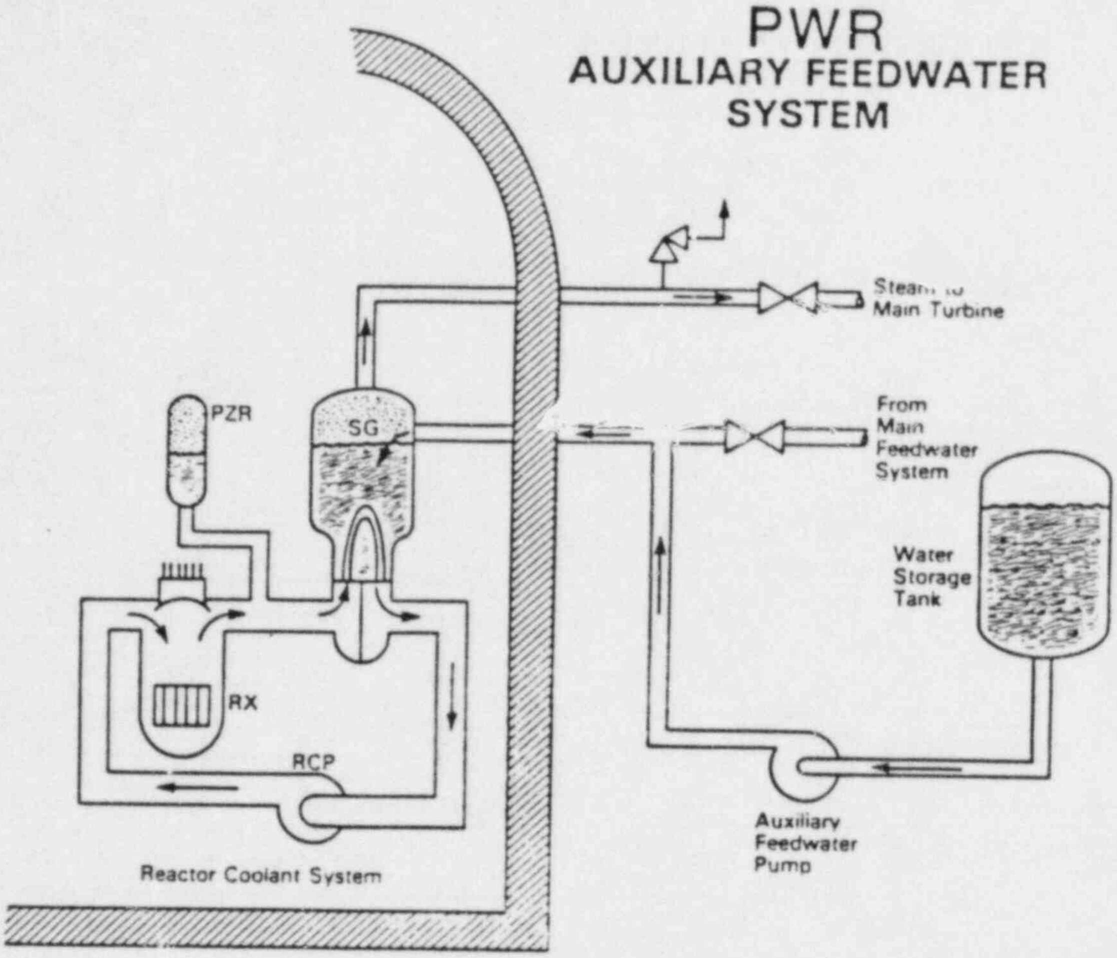
The Chemical and Volume Control System provides filtration, chemical cleanup, chemical addition and waste removal for the PWR's reactor coolant system. The CVCS also responds to demands for volume changes in the reactor coolant system due to temperature changes and minor leakage.



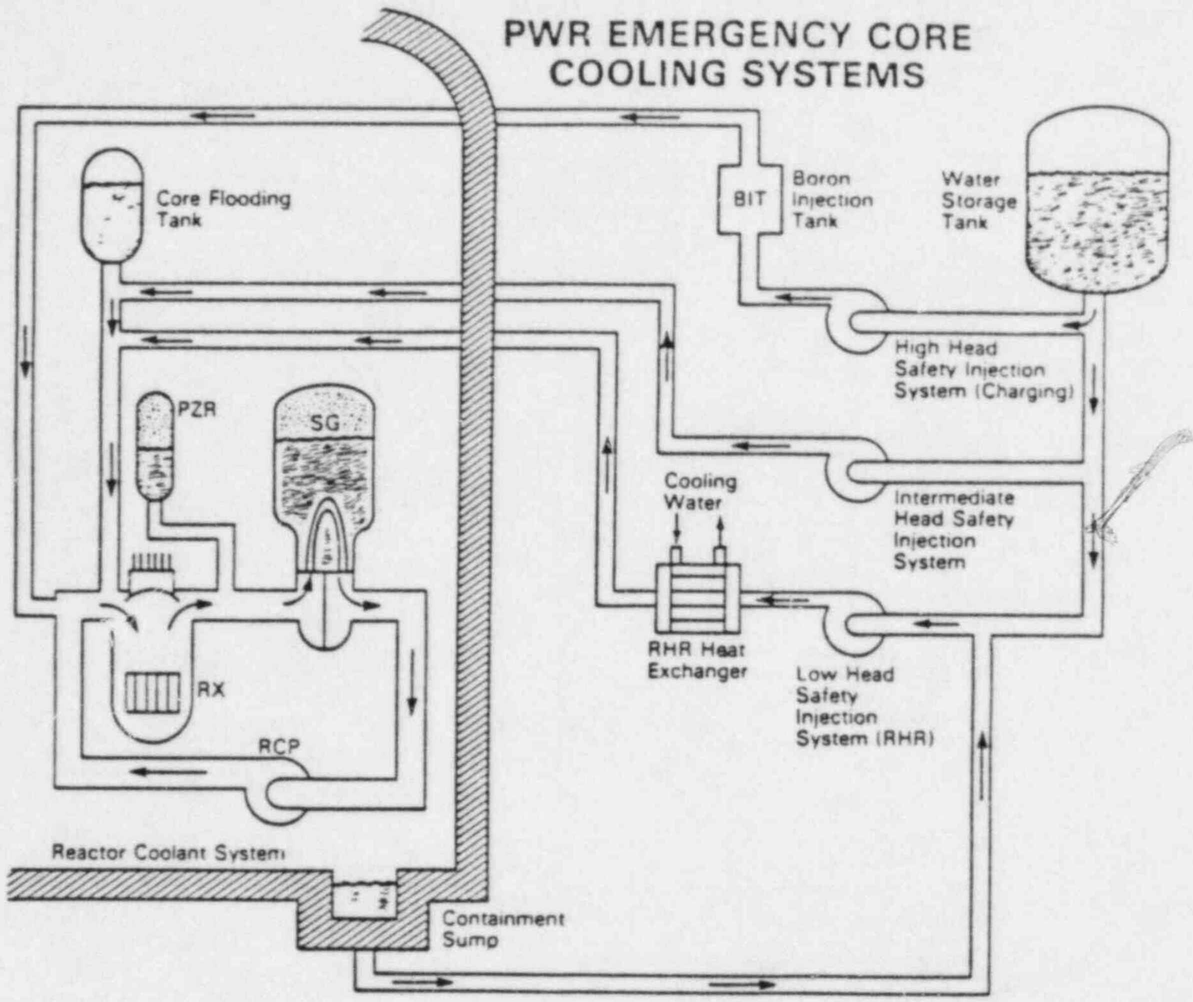
PWR RESIDUAL HEAT REMOVAL

The Residual Heat Removal System (RHR) provides a heat exchange method for the transfer of decay heat from the reactor core to the environment. RHR is only operated after the reactor fission process has been stopped and the reactor coolant system has been partially cooled and depressurized.

PWR AUXILIARY FEEDWATER SYSTEM

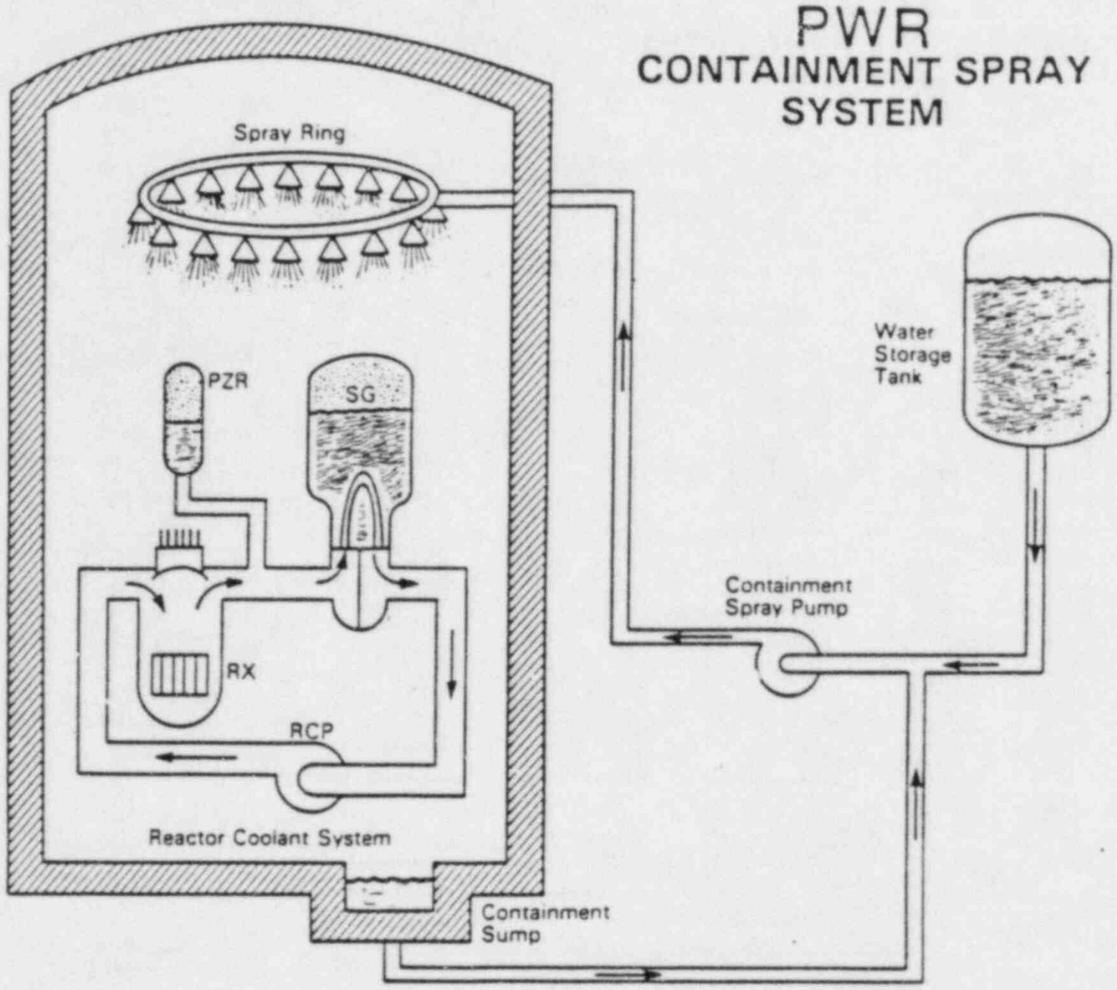


The Auxiliary Feedwater System provides feedwater from a storage tank to the steam generators during reactor startup and shutdown. Aux Feed can remove the reactor's decay heat and (as steam) transfer that energy to the main condenser or out steam relief valves to the environment.

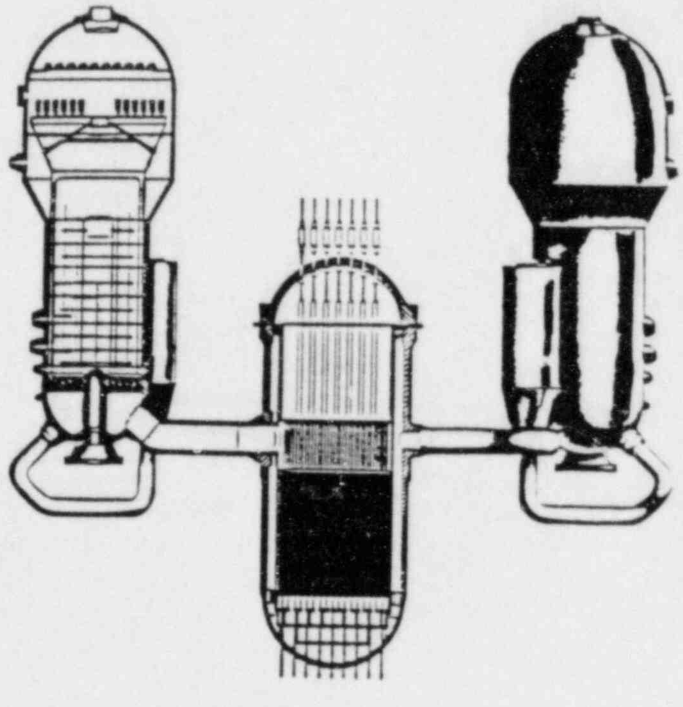


In an emergency, a PWR might need additional neutron poisons (to insure a safe reactor shutdown) or additional water (to makeup for rapid changes in volume due to leaks and decreasing reactor coolant temperature). The PWR's emergency safety systems must be capable of injecting Boric Acid and a large quantity of water to the reactor under a wide variety of emergency conditions.

PWR
CONTAINMENT SPRAY SYSTEM

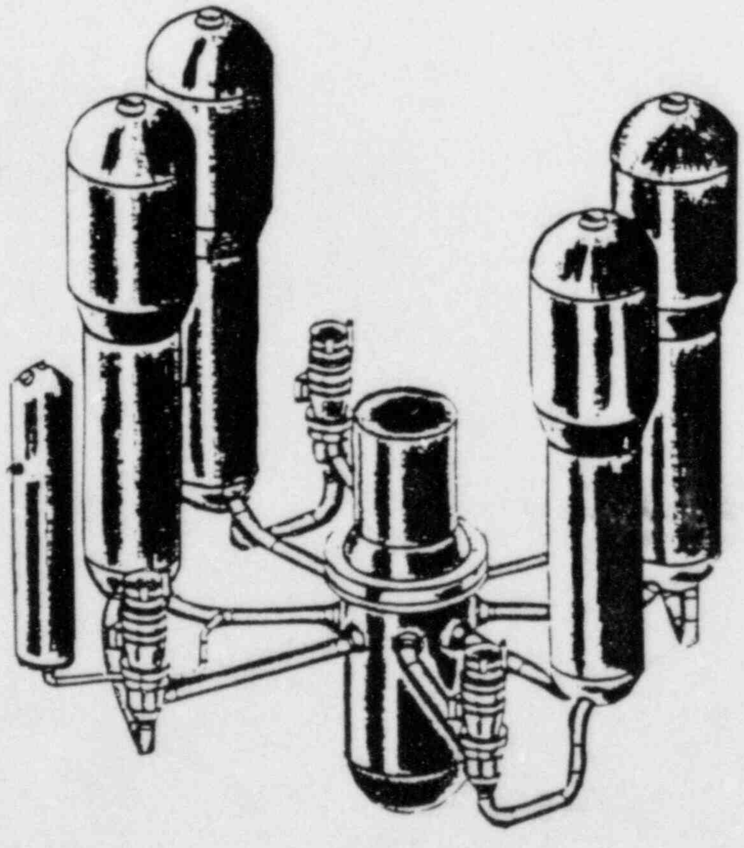


The PWR Containment must be able to withstand the stress of a complete depressurization (leak) of the reactor coolant system. One system installed to reduce containment pressure is the Containment Spray System which pumps water to the top of the building and sprays the water over the steam which would result from a large Reactor Coolant System leak.

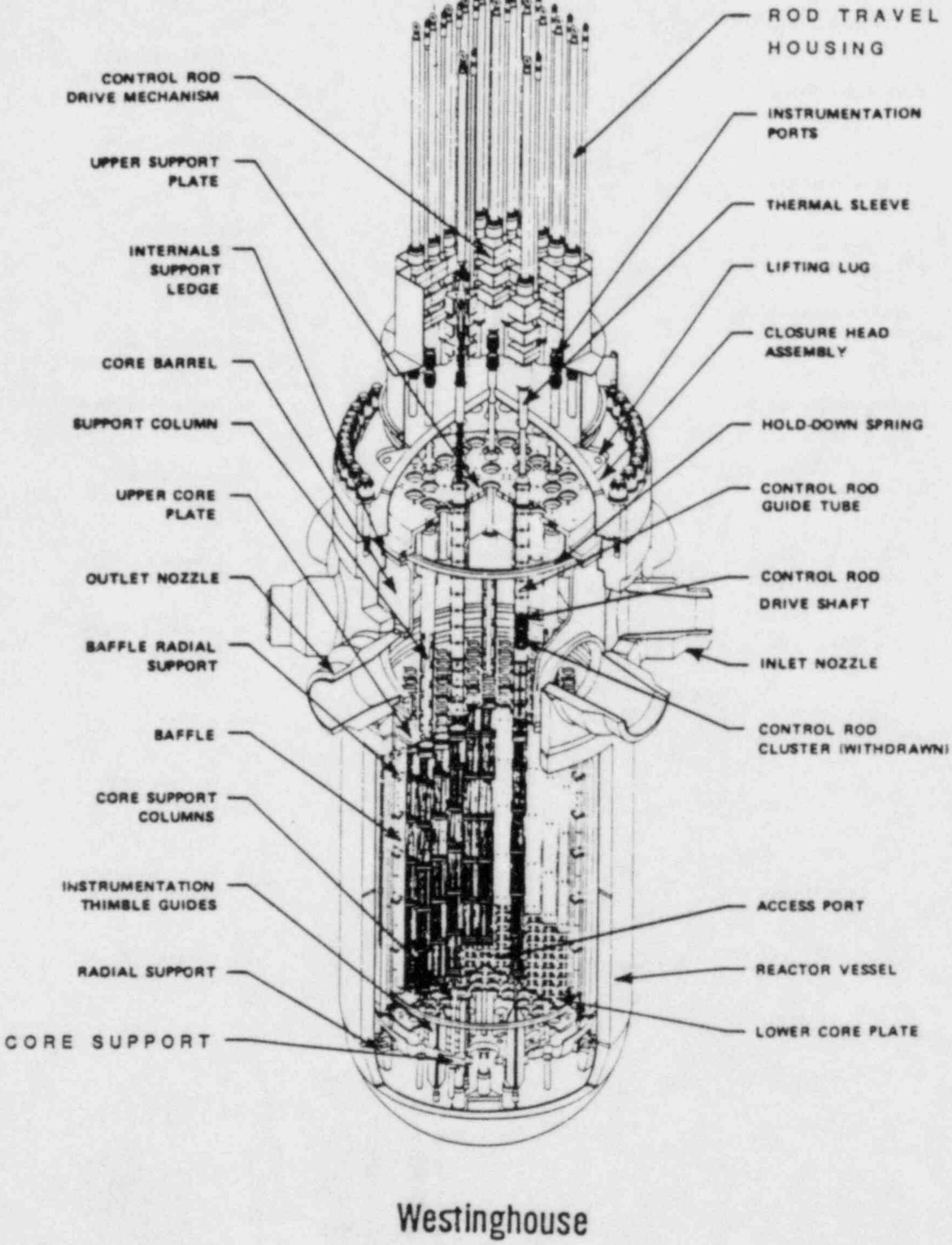


POWER SYSTEMS
COMBUSTION ENGINEERING INC

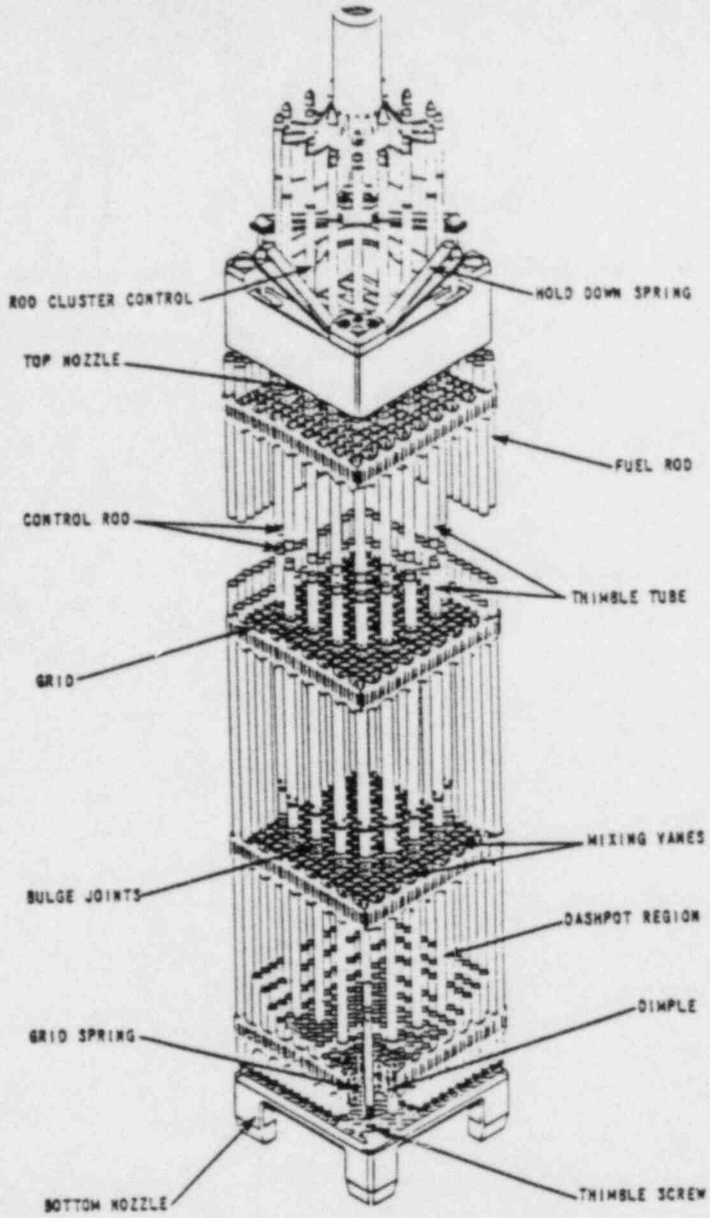
These drawings show the basic layout of components for the three PWR vendors in the United States.



Westinghouse

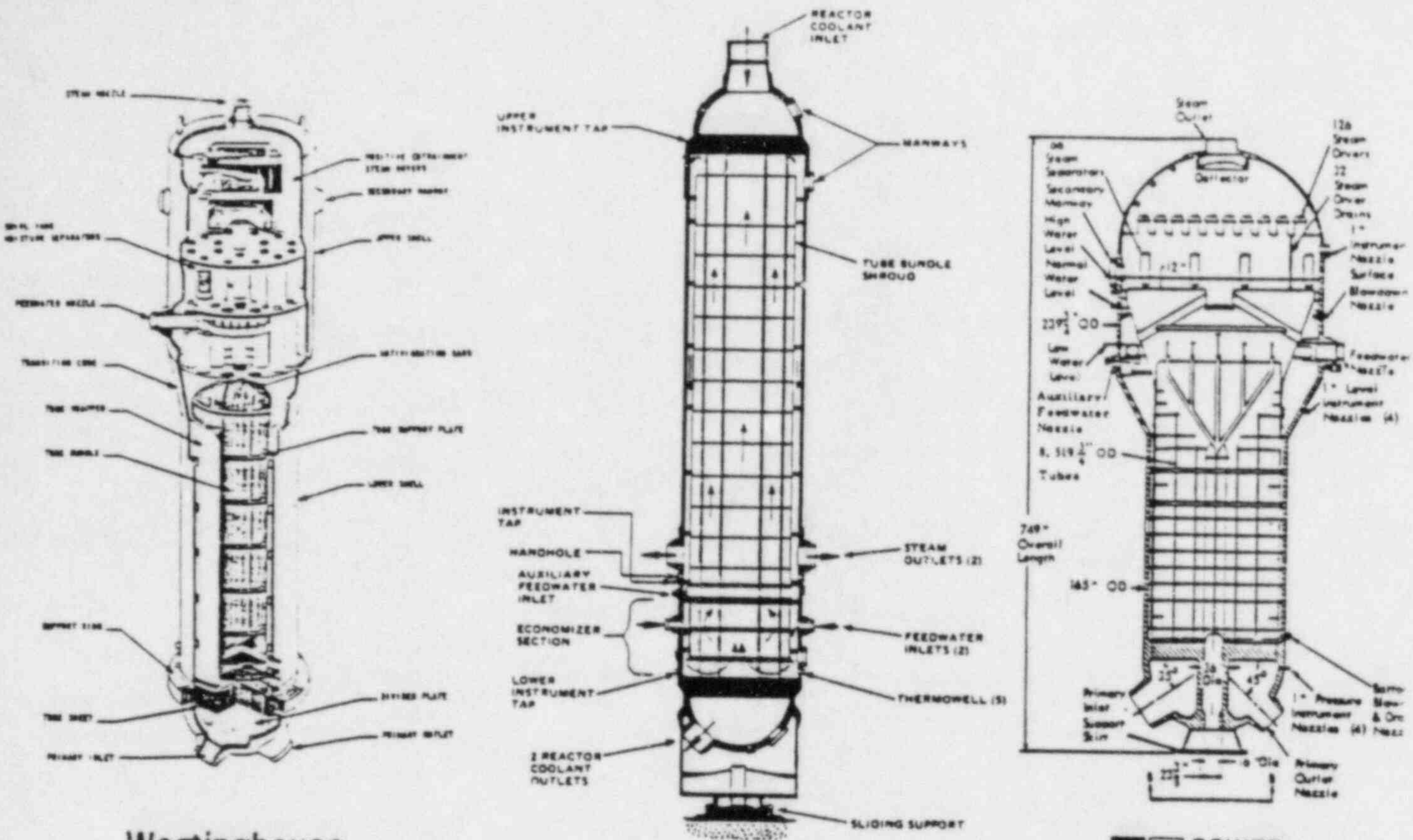


This cutaway drawing shows the major components of a typical PWR reactor vessel.



Westinghouse

This cutaway drawing shows the major components of a typical PWR fuel assembly.

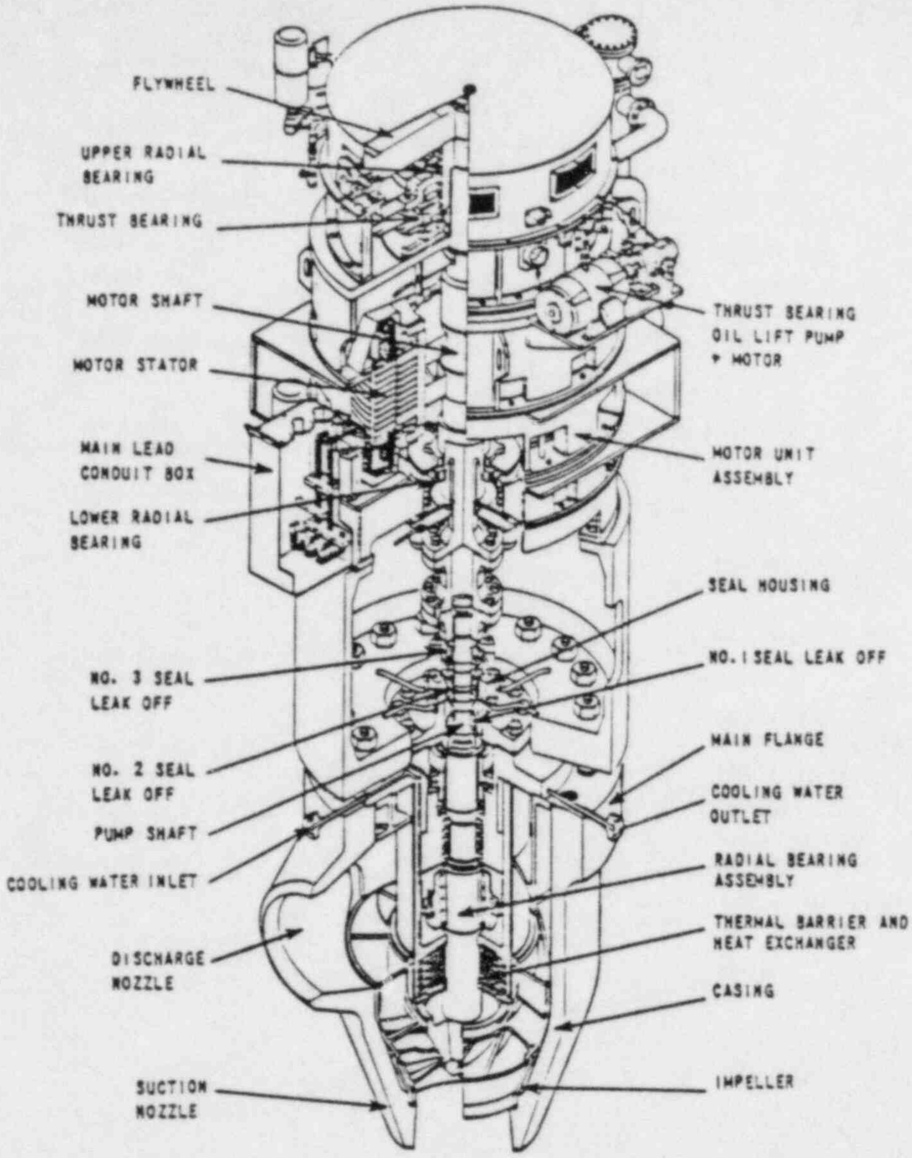


Westinghouse

Babcock & Wilcox

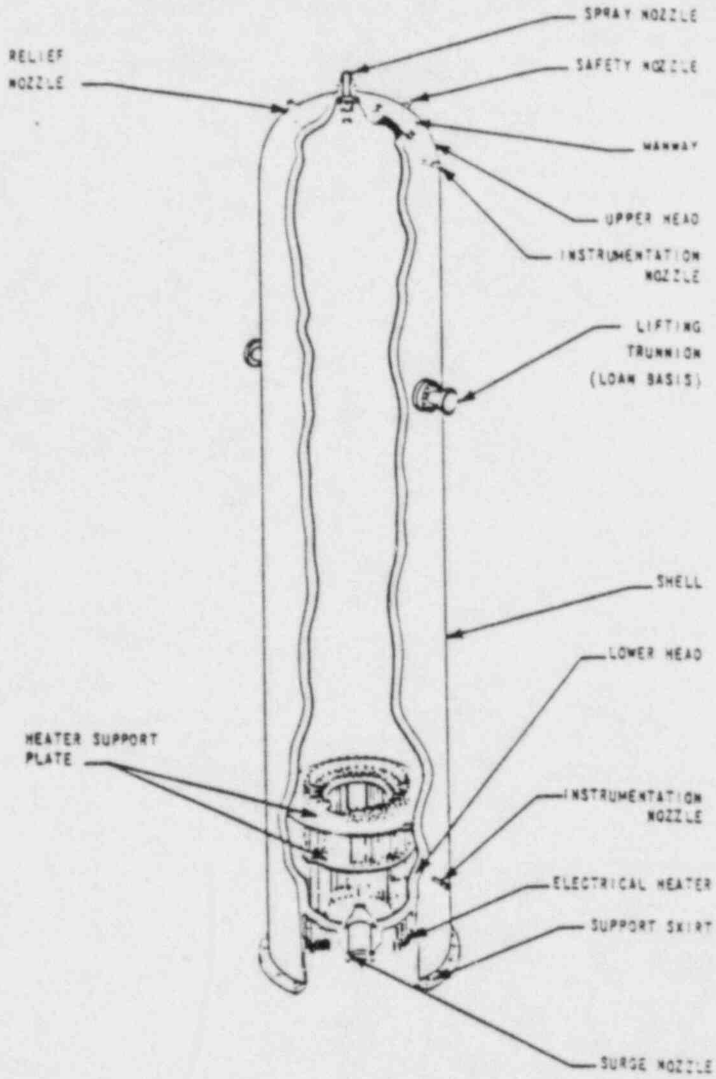
CE POWER SYSTEMS
COMBUSTION ENGINEERING INC

These cutaway drawings show the basic steam generator designs of the three PWR vendors in the United States.



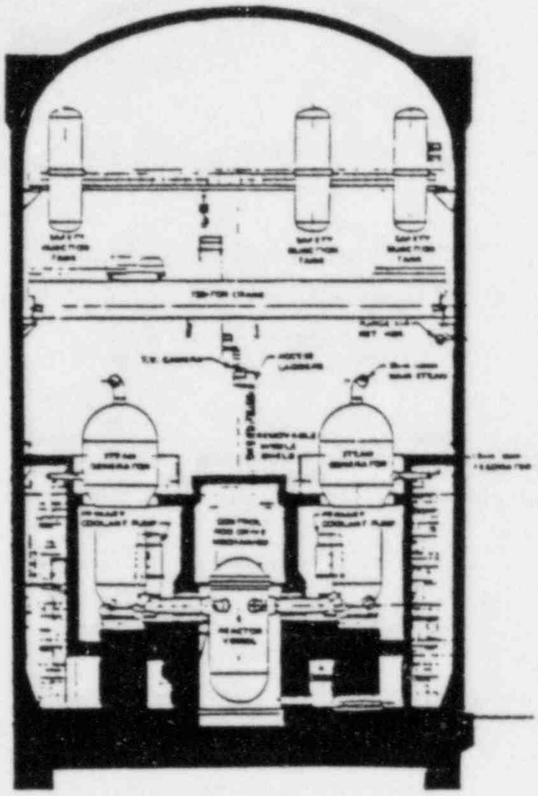
Westinghouse

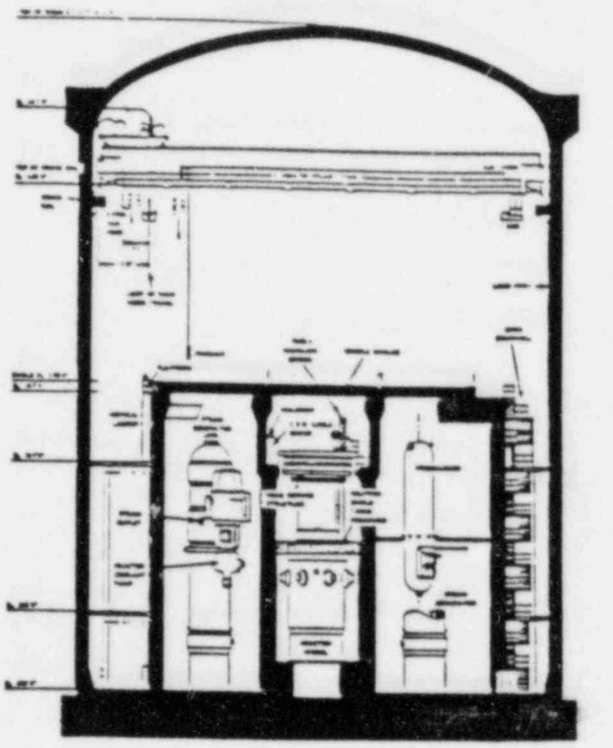
This cutaway drawing shows the major components of a typical PWR reactor coolant pump.

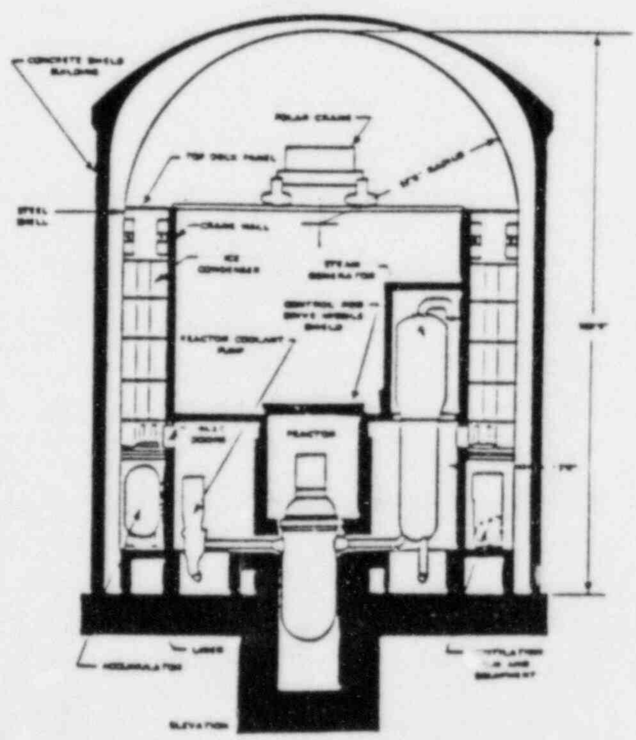


Westinghouse

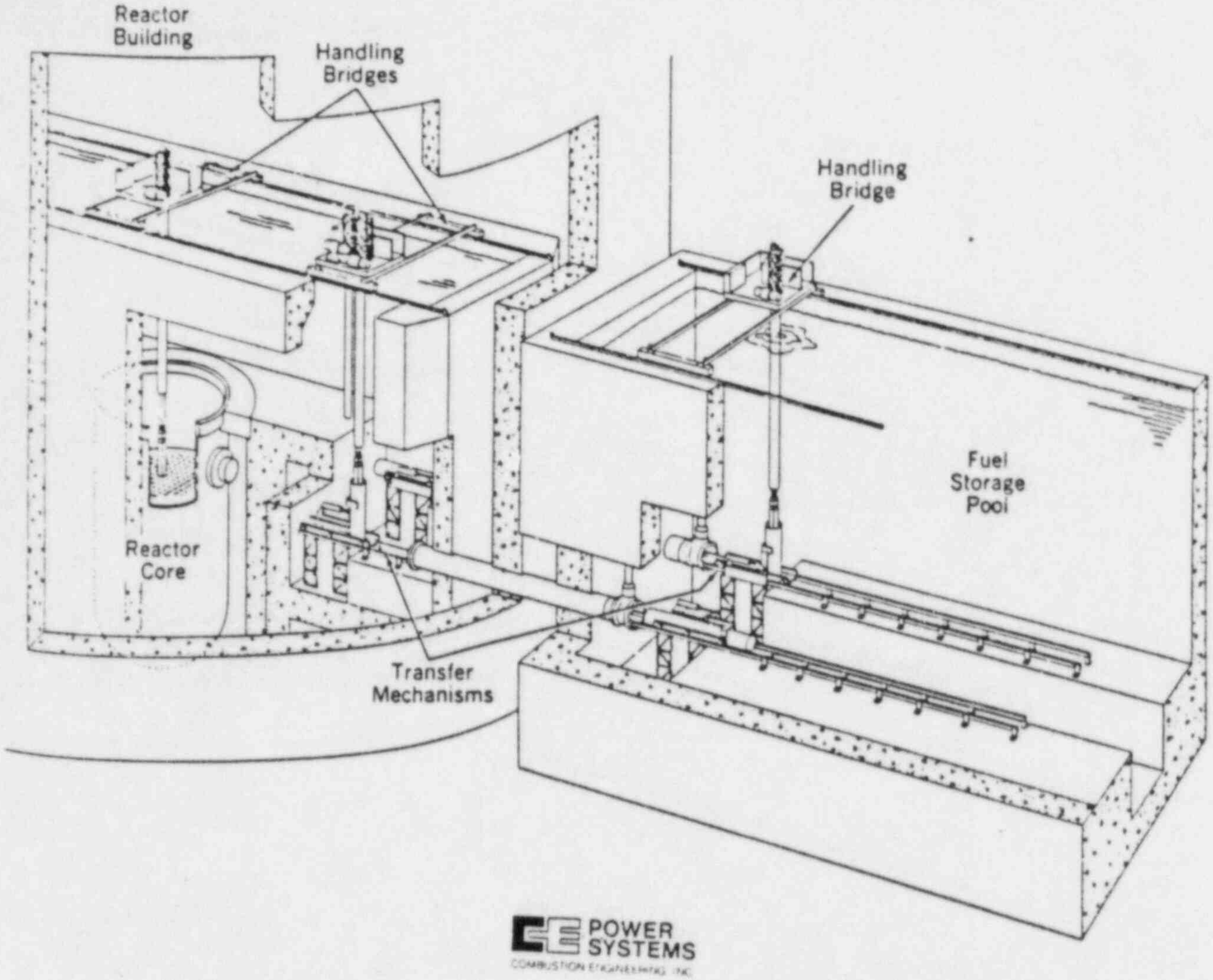
This cutaway drawing shows the major components of a pressurized water reactor's pressurizer vessel.



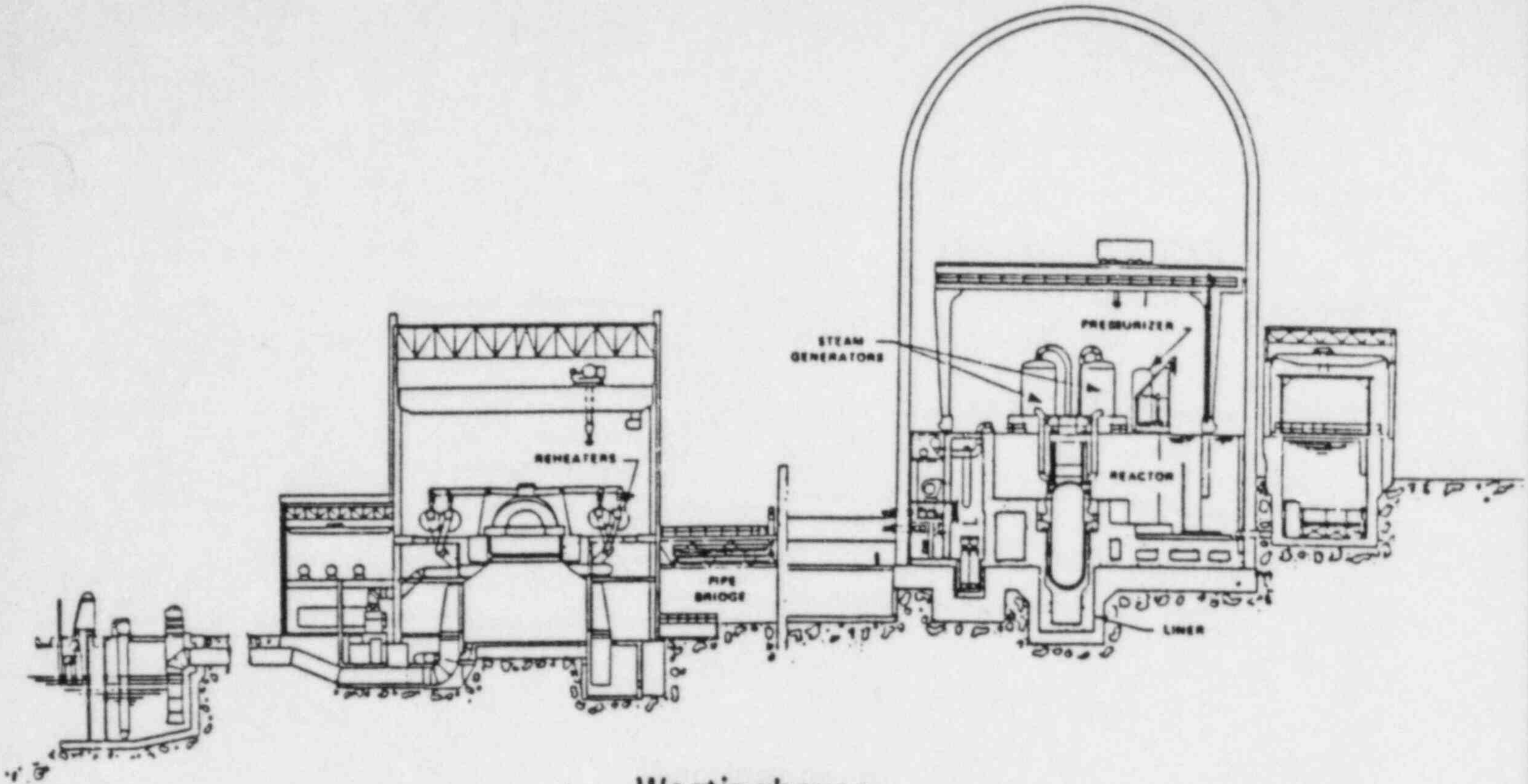




These cutaway drawings show the general layout of major components inside a PWR containment building.



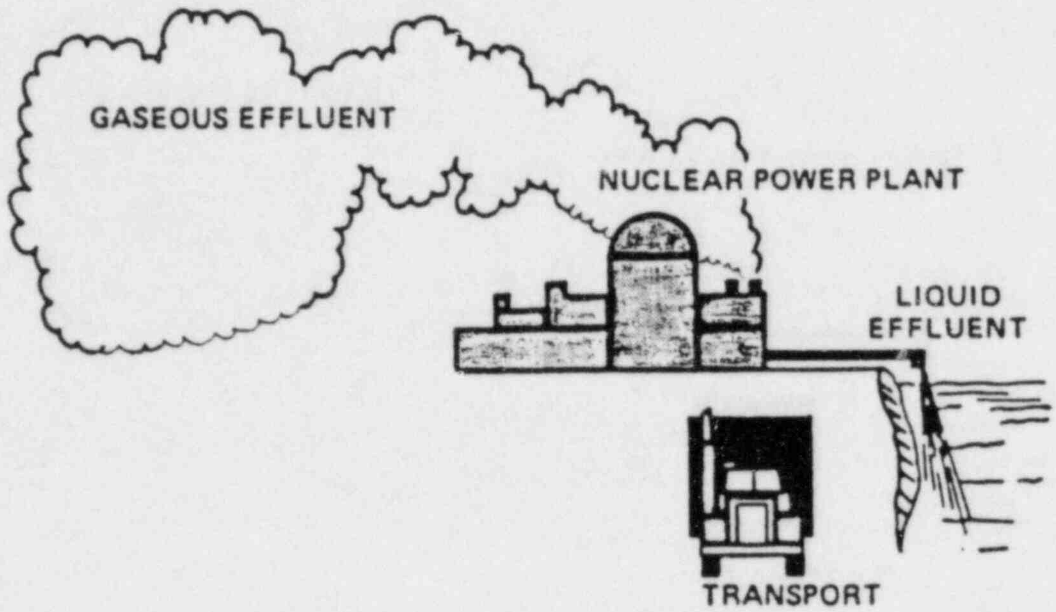
This cutaway drawing shows the major components involved in fueling/refueling a pressurized water reactor.



Westinghouse

This cutaway drawing shows the general arrangement of buildings at a Pressurized Water Reactor nuclear plant.

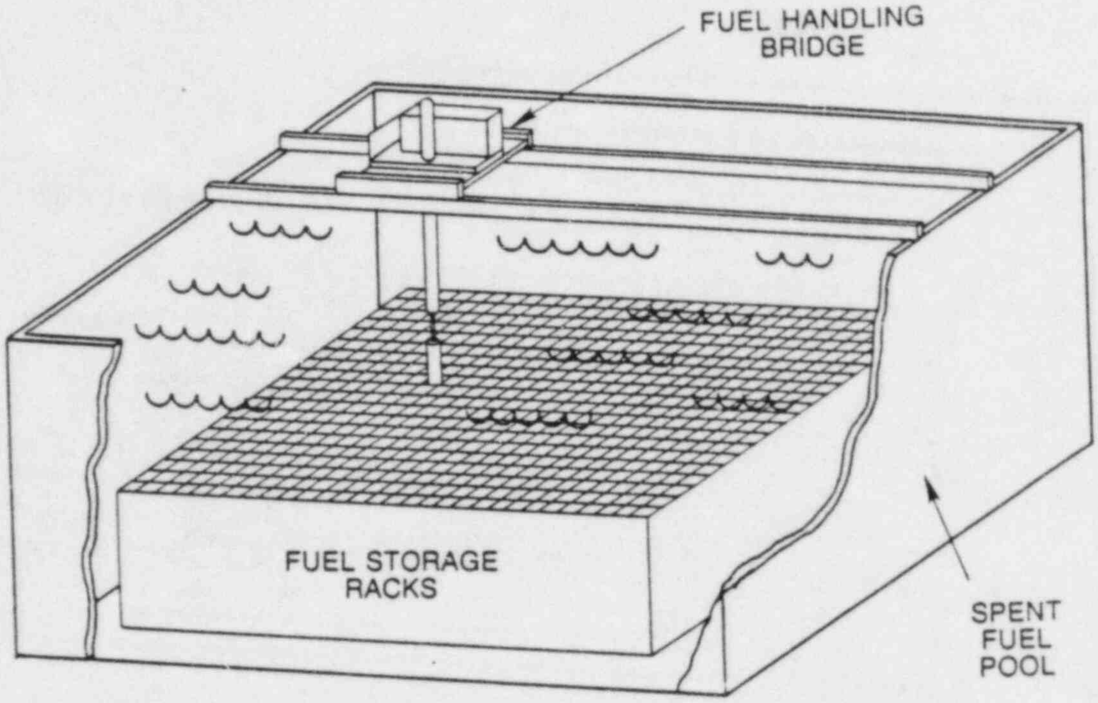
RADIOACTIVE WASTE



DISPOSAL

This section discusses the sources, handling and ultimate disposal of radioactive wastes generated by Nuclear Power Plant operations.

HIGH-LEVEL RADIOACTIVE WASTE



SPENT FUEL ASSEMBLIES

(FISSION PRODUCTS)

High Level Radwaste (fission products) are sealed inside the spent fuel rods. They are presently being stored in spent fuel pools at nuclear plants and at some off site temporary storage facilities.

LOW LEVEL WASTE SOURCES

LIQUID:

1. EQUIPMENT LEAKOFF POINTS
2. EQUIPMENT VENTS AND DRAINS
3. FLOOR DRAIN SYSTEM
4. RELIEF VALVE DISCHARGES
5. SOLID WASTE SYSTEM (DE-WATER)

SOLID:

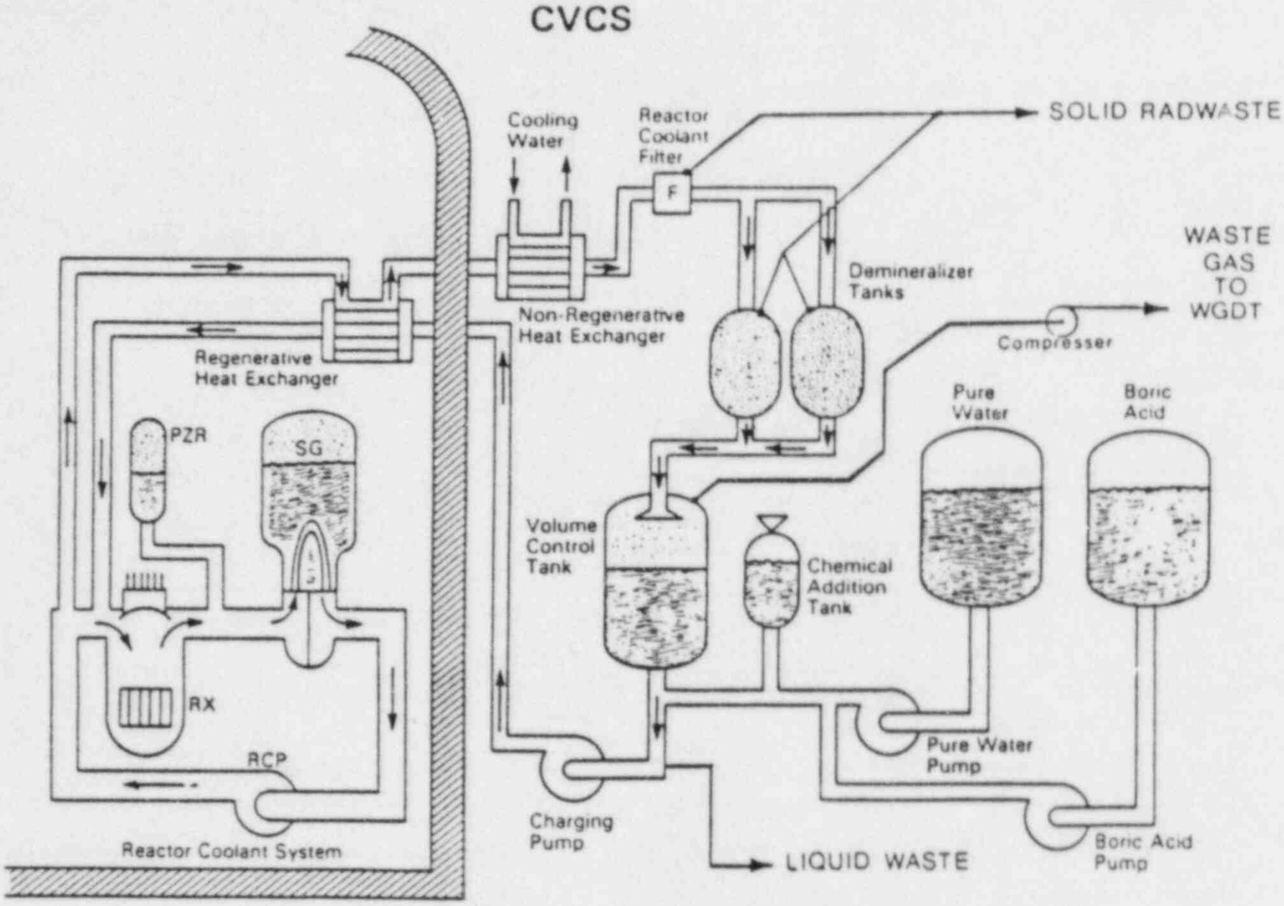
1. CONTAMINATED RAGS, TOOLS, CLOTHING, ETC.
2. SPENT FILTER CARTRIDGES
3. SPENT DEMINERALIZER RESINS

GASEOUS:

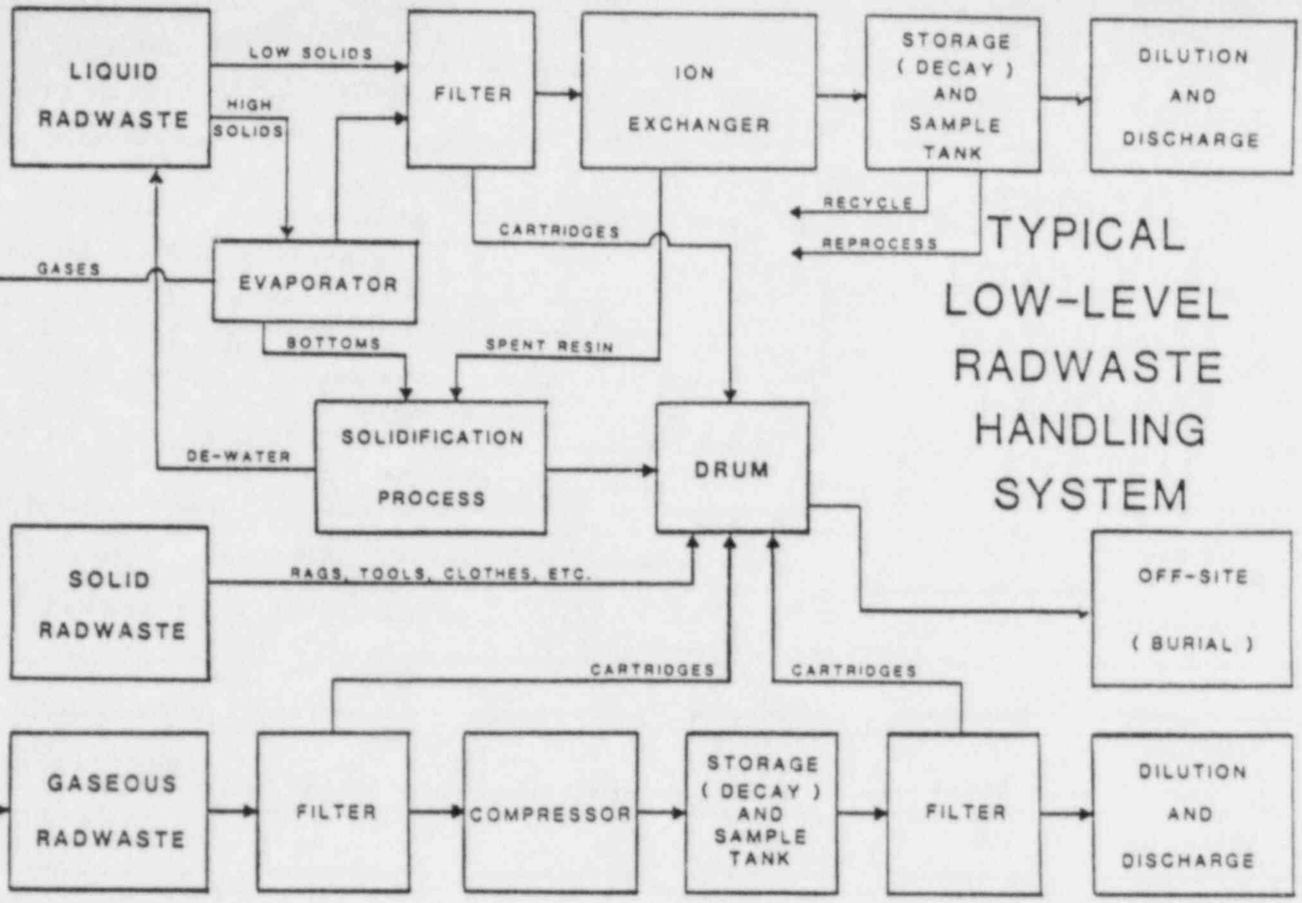
1. EQUIPMENT VENTS
2. LIQUID WASTE SYSTEM (EVAPORATOR GAS STRIPPER)

The principal sources of low level radwaste are the reactor coolant (water) and the components and equipment which come in contact with the coolant. The major constituents of radwaste are activation products (crud) with a very small percentage of fission products.

WASTE
FROM
CVCS

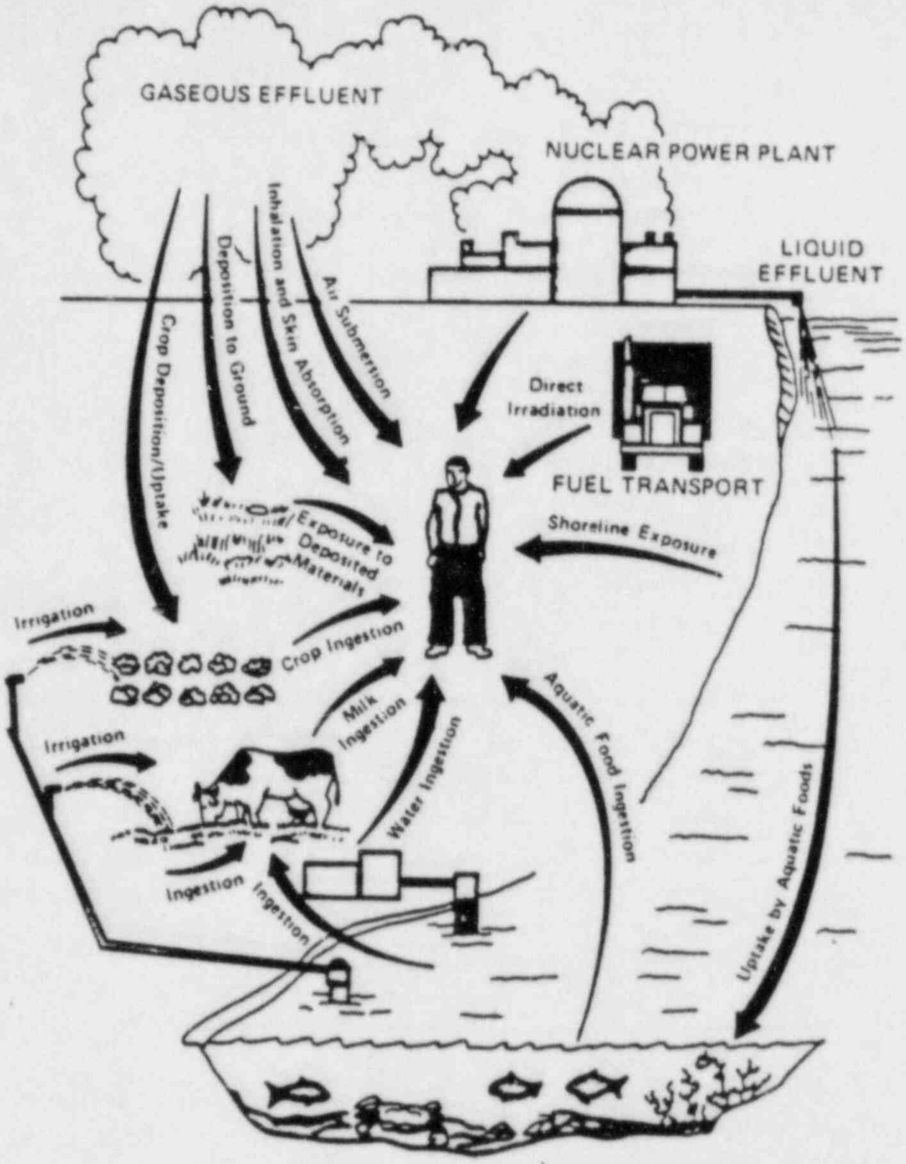


The drawing above shows some of the sources of low level radwaste from a pressurized water reactor. In the Chemical and Volume Control System solid particles (some of which are radioactive) are removed by the Reactor Coolant Filter and Demineralizers. Gases are removed in the Volume Control Tank. Liquids can be pumped to storage tanks for sampling and reprocessing as necessary.



TYPICAL LOW-LEVEL RADWASTE HANDLING SYSTEM

The block diagram above shows the layout for a simple radwaste handling system. Solids, liquids and gases are first separated from one another and then processed individually. All solid low level wastes will be shipped to licensed burial sites. Liquids and gases will be held up to allow most of the short-lived radioactivity to decay off and then will be diluted and released into the river/lake/ocean (for liquids) or the atmosphere (for gases).



The drawing above shows many of the possible pathways for radiation exposure to a member of the general public.

10 CFR 20 DOSE STANDARDS

2 m REM	IN ANY HOUR
100 m REM	IN ANY 7 DAYS

10 CFR 50 DESIGN OBJECTIVES

LIQUIDS	3 m REM / YR	TO WHOLE BODY
	10 m REM / YR	TO ANY ORGAN
GASES	5 m REM / YR	TO WHOLE BODY
	15 m REM / YR	TO SKIN
SOLIDS & IODINE	15 m REM / YR	TO ANY ORGAN

The licensee must not release radioactive material so that any member of the public receives a dose of 2 m Rem in any hour or 100 m Rem in any seven consecutive days. Additionally, the NRC has issued numerical design limits for each reactor unit for exposure to releases into water and air which are considerably lower than the limits published in 10 CFR 20.

REACTOR

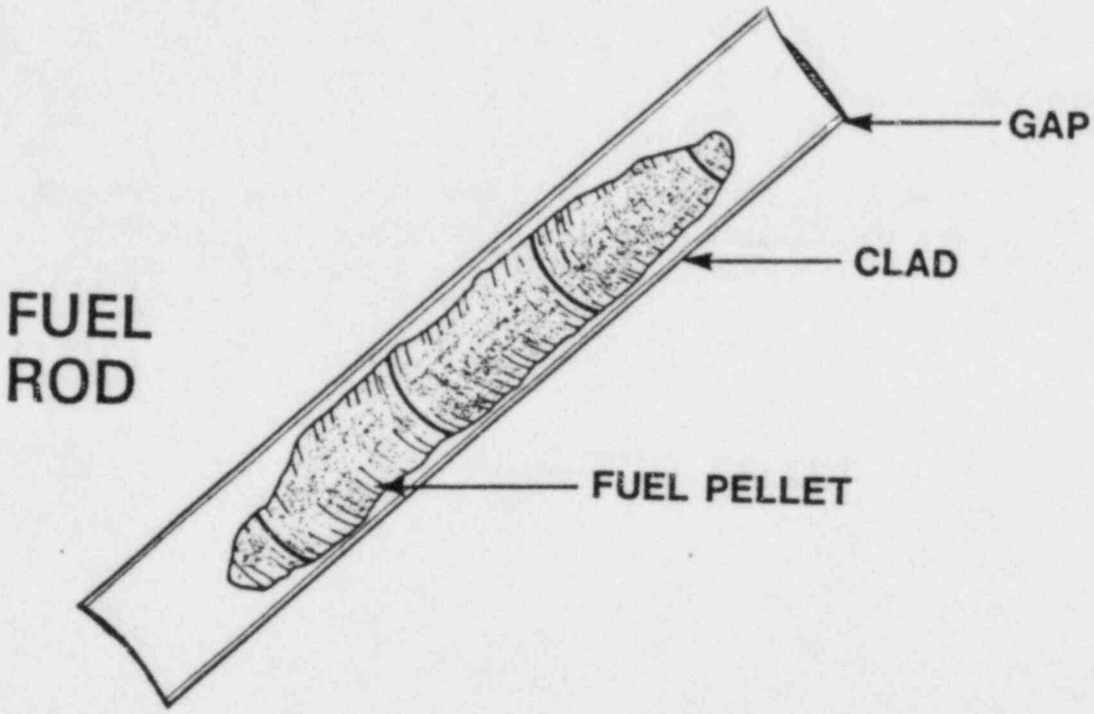
EMERGENCIES

This section discusses some of the possible events which could lead to a significant release of fission products from the reactor core and the emergency systems, structures and components designed to prevent these accidents or mitigate their consequences to protect public health and safety.

REACTOR EMERGENCIES

OVERHEATING FUEL RODS

MECHANICAL DAMAGE TO RODS



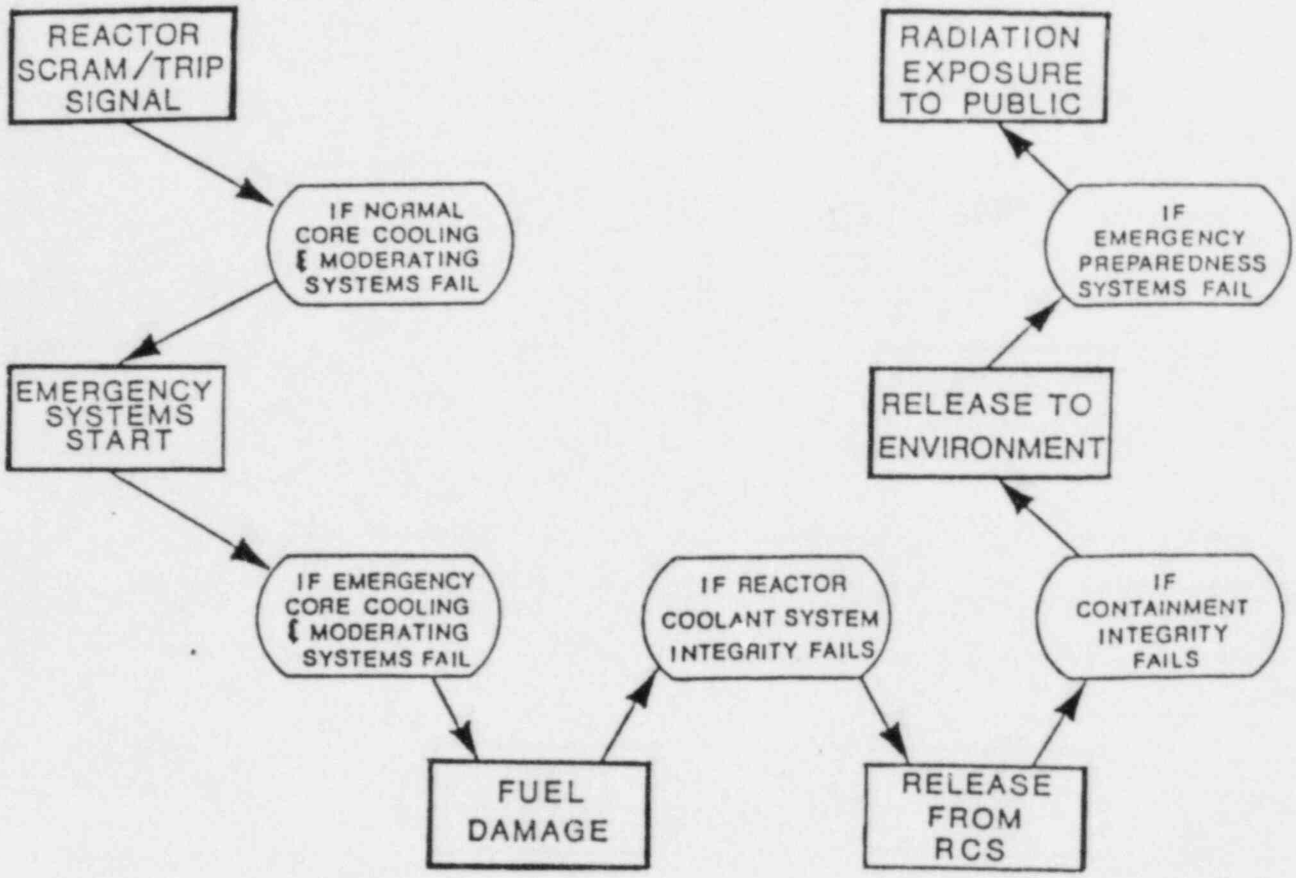
Fission product release can be a result of overheating or mechanical shock to the fuel rods. An abnormally high rate of fission or lack of decay heat removal can result in overheated fuel. Mechanical damage could be caused by a fuel handling accident, spent fuel pool damage or industrial sabotage.

EMERGENCY SAFETY SYSTEMS

- PROTECT FUEL RODS
- PROTECT RCS
- PROTECT CONTAINMENT
- PROTECT THE PUBLIC

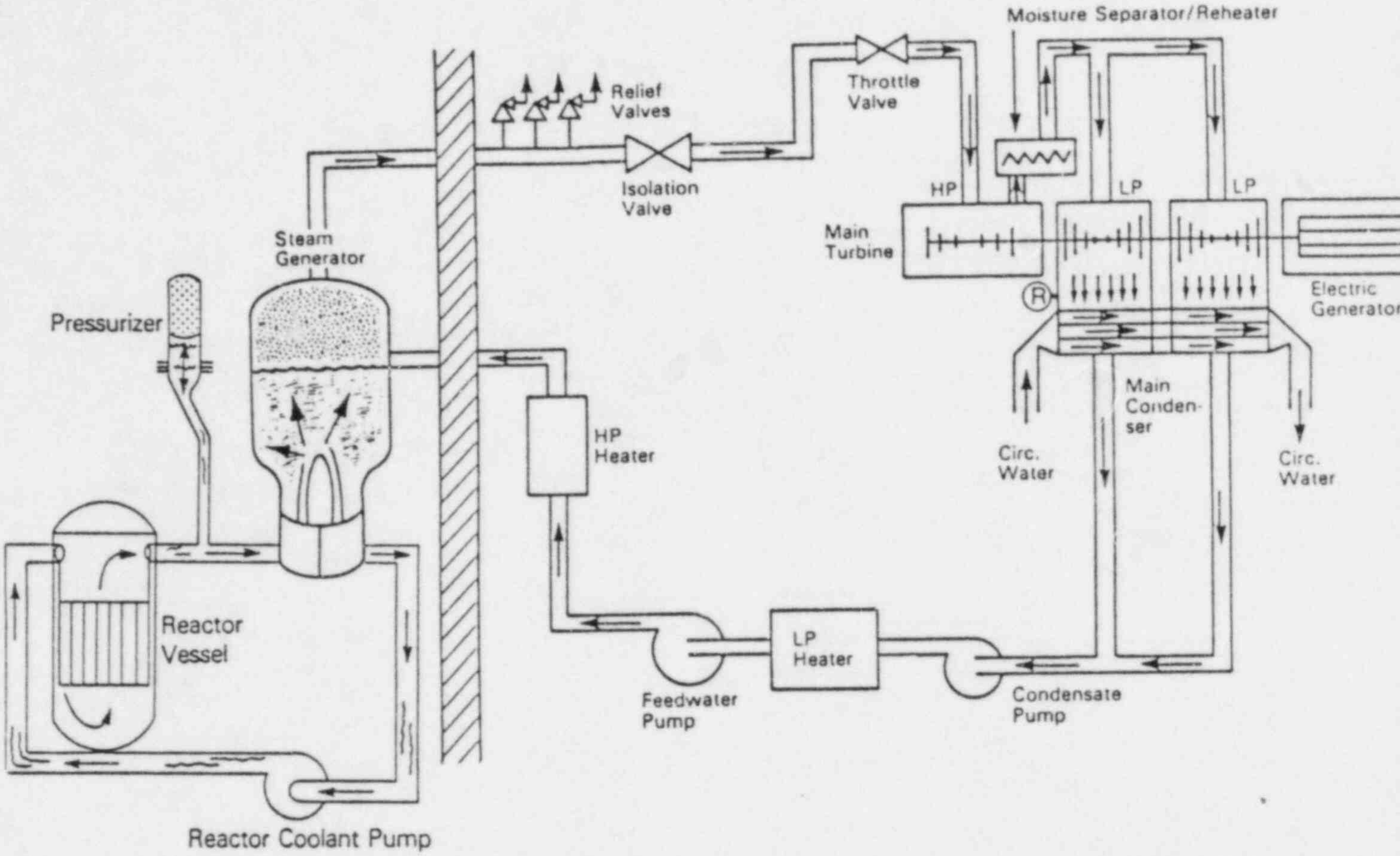
All power reactors must have specially designed safety systems to insure the reactor can be shutdown and the fuel cooled under a wide variety of emergencies. The reactor safety systems are designed to protect or mitigate the consequences of damage to the fuel rods, the reactor coolant system and the containment structure. The overall goal is to protect public health and safety from the consequences of an accident.

REACTOR EMERGENCIES

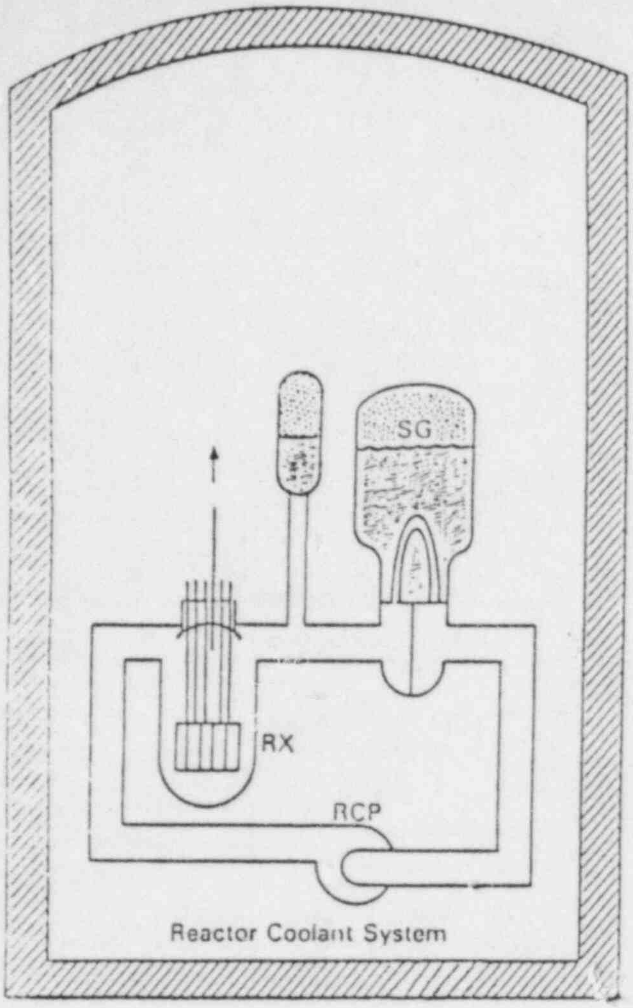


A combination of several low probability failures must occur for a significant amount of fission products to be released from reactor fuel into the environment. If these failures combine with an inadequate emergency preparedness system the released radioactive materials can cause an exposure to the public.

STEAM GENERATOR TUBE RUPTURE



In a PWR, a steam generator tube rupture could lead to releases of radioactive material due to increased steam line pressure. The operator's main goal in this situation is to provide an orderly shutdown and cooldown of the reactor coolant system so that the leaking steam generator can be completely isolated and the steam relief valves will not open.

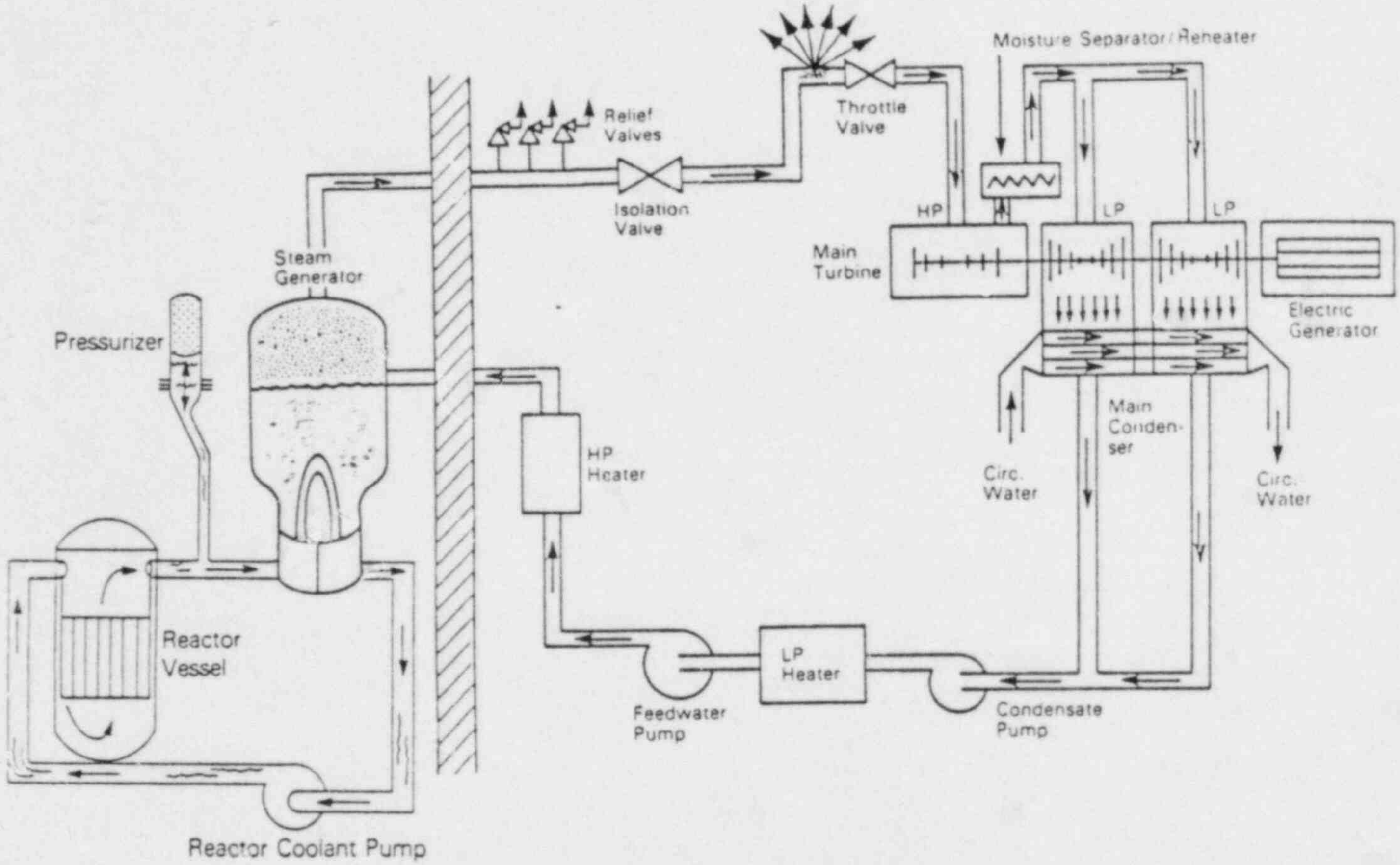


CONTROL ROD MALFUNCTION OR ROD EJECTION

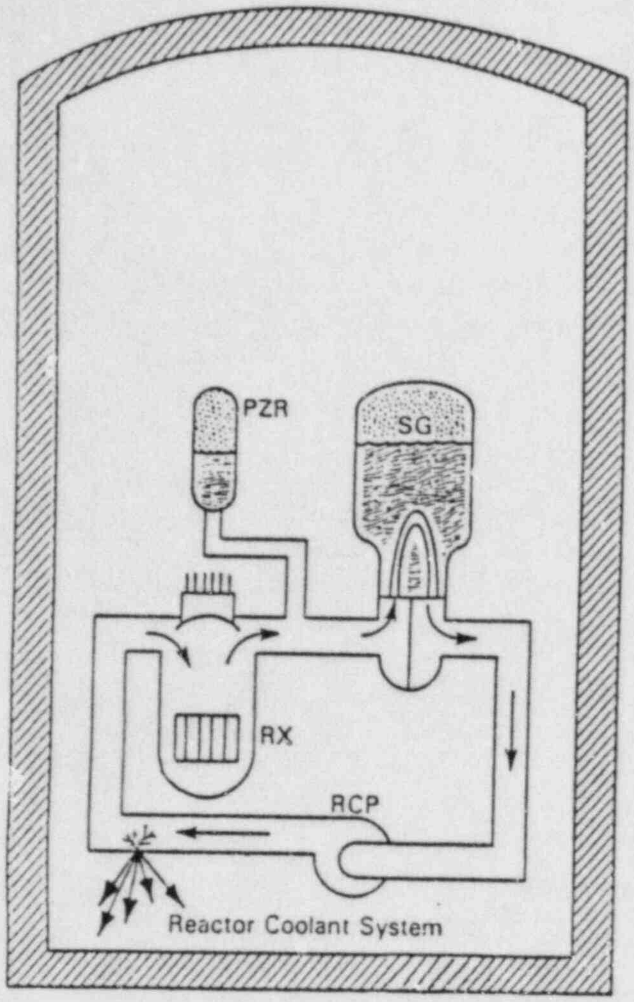
SAFETY INJECTION SYSTEM (BORON)

A control rod malfunction or control rod ejection may require the insertion of additional neutron poisons. Both PWR's and BWR's have systems which can pump a boron solution into the reactor to provide the necessary neutron poisons for reactor shutdown.

- STEAM LINE BREAK-
SAFETY INJECTION SYSTEM



In a PWR, a steam line break can cause a rapid temperature drop in the reactor's coolant system. As coolant temperature decreases, more neutrons are moderated and reflected back into the reactor core causing more fissions and higher fuel rod temperatures. This situation requires a rapid reactor shutdown which may include the injection of boric acid solution to ensure the reactor remains shutdown.

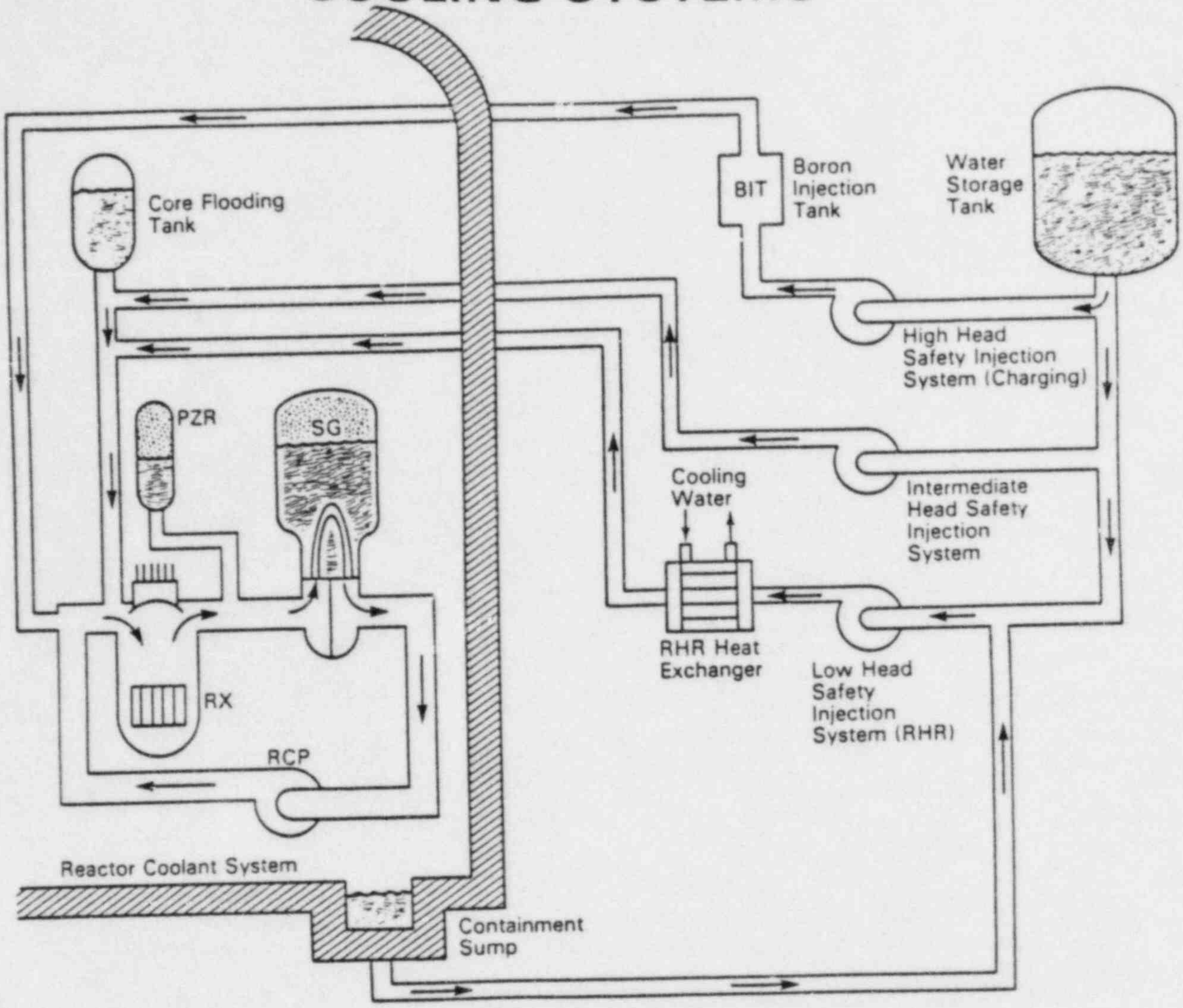


LOSS OF COOLANT ACCIDENT

EMERGENCY CORE COOLING SYSTEMS, CONTAINMENT SYSTEMS

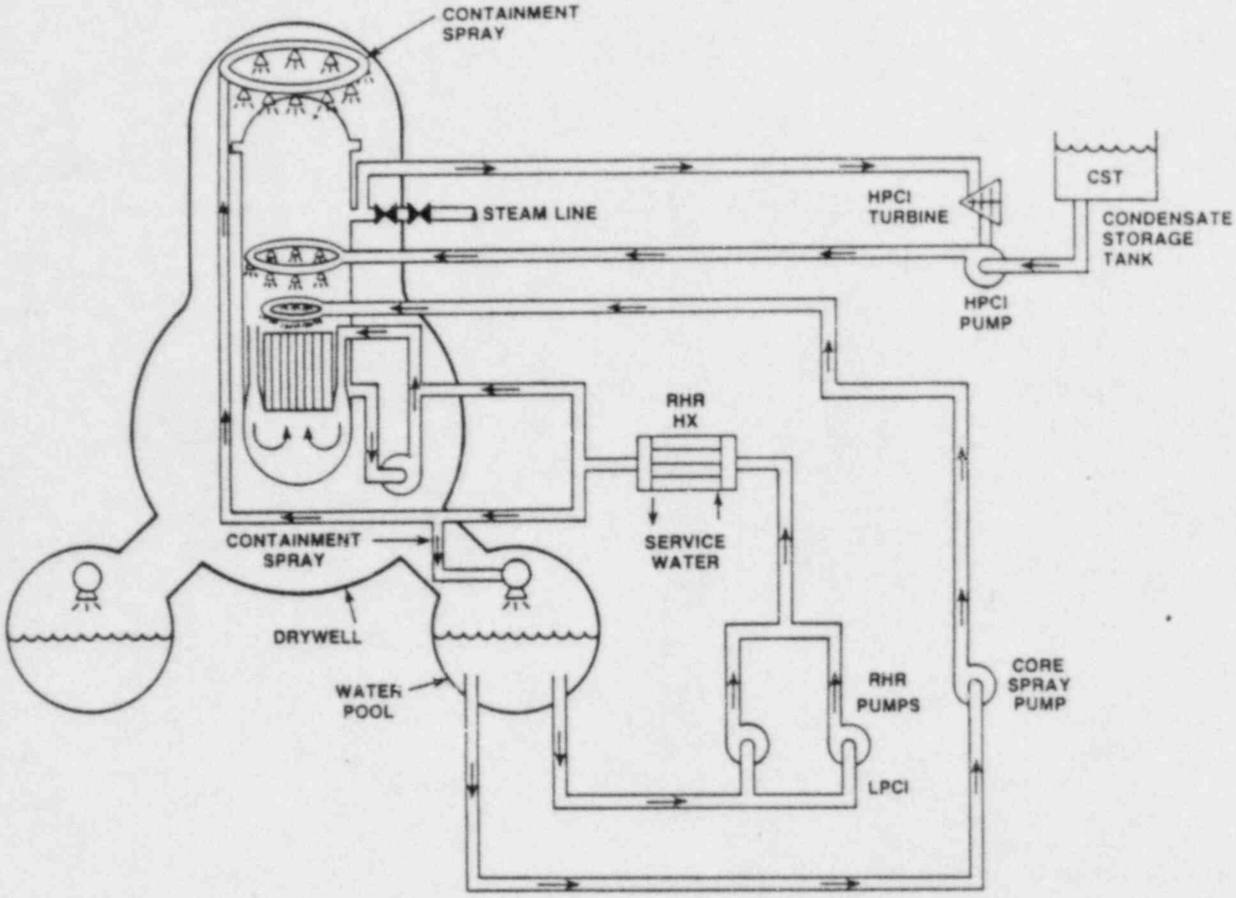
A loss of coolant accident decreases the reactor coolant system's ability to transfer decay heat away from the reactor core. The plant's emergency core cooling syster. rust be able to provide the necessary volume of water to prevent [illegible] mage.

PWR EMERGENCY CORE COOLING SYSTEMS



The above drawing shows a simplified version of a PWR Emergency Core Cooling System which can inject borated water into the primary system under a variety of accident conditions.

BWR EMERGENCY COOLING SYSTEMS



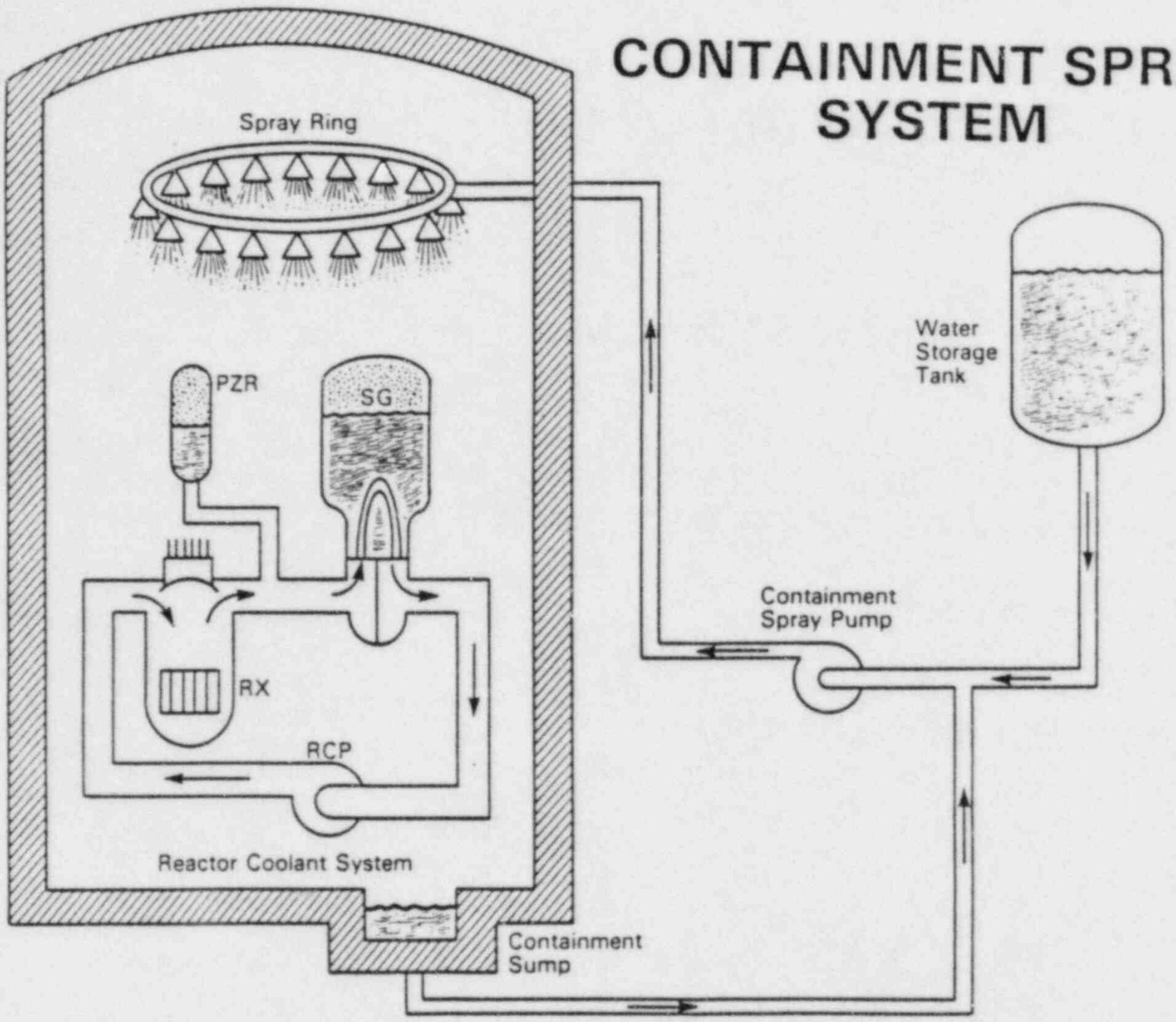
The above drawing shows a simplified version of a BWR's Emergency Cooling Systems. These systems can inject pure water into the reactor vessel (and provide containment cooling) under a variety of accident conditions.

CONTAINMENT BUILDING

- ISOLATION SYSTEM
- SPRAY SYSTEM
- AIR COOLING SYSTEMS
- AIR PURIFICATION SYSTEMS

Should serious fuel damage occur, fission products will be released from the fuel rods into the reactor coolant system. The primary function of the containment structure is to block the escape of this highly contaminated fluid. The containment must be properly isolated, cooled and decontaminated in order to minimize fission product release to the environment.

CONTAINMENT SPRAY SYSTEM



The drawing above shows a simplified version of a PWR's Containment Spray System. Containment Spray is one method available to cool and depressurize the PWR containment in the event of a loss of coolant accident.

EMERGENCY ACTION LEVELS

UNUSUAL EVENT

ALERT

SITE EMERGENCY

GENERAL EMERGENCY

INCREASING SEVERITY

The Emergency Action Levels (shown above) have been established to provide prompt notification of minor events which could lead to more serious consequences or which may indicate more serious conditions which have not yet been fully realized.

UNUSUAL EVENT

ECCS ACTUATION

HIGH COOLANT ACTIVITY SAMPLES

ABNORMAL COOLANT / FUEL TEMPERATURES

VALVE / PIPE FAILURES

POWER FAILURES (OFF SITE)

FIRE OR DEGRADATION OF FIRE PROTECTION

LOSS OF MONITORING / COMMUNICATION SYSTEMS

SECURITY THREAT

ABNORMAL NATURAL PHENOMENON

AIRCRAFT / TRAIN ACCIDENT ON SITE

The Notification of Unusual Event indicates that there is a potential degradation in the level of plant safety. The notification:

1. Provides current plant status information.
2. Assures that the first step in any later response found to be necessary has been carried out.
3. Provides a test of emergency communication systems.

ALERT

SEVERE CLAD DAMAGE

RELEASE 10 TIMES GREATER THAN TECH SPECS

SIGNIFICANT PRIMARY COOLANT LEAKAGE

LOSS OF AC OR DC POWER SUPPLIES

INABILITY TO COMPLETELY SHUTDOWN/COOLDOWN

FUEL HANDLING ACCIDENT

FIRE POTENTIALLY INVOLVING SAFETY SYSTEMS

LOSS OF ALARM/ANNUNCIATOR SYSTEMS

SEVERE NATURAL PHENOMENA

AIRCRAFT/EXPLOSION DAMAGE TO FACILITY

ANTICIPATED OR ACTUAL EVACUATION OF THE CONTROL ROOM

ON GOING SECURITY COMPROMISE

The Alert classification indicates that events have occurred (or are occurring) which involve an actual or potentially substantial degradation of plant safety. This notification:

1. Assures emergency response personnel will be available if needed.
2. Provides an updated plant status report.
3. Provides a test of emergency response centers and personnel.

SITE EMERGENCY

SIGNIFICANT CORE DAMAGE

LOSS OF COOLANT (BEYOND MAKEUP CAPACITY)

LOSS OF AC OR DC POWER FOR 15 MINUTES

MAJOR DAMAGE TO SPENT FUEL FACILITIES

NATURAL PHENOMENA BEYOND DESIGN LEVELS

DAMAGE TO SAFETY EQUIPMENT BY FIRE / IMPACT / EXPLOSION

EVACUATION OF CONTROL ROOM WITH NO LOCAL CONTROL ESTABLISHED

IMMINENT LOSS OF PHYSICAL SECURITY

The Site Emergency classification indicates that events are occurring (or have occurred) which involve actual or likely failure of major plant functions necessary to insure public health and safety. This notification:

1. Assures response centers are staffed.
2. Assures response teams are dispatched.
3. Provides all response organizations with current plant status information.
4. Provides a test for loca', state and national response organizations.

GENERAL

EMERGENCY

MAJOR INTERNAL/EXTERNAL EVENT (OR COMBINATION OF EVENTS) WHICH WOULD CAUSE:

LOSS OF 2 OF 3 FISSION PRODUCT BARRIERS

FAILURE OF ECCS TO SHUTDOWN AND COOLDOWN REACTOR

OFF SITE DOSE RATES:

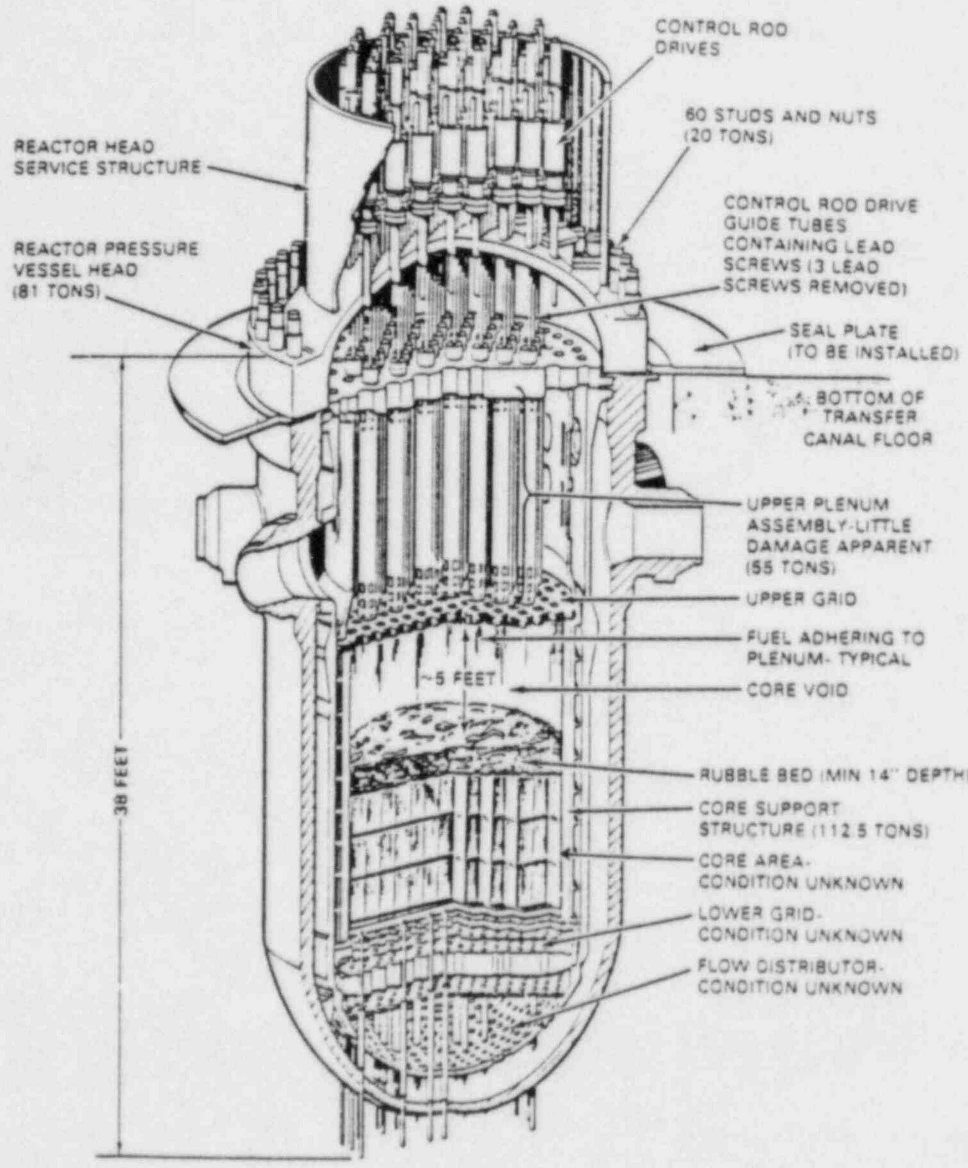
1 REM/HOUR WHOLE BODY

5 REM/HOUR THYROID

The General Emergency classification indicates that events are occurring (or have occurred) which involve actual or imminent substantial core damage with the potential loss of containment integrity. This notification:

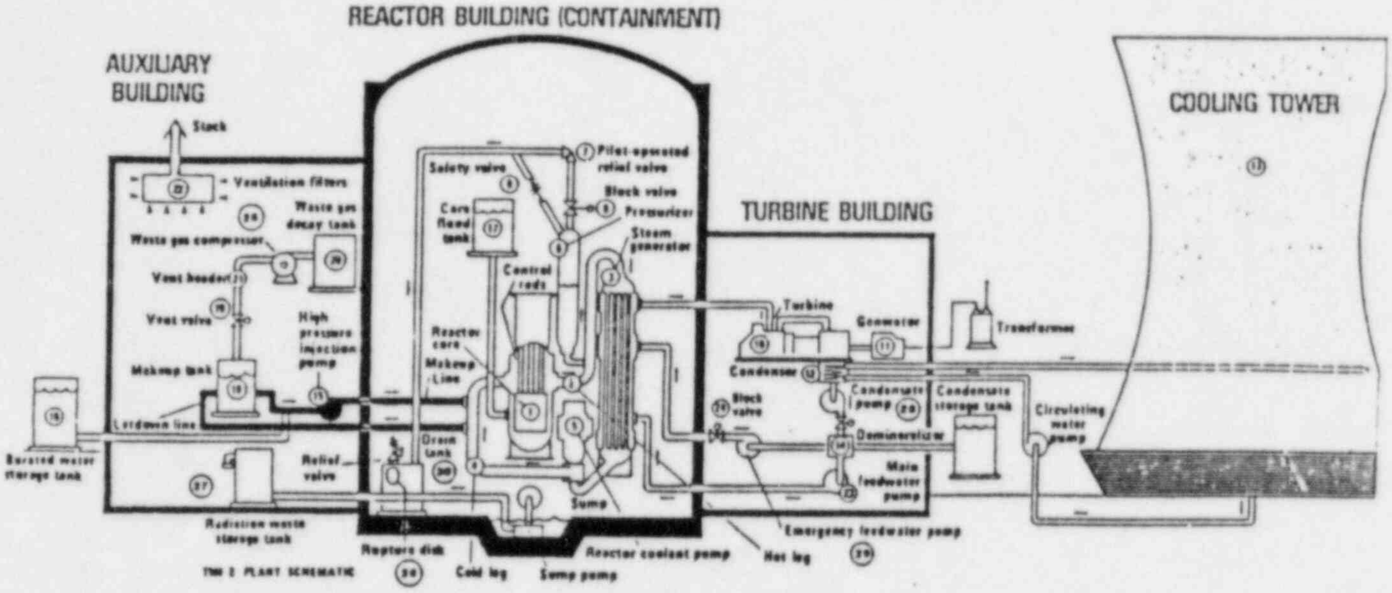
1. Provides current and continuous plant status information to all response organizations.
2. Initiates predetermined actions for the protection of the public.
3. Initiates other protective measures as indicated by the situation.

THE THREE MILE ISLAND ACCIDENT

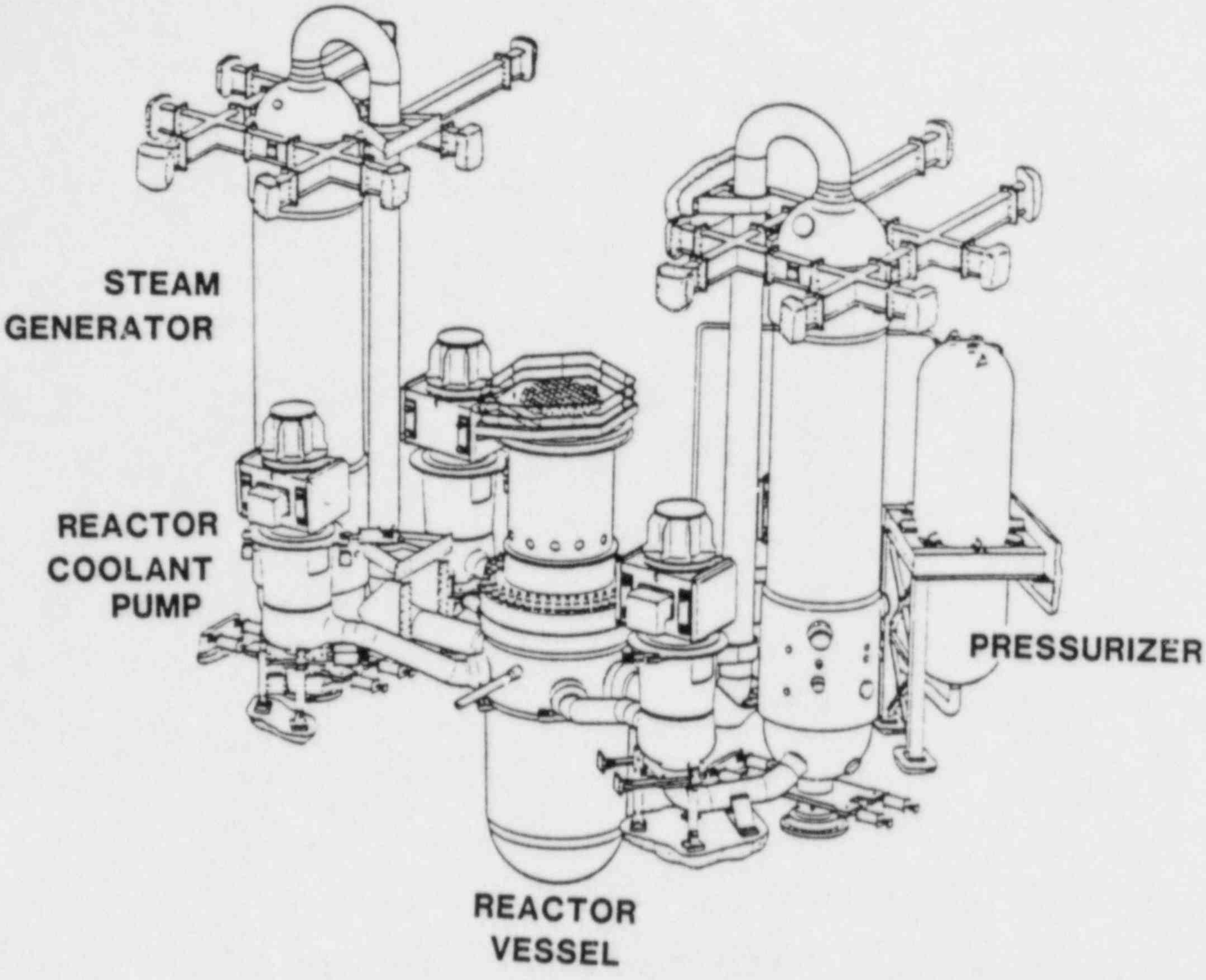


This section discusses the core damage and the release of radioactive material resulting from the Three Mile Island accident.

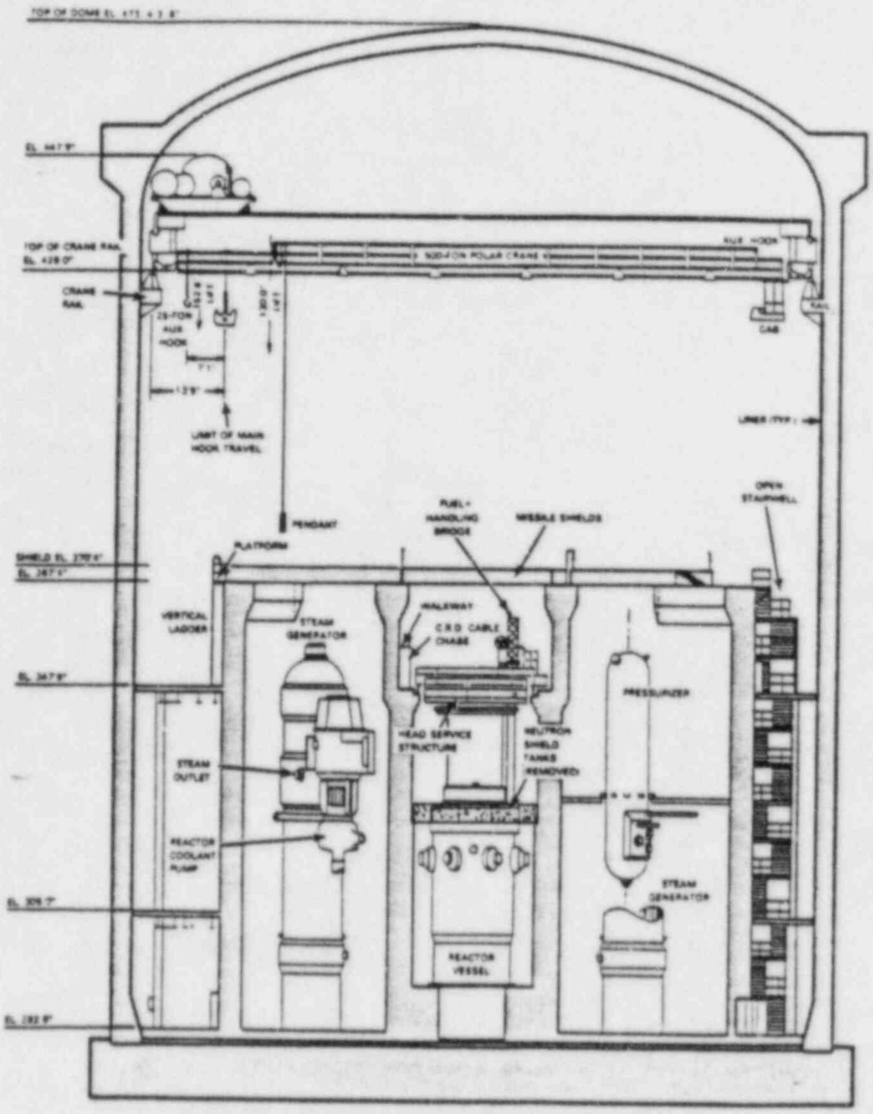
THREE MILE ISLAND



This drawing shows the general layout of structures and components at Three Mile Island Unit Two.



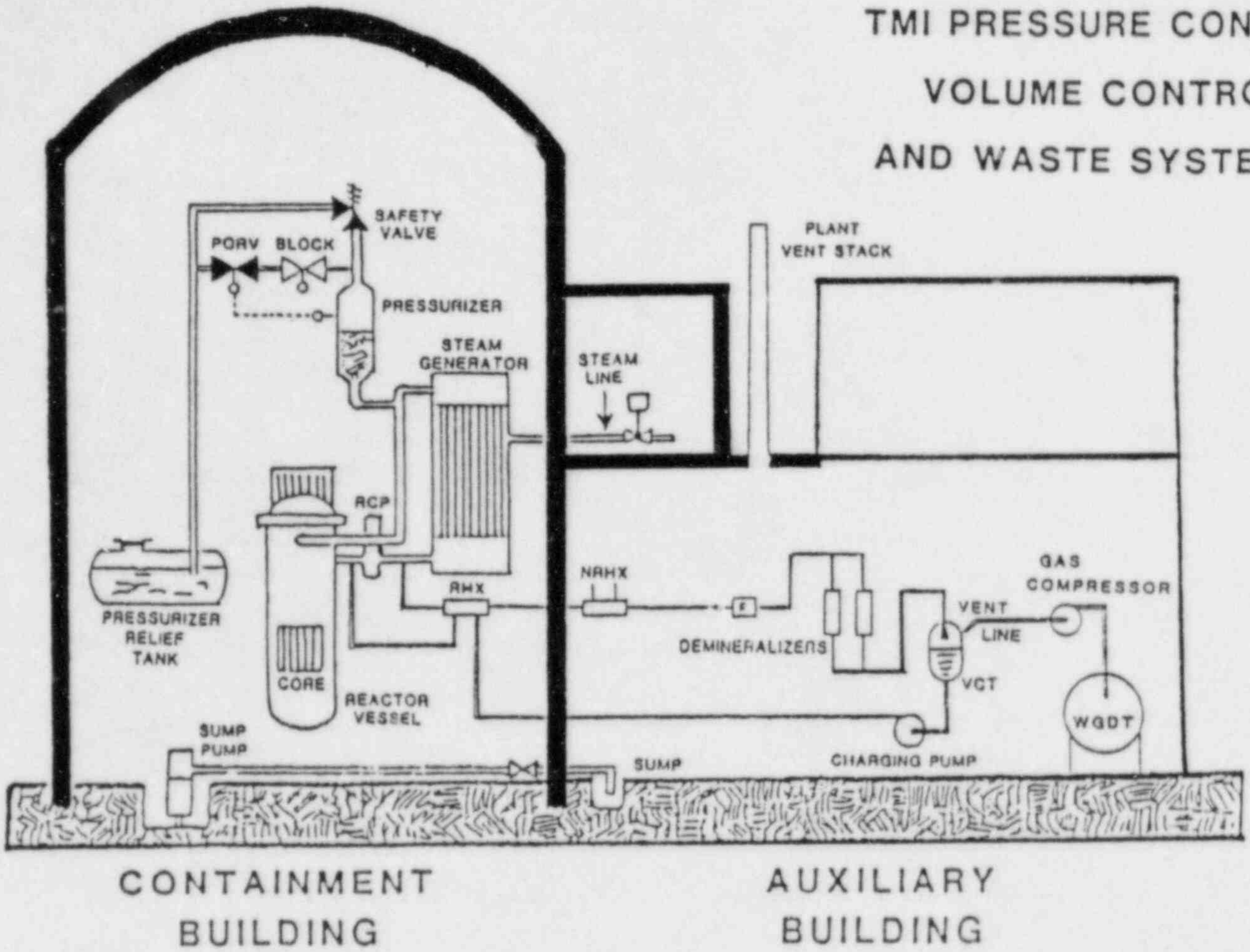
This drawing shows the major reactor coolant system components at Three Mile Island.



TMI REACTOR BUILDING
(CONTAINMENT)

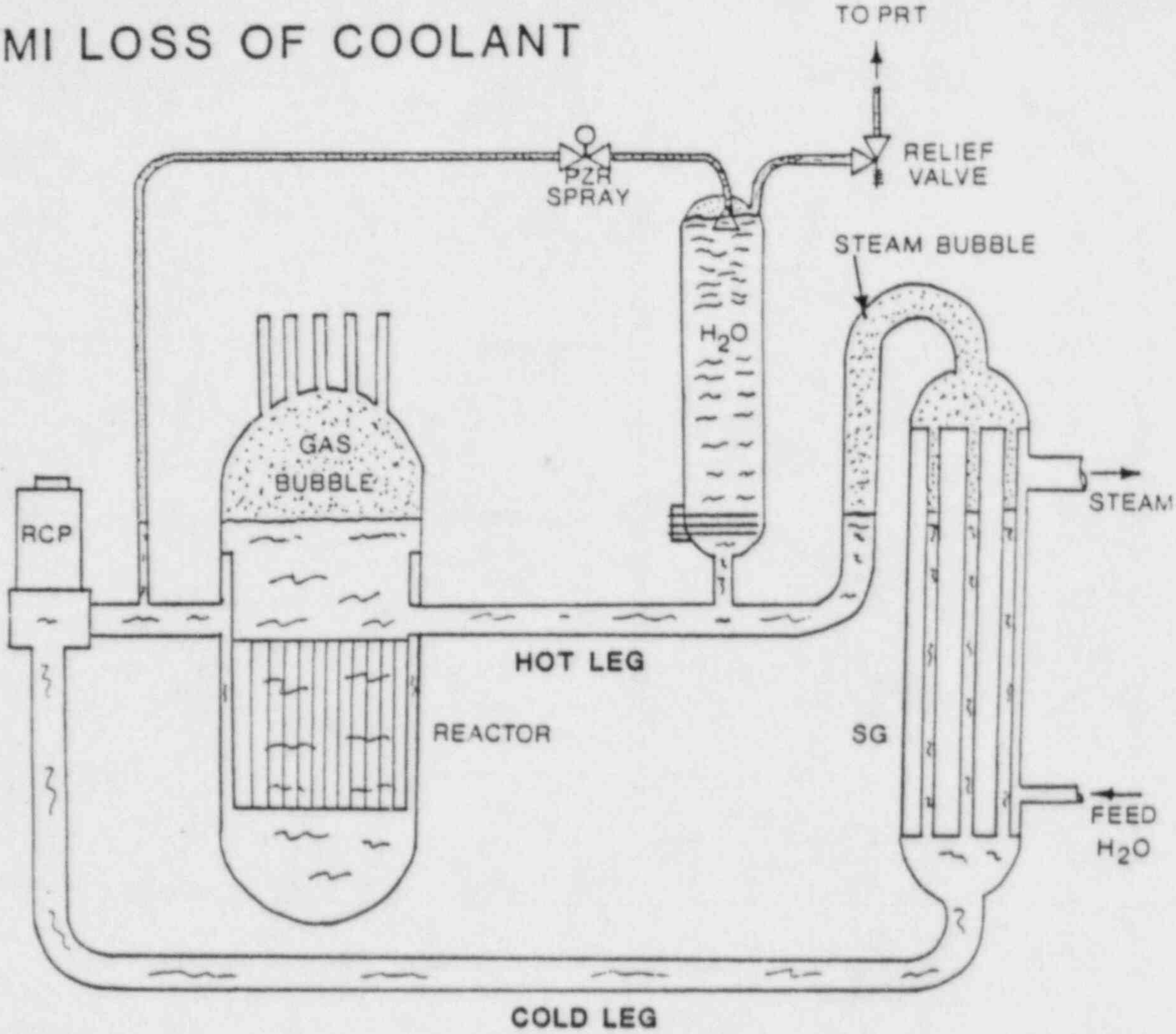
This cutaway drawing shows the layout of components inside the TMI Reactor Building.

TMI PRESSURE CONTROL, VOLUME CONTROL AND WASTE SYSTEMS



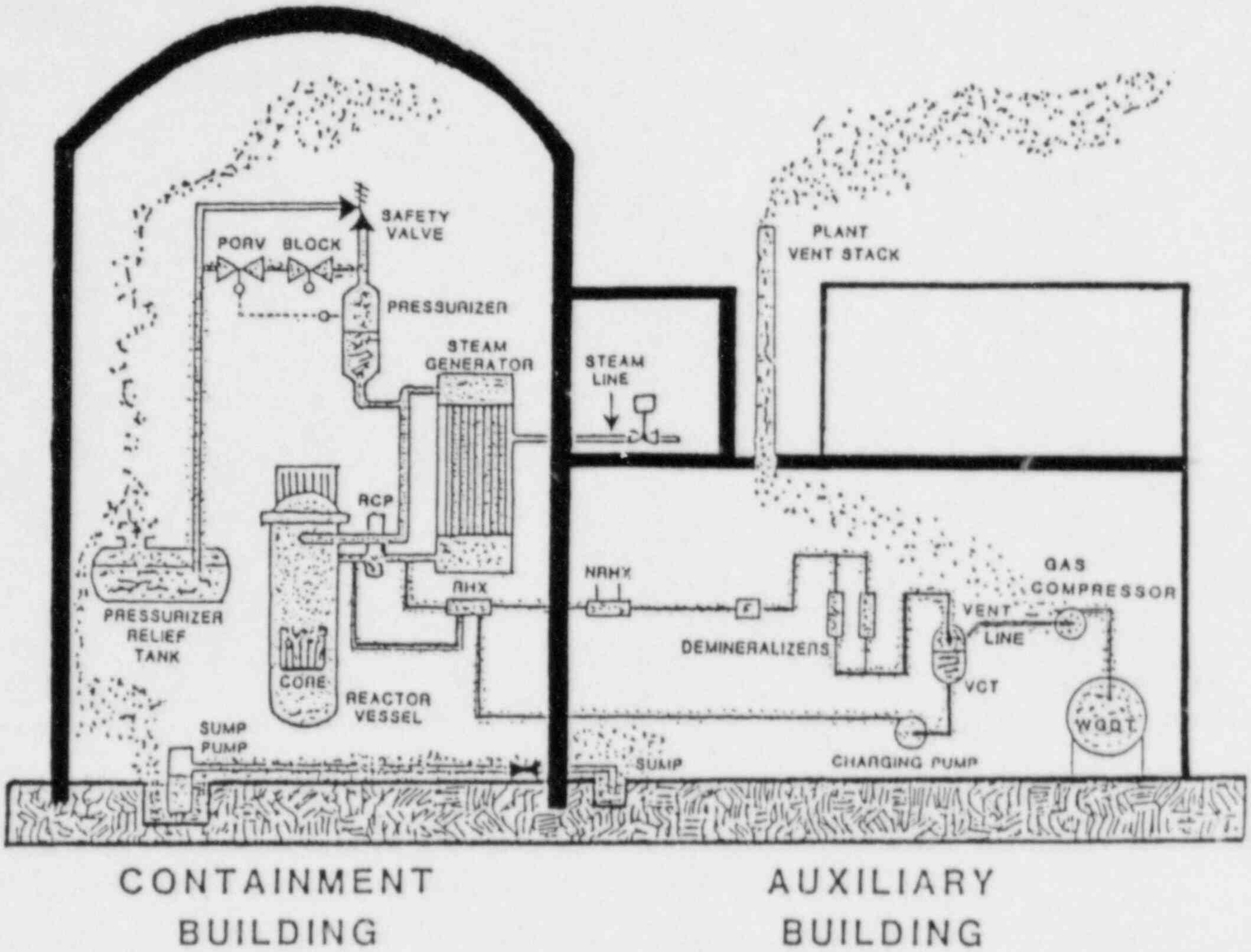
The major systems involved in the TMI radiation release are the Reactor Coolant System, the Pressurizer and its's relief valves, the Chemical and Volume Control System, the Waste Gas Handling System and the Auxiliary Building Ventilation System.

TMI LOSS OF COOLANT

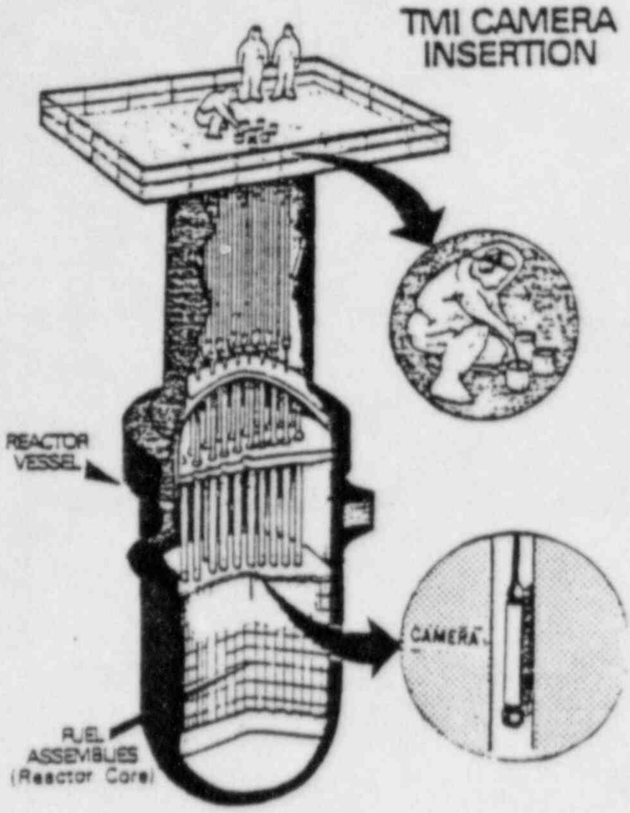


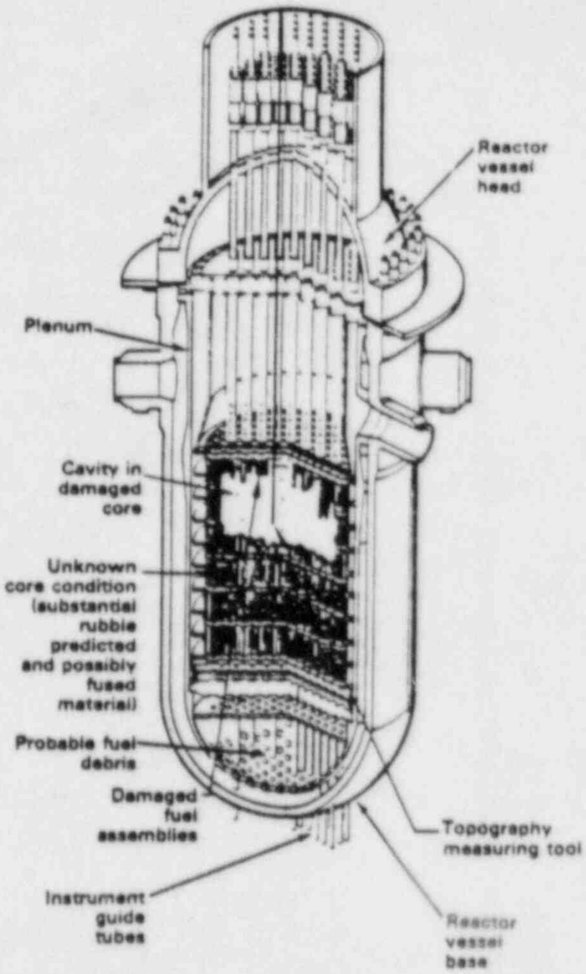
Following a relatively common reactor scram, a pressurizer relief valve stuck open causing a gradual loss of coolant pressure. Automatic safety equipment started as designed but was stopped in order to prevent the pressurizer from overfilling with water. (The rate of water pumped into the Chemical and Volume Control System was increased for this same reason). The resulting low pressure and high temperature caused the coolant water to boil. The low coolant pressure also caused the reactor coolant pumps to be shutdown. With little or no cooling available to remove decay heat, the reactor fuel rods started to crack and breakdown. Some radioactive fission products (mostly gases such as Xenon and Krypton) were released into the reactor coolant. Later, when the stuck open relief valve was isolated, the reactor coolant pumps were restarted. This caused cold water (which had been away from the reactor) to be pumped onto the now very hot and very brittle fuel rods causing severe core damage.

TMI RADIATION RELEASE PATH



Fission products (mostly gases) escaped from the damaged reactor core into the reactor coolant. Reactor coolant was moving through the Auxiliary Building and through the pressurizer. Leakage from the pressurizer relief tank severely contaminated the Reactor Building. The concentration of fission products in the Auxiliary Building piping caused that building to be evacuated. Some of the fission product gases leaked from the Auxiliary Building piping and were picked up by the Auxiliary Building Ventilation System and blown out the plant vent stack.





REACTOR VESSEL SHOWING DAMAGED FUEL AND CAVITY

Television cameras lowered into the TMI core indicate a large void area at the top half of the core and a bed of rubble (fuel pellets, fuel rod debris, etc.) on top of the remaining lower half. The exact condition of the lower portion of the core has not been determined.

TMI CONSEQUENCES

- MAXIMUM PROJECTED OFF-SITE DOSE: LESS THAN 100 m REM
- AVERAGE DOSE TO POPULATION: $\approx$ 1.4 mREM/PERSON
- PROJECTED ADDITIONAL CANCERS: 0-1

Fortunately the environmental and public health consequences of the TMI accident were very small (compared to other industrial accidents) but the psychological effects and the impact on the nuclear industry were (and continue to be) enormous.