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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 26 1980

Ms. Sylvia Colt
83 Horatio Street
New York, NY 10014

Dear Ms. Colt:

This is in reply to your letter of April 5, 1979, about nuclear energy. I am sorry for the long delay in responding, but we have been very busy with the aftermath of the Three Mile Island accident.

After the accident at Three Mile Island, the Nuclear Regulatory Commission decided not to license new nuclear power plants until criteria for improved safety had been developed. The NRC has found that actions recommended by its own staff and by the President's Commission on the Accident at Three Mile Island in the areas of human factors, operational safety, emergency planning, nuclear power plant design and siting, health effects, and public information are necessary and feasible. Interim measures have been taken, and an Action Plan has been developed to include other safety improvements, detailed criteria for their implementation, and various implementation deadlines. Meanwhile, in order to avoid unnecessary delays, the NRC has approved the issuance of licenses for three nuclear power units to load fuel and, under specified conditions, to operate at low power levels for testing.

Every effort is being made to protect the public health and safety at all nuclear power plants that are currently in operation or that may start operating in the future. Any plants that are found to be unsafe will not be allowed to operate.

You asked for information on the process of producing nuclear energy. Enclosed are excerpts on this subject from a report on "Energy Alternatives: A Comparative Analysis."

Sincerely,

Harold Denton

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Enclosure:
As stated

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POOR QUALITY PAGES

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Energy Alternatives: A Comparative Analysis

EXCERPTS

Prepared for

Council on Environmental Quality
Energy Research and Development Administration
    Office of the Assistant Administrator
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CHAPTER 6

THE NUCLEAR ENERGY--FISSION RESOURCE SYSTEM

6.1 INTRODUCTION

6.1.1 History of Nuclear Energy

Commercial use of nuclear fission as an energy source has a history of less than 20 years: the first electric power generating plant went into operation at Shippingport, Pennsylvania in 1957. The use of nuclear power as an energy source grew out of nuclear weapons development during World War II. With the creation of the Atomic Energy Commission (AEC) following the war came an explicit effort by the government to fund and develop the commercial use of nuclear energy. The major rationale behind this development has been the assumption of a large supply of nuclear resources that could one day be substituted for the more limited fossil fuel sources.

The development of nuclear fission as an energy source has been strongly influenced by the complex technologies and the hazards from radioactivity. The complexity of the technologies has required continuous research and development, and as a result, development costs have been higher than the private sector has been willing to bear. Together with the need for regulating radioactive materials, the level of cost has resulted in a major role for the federal government in the development of nuclear energy.

6.1.2 Basics of Nuclear Energy

Nuclear fission is the process whereby certain heavy atoms split into two dissimilar atoms and, in doing so, release energy and one or several neutrons (a basic nuclear particle). The neutrons can then react with other atoms, causing them to fission, and thus create a "chain reaction." The term "nuclear criticality" is used to describe a sustaining chain reaction; that is, the chain reaction will continue until conditions are altered to make the reaction cease. In a nuclear reactor, the controlled chain reaction creates heat, which can be converted to electrical energy.

Three isotopes* fission readily and are usually referred to as fissile** fuels: U-235, Pu-239 (Plutonium-239), and U-233. When an atom fissions, the two newly formed atoms are called fission products or fission fragments. Since the splitting can occur in a variety of different ways, various fission products are formed; for example, strontium, cesium, iodine, krypton, xenon, etc. The nuclear fuels and most of these fission products are radioactive, thereby creating fuel and fuel by-product handling problems that are unique to the nuclear power industry.

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*Isotopes are atoms that contain the same number of protons but a different number of neutrons. Two or more isotopes of an element exhibit similar chemical properties but different physical properties because of their different atomic weight. For example, uranium has three isotopes, Uranium-233, Uranium-235, and Uranium-238. All contain 92 protons but a different number of neutrons.

**Fissile is a term that describes nuclear fuels that will fission when bombarded with low-energy neutrons. Fertile is a term that describes a material which, when bombarded by a neutron, becomes fissile.

6.2 LIGHT WATER REACTOR (LWR) SYSTEM

6.2.1 Introduction

The light water reactor gets its name from the use of ordinary water (terms light water[*]) to transfer heat from the fissioning of uranium to a steam turbine. The primary energy sources for the LWR is U-235, and there are 10 major activities in the LWR fuel cycle as indicated in Figure 6-1: exploration for uranium; mining of uranium ore and reclamation; milling of uranium ore to produce yellowcake (U_3O_8);[**] production of uranium hexaflouride (UF_6); enrichment to produce a higher concentration of U-235; fuel fabrication; use of the LWR to produce electricity; reprocessing of used fuel to recover the remaining U-235 and Pu-239; radioactive waste management; and transportation of radioactive materials at various stages in the LWR system.

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[*] Light water is pure H_2O (two hydrogen atoms plus one oxygen atom). Heavy water is deuterium oxide, D_2O (two deuterium atoms plus one oxygen atom). Deuterium is a heavy isotope of hydrogen.

[**] The product of a milling process that converts ore containing 0.2-percent U_3O_8 into "yellowcake" containing approximately 80-percent U_3O_8.

6.2.5.4 Fuel Fabrication

The fuel fabrication step converts the enriched UF_6 into UO_2 pellets and then encases them in long metal tubes known as cladding. From 50 to 200 of the cladding tubes are positioned in a grid to form a fuel assembly. Several of these fuel assemblies are shipped to an LWR each year.

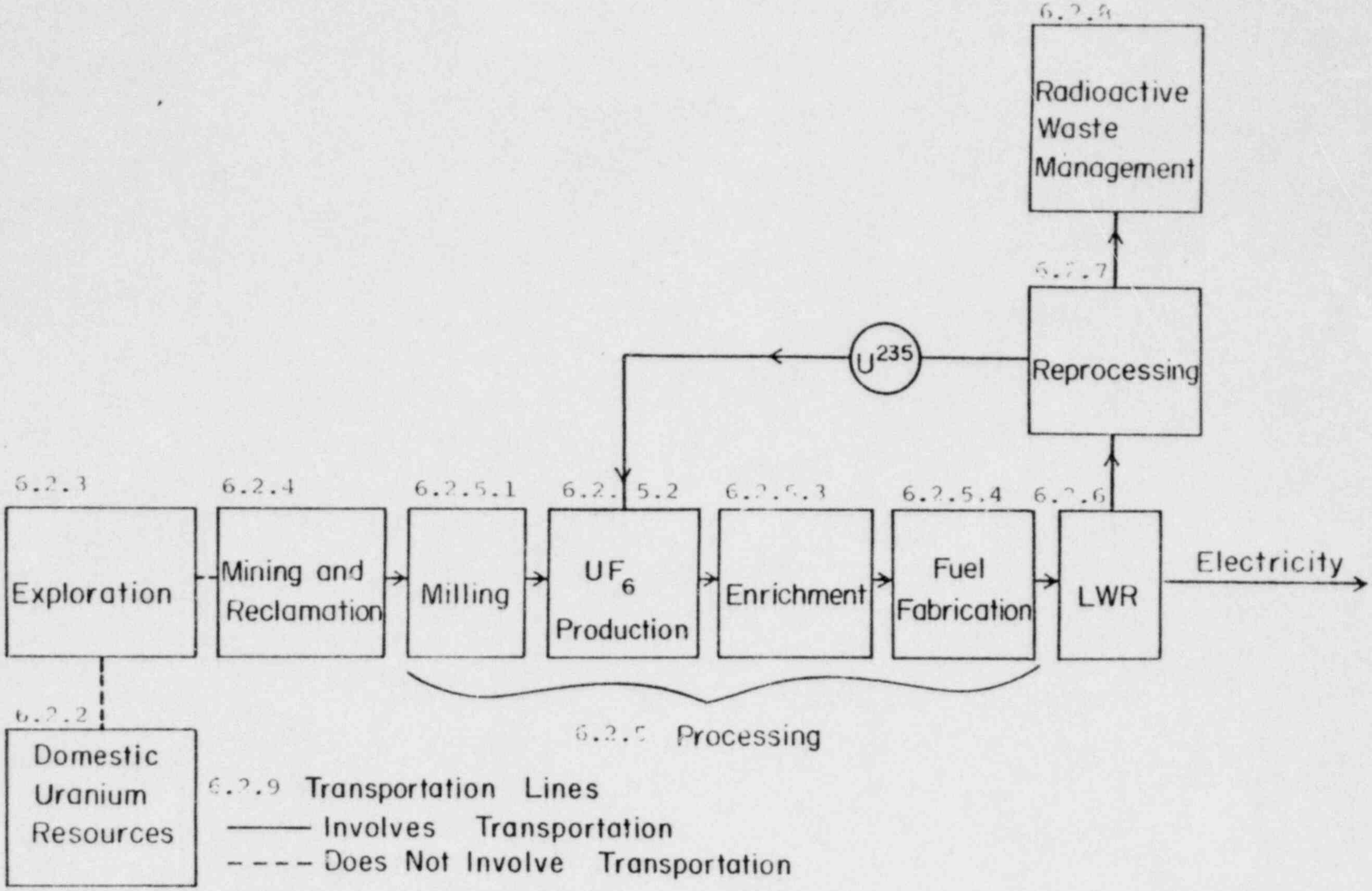

Figure 6-1. Light Water Reactor Fuel Cycle

6.2.6 Light Water Reactors

6.2.6.1 Technologies

A nuclear-electric power plant is similar in nature to the fossil-fueled power plants described in Chapter 12 except that the nuclear steam supply system replaces the conventional fuel boiler and the nuclear fuel core replaces the fossil fuel supply. In LWR's, the heat energy comes basically from the fissioning of U-235 atoms, with a small contribution from the fissioning of U-238 atoms. However, as the reactor operates, a fissile atom (Pu-239) is produced from U-238. For each gram of U-235 consumed in LWR fuel, as much as 0.6 gram is formed. Generally more than half of the plutonium formed undergoes fission in the core, thus contributing significantly to the energy produced in the power plant (AEC, 1974d: Vol. IV, p. A.1.1-2). LWR's typically employ partial refueling annually, with somewhere between one-fourth and one-third of the fuel assemblies being removed and replaced with fresh fuel each year. Spent fuel assemblies are stored underwater at the power plant for a period of five to six months to allow their radioactivity level to decrease prior to shipment to a fuel reprocessing plant (AEC, 1974d: Vol. IV, p. A.1.1-15). Since the historical origin of nuclear power is from nuclear weapons, it is important to point out that a nuclear reactor cannot explode like a bomb. A different type of fuel and different fuel configuration are used in a reactor.

There are currently two different types of U.S. LWR's: the boiling water reactor (BWR) manufactured by General Electric and the pressurized water reactor (PWR) manufactured by Babcock and Wilcox, Combustion Engineering, and Westinghouse.

6.2.6.1.1 Boiling Water Reactors

Figure 6-9 is a simplified schematic of a boiling water reactor. In this type of reactor, water is pumped in a closed cycle from the condenser to the nuclear reactor. In the reactor core, heat generated by the fissioning uranium pellets is transferred through the metal cladding to the water flowing around the fuel assemblies. The water boils and a mixture of steam and water flows out the top of the core and through steam separators in the top of the pressure vessel. The separators clean and "dry" the steam before it is piped to the turbine-generator(s). The turbine exhaust is condensed and returned to the reactor pressure vessel to complete the cycle. (See Chapter 12 for a more complete description of steam power plants).

Because the energy supplied to the water from the hot fuel is transported directly (as steam) to the turbine, the BWR system is termed a "direct cycle" system The pressure in a typical BWR is maintained at about 1,000 pounds per square inch (psi), with a steam temperature of 545°F (AEC, 1974d: Vol. IV, p. A.1.1-18). Neutron-absorbing control rods, operated by hydraulic drives located below the vessel, are used to control the rate of the fission chain reaction (and thus the heat output).

One major concern with light water reactors is an accidental depressurization or coolant loss (e.g., resulting from a high-pressure steam pipe rupture). If no safety measures were in effect, such events would cause the core to overheat and melt, and

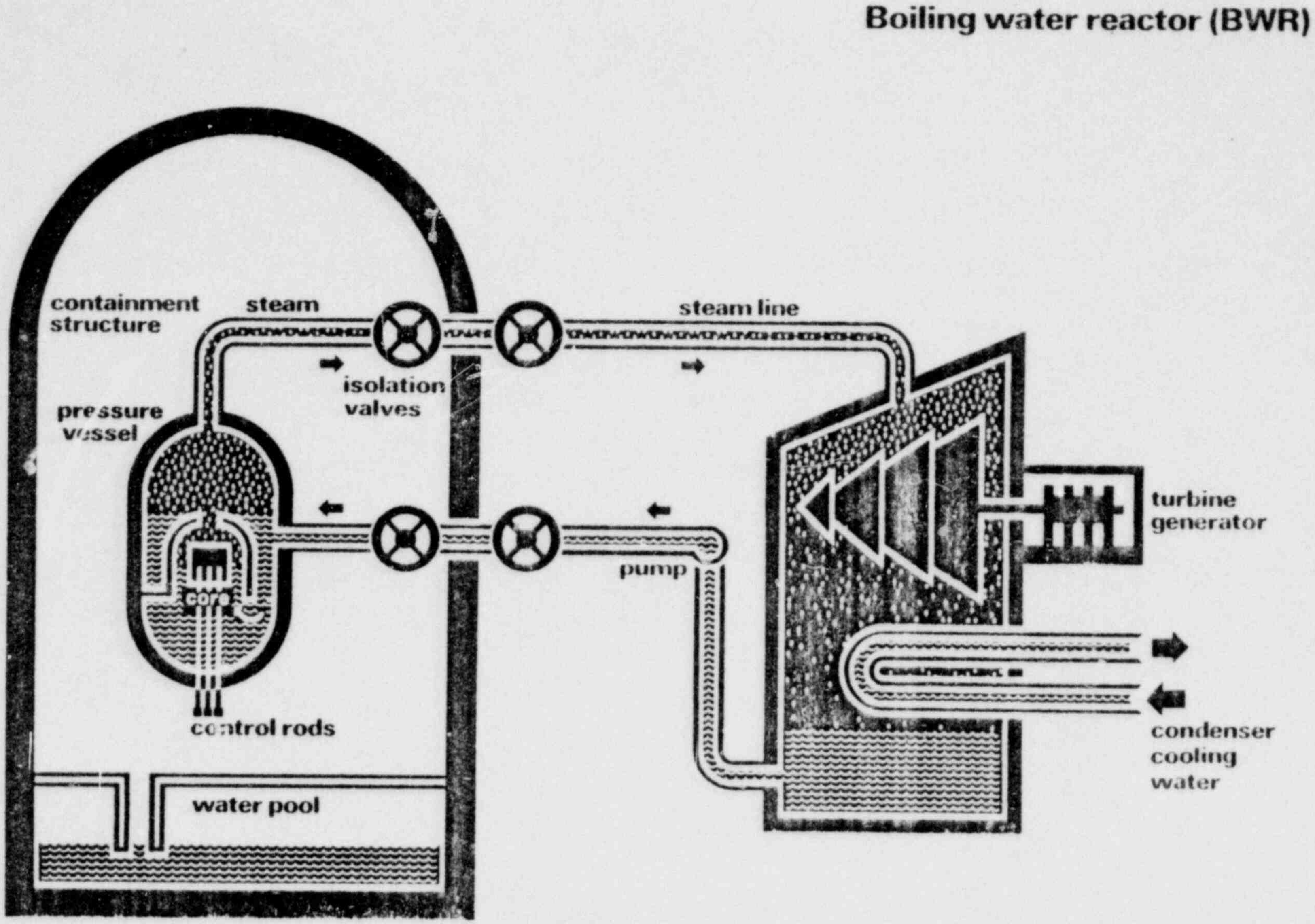

Figure 6-9. Boiling Water Reactor

Source: Atomic Industrial Forum, Incorporated.

large amounts of high-level radioactivity might be released to the environment. To prevent such catastrophes, reactor systems include emergency core cooling systems (ECCS's) to prevent meltdowns and containment systems for preventing the release of radioactivity in the event of any type of accident.

Although provisions differ from plant to plant, all BWR's have multiple provisions for cooling the core fuel in an emergency. Typical ECCS's involve either a high-pressure core spray system (early BWR's) or both core sprays and a high-pressure coolant-injection system (latest BWR's) to assure adequate cooling of the core in the event of reactor system depressurization (AEC, 1974d: Vol. IV, pp. A.1.1-20).

To prevent such accidents from releasing radioactivity and other pollutants to the environment, BWR designs generally provide both "primary" and "secondary" containment. The primary containment system, shown in Figure 6-9 as the "containment structure," is a steel pressure vessel surrounded by reinforced concrete and designed to withstand the peak transient pressures that might occur in the most severe of the postulated loss-of-coolant accidents. The primary containment system employs a "drywell," which encloses the entire reactor vessel and its recirculation pumps and piping. The drywell is connected to a lower-level, pressure suppression chamber in which a large pool of water is stored. In the event of an accident, valves in the main steam lines from the reactor to the turbine-generators (the "isolation valves" in Figure 6-9) would close automatically and any steam escaping from the reactor system would be released into the drywell. The resulting increase in drywell pressure would force the air-steam mixture in the drywell down into and through the large pool of water where the steam would be completely condensed, thereby preventing any large pressure buildup. This pressure injection pool also serves as a potential source of water for the emergency core spraying system (AEC, 1974d: Vol. IV, p. A.1.1-21).

The "secondary" containment system is the building that houses the reactor and its primary containment system (not shown in Figure 6-9). Reactor buildings are constructed of poured-in-place, reinforced concrete and have sealed joints and interlocked double-door entries. Under accident conditions, the normal building ventilation system would shutdown, and the building would be exhaust-ventilated by two parallel standby systems. These ventilating systems incorporate effluent gas treatment devices, including high-efficiency particulate cleaners and solid absorbents for trapping radioactive halogens (particularly iodine) that might have leaked from the primary containment system (AEC, 1973: 1-24).

6.2.6.1.2 Pressurized Water Reactors

Figure 6-10 is a simplified schematic of a pressurized water reactor. The primary difference between a PWR and a BWR is that all PWR's employ a dual coolant system for transferring energy from the reactor systems. In the dual coolant system, the primary loop is water that is pumped through the core and the heat exchanger. The secondary loop is water that is pumped through the heat exchanger and the turbine. The water is heated to about 600°F by the nuclear core in the pressure vessel, but pressure is sufficiently high (about 2,250 psi) to prevent boiling. The high-pressure water is piped out of the reactor vessel into usually two or more "steam generators" that form a basic heat exchanger. The primary heat is transferred to the secondary stream. The secondary stream boils, providing steam for the turbine. The secondary stream is then condensed and the water is pumped back to the

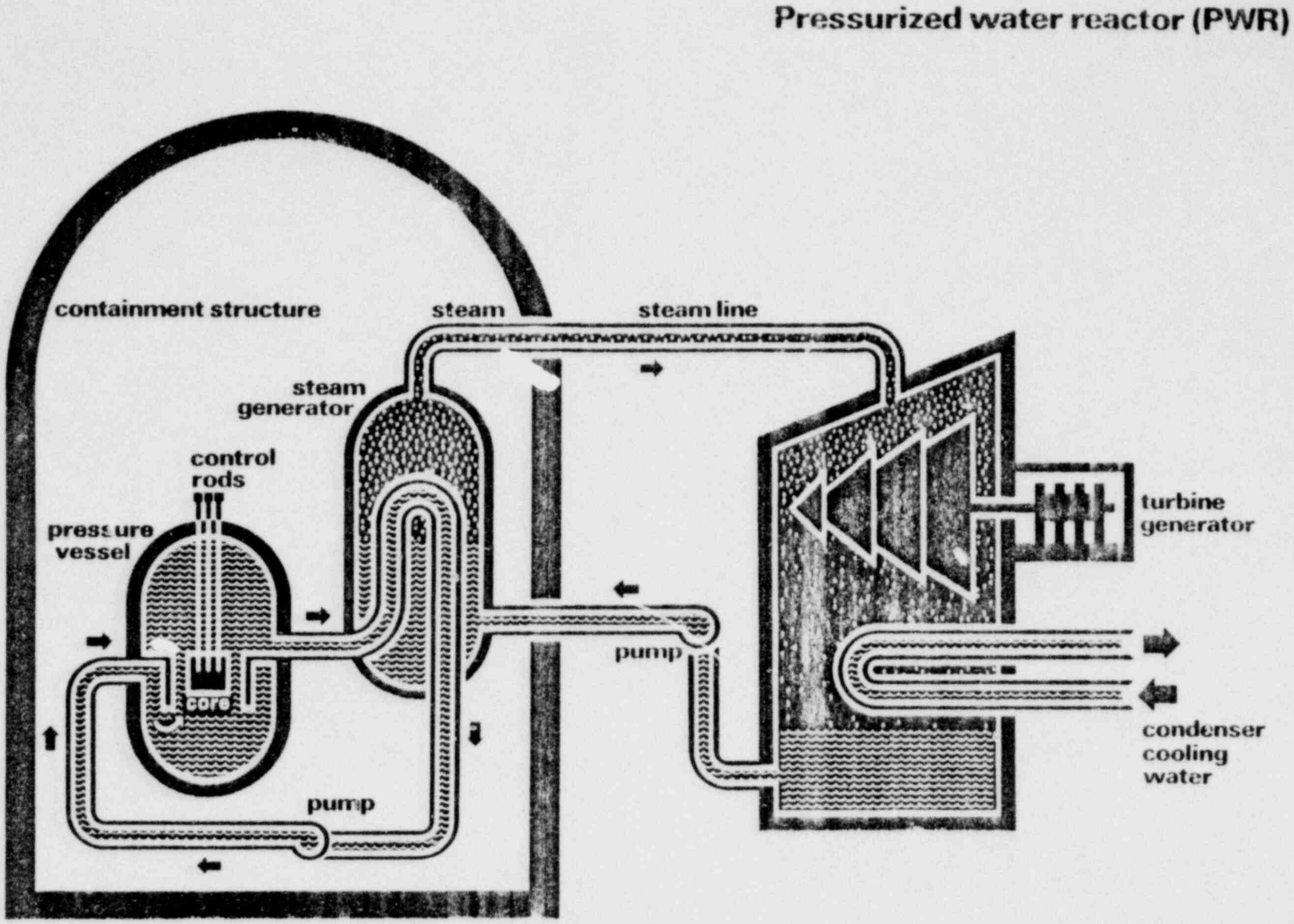

Figure 6-10. Pressurized Water Reactor

Source: Atomic Industrial Forum, Incorporated.

steam generator to begin the cycle over. No steam is generated in the primary loop and the water is returned to the core from the steam generator to start the primary cycle over. As in BWR's, the nuclear chain reaction is controlled through the use of neutron-absorbing rods; however, in PWR's, additional control can be obtained through the dissolution of such variable-concentration neutron-absorbing chemicals as boron (which may also serve other purposes) in the primary system coolant.

The PWR ECCS's consist of several independent subsystems, each characterized by redundancy of equipment and flow path. Although the arrangements and designs of PWR ECCS's vary from plant to plant (depending on the vendor of the steam supply system), all modern PWR plants employ both accumulator injection systems and pump injection systems. Accumulator injection systems are called passive systems because they operate automatically without activation of pumps, motor driven valves, or other equipment. The systems consist of pressurized tanks of cool borated water which are connected through check valves to the reactor vessel. Should the primary coolant system lose pressure, the check valves would open and a large volume of water would be rapidly discharged into the reactor vessel and core. Two pump injection (active) systems are also incorporated in PWR ECCS's. One is a low-pressure system to provide coolant after the above mentioned accumulator tanks are empty, and the other is a high-pressure system designed to function if the break is small and the primary coolant pressure remains too high to activate the passive systems (AEC, 1973: 1-14).

The containment structure for PWR's is of reinforced concrete with a steel liner and is stressed to withstand the maximum expected temperature and pressure if all the water in the primary system was expelled into the containment. However, containment system designs vary widely from plant to plant. For example, in some plants, the containment space is kept slightly below atmospheric pressure so that leakage through the containment walls would, at most times, be inward from the surroundings. Other systems have double barriers against escape of material from the containment space. In addition, to condense the steam resulting from a major break of the primary system, either cold-water sprays or stored ice is provided (AEC, 1973: 1-17).

6.2.6.2 Energy Efficiencies

The overall energy efficiency for the power plant is the ratio of electric energy output to total heat energy produced. LWR's (both BWR's and PWR's) have energy efficiencies around 32 percent, as compared to 38 to 40 percent for modern fossil-fueled plants (see Chapter 12). The reason for this lower efficiency is that LWR plants can only operate at a maximum steam temperature of around 600°F while fossil plants can operate at 1,000°F or higher.