SECTION 9.14
NUCLEAR

9.14.1
NUCLEAR ELECTRIC GENERATION

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APPLICATION

The primary difference between the pumps for nuclear service and conventional steam generation is the stringent requirements for reliability and safety. The continuous functioning of nuclear pumps is critical to the safe operation of the plant. In addition, many of these units maintain the responsibility of ensuring safe shutdown of the facility during emergency conditions. Because the release of radioactive fluids could result in potential personnel and environmental hazards along with associated costly clean-up, nuclear pumps must be self-contained. The rules and regulatory standards for nuclear pumps are dedicated to the promotion of public safety through reliable operation. Pump manufacturers must be fully knowledgeable of these standards and certified by the American Society of Mechanical Engineers (ASME) (or an equivalent authority outside the United States) before they can offer pumps for the nuclear market.

All nuclear power plants built for public utility service involve the generation of steam. The method of steam generation differentiates the two major types of plants. The pressurized water reactor (PWR) employs two distinct systems, a primary and a secondary loop. The primary loop circulates pressurized radioactive fluid from the reactor to the steam generator where it heats the secondary fluid. The secondary loop directs steam from the steam generator to the turbines and condensed fluid back to the generators. A boiling water reactor (BWR), on the other hand, only employs one loop. The steam is generated in the reactor and then circulated through the turbines, condensers, and heaters and back to the reactor.

It is usual for the plant to contain one major system, or loop, and a number of supporting systems. Because virtually every system requires some form of pumping, it is conventional to designate each pump by the name of the system with which it is associated. For each of the systems previously discussed, the main and auxiliary systems are reviewed, including brief descriptions of the pumping requirements.

PWR Plants Pressurized water reactor (PWR) plants employ two separate main systems to generate steam. In the primary system, the water is circulated by *reactor coolant pumps* through the nuclear reactor and large steam generators. Overpressure is provided to prevent vapor formation. The secondary side of the steam generator provides nonradioactive steam to the turbogenerator. Typical primary water conditions are 2250 lb/in^2 gauge (15.51 MPa) and 550°F (288°C). Table 1 lists the parameters of the more important pumps used in PWR plants.

Figure 1 is a simplified flow diagram of a PWR reactor coolant system. Only one primary loop is shown, but in practice, plants use two, three, or four loops in parallel, each loop consisting of its own reactor coolant pump, steam generator, and optional stop valves. A single reactor and pressurizer supply all loops. The pressurizer provides the overpressure referred to by maintaining a body of water at an elevated temperature such that its vapor pressure satisfies the primary loop pressure requirements.

In the PWR plant, high-pressure water circulates through the reactor core to remove the heat generated by the nuclear chain reaction. Figure 2 is an illustration of a typical PWR reactor vessel. The heated water exits from the reactor vessel and passes via the coolant loop piping to the primary side of the steam generators. Here it gives up its heat to the feedwater to produce steam for the turbogenerator. The primary-side cycle is completed when the reactor water is pumped back to the reactor by the reactor coolant pumps. The secondary-side cycle, isolated from the primary loops, is completed when the *feedwater pumps* return water to the secondary side of the steam generator.

Because a reactor, after it has been critical, continues to generate heat even when shut down, *residual heat removal* (RHR) *pumps* are provided to circulate reactor water through coolers any time the reactor is inoperable and at low pressure, even during refueling. These pumps serve other functions also, as described next.

The chemical and volume control system (Figure 3) performs a number of functions. Through *charging pumps,* which may be centrifugal or positive displacement or may include some of each type, the primary system can be filled and pressurized when cold. When the system is hot, the pumps are used to maintain the water level in the pressurizer and to replenish any fluid drawn from the primary loops by other systems. Additionally, the pumps supply clean water to the reactor coolant pump seals and are used to adjust the boric acid concentration in the reactor coolant water, which provides an auxiliary means of reactor power regulation. If positive displacement pumps are included in the chemical and volume control system, they are also used to hydrostatically test the reactor primary coolant system. Where all the charging pumps are centrifugal, it is customary to provide a small positive displacement pump exclusively for this hydrostatic testing.

For cooling essential components and for supplying a variety of heat exchangers, a component cooling water system is provided. *Component cooling water pumps* circulate clean water at low system pressures for the purpose of cooling (1) primary water, which is continuously bled for purification, (2) main and auxiliary pump bearings and seals, (3) primary pump thermal barriers, (4) large motors, (5) the containment vessel, and (6) the spent fuel pit water.

When the primary pressure boundary is breached, elements of the emergency core cooling system (ECCS) are immediately activated. The primary function of the ECCS following a loss-of-coolant accident is to remove the stored and fission product decay heat from the reactor core. The safety injection system (Figure 4) does most of this. Upon actuation of the safety injection signal, the charging pumps inject boric acid solution, which is stored in special tanks and continuously circulated by the *boron injection recirculation pumps,* into the reactor coolant system. At the same time, the *residual heat removal pumps* are started. These pumps take suction from a large refueling water storage tank and inject cold water into the reactor coolant circuit. To provide additional capacity, the *safety injection pumps* are started, taking suction from the cold water in the refueling water storage tank and pumping this water into the reactor coolant system. If the large storage tank should run dry, these pumps will take suction from the containment sump.

Operated by a pressure signal, *containment spray pumps* condense any steam in the containment in order to lower the temperature and pressure in that environment. By taking suction from the containment sump, these pumps continue to circulate water through spray nozzles located near the top of the containment until the pressure has been reduced to an acceptable level.

TABLE 1 Typical nuclear pump parameters in PWR plants

Pump	Number per plant	Flow, gpm (m^3/h)	Head, ft (m)	Design pressure, lb/in^2 (MPa)	Design temp., °F (°C)	Driver hp (kW)	Shaft	Length or height, including driver, in (mm)	Speed (nominal), rpm	Notes
Reactor coolant	4	100,000 (22,700)	290 (88)	2500 (17.2)	650 (343)	7000 (5220)	Vert.	305 (7750)	1200	
Component cooling water	3	4800 (1090)	250 (76)	200 (1.38)	200 (93)	450 (336)	Horiz.	110 (2790)	1800	
Residual heat removal	2	3800 (863)	350 (107)	600 (4.14)	400 (204)	500 (373)	Vert.	97 (2460)	1800	
Containment spray	2	2600 (590)	450 (137)	300 (2.07)	300 (148)	400 (298)	Horiz.	112 (2840)	1800	
Spent fuel pit cooling	3	4500 (1022)	150 (46)	150 (1.03)	200 (93)	250 (186)	Horiz.	87 (2210)	1800	
Charging (centrifugal)	2	120 (27)	5800 (1768)	2800 (19.3)	300 (148)	600 (448)	Horiz.	234 (5940)	4850	Gear drive
Charging (reciprocating)	1	98 (22)	5800 (1768)	2800 (19.3)	250 (121)	200 (149)	Horiz.	208 (5280)	205	Reciprocating
Safety injection	2	440 (100)	2680 (817)	1750 (12.07)	300 (148)	450 (336)	Horiz.	190 (4830)	3600	
Chilled water	2	400 (91)	150 (46)	150 (1.03)	200 (93)	40 (30)	Horiz.	52 (1320)	3600	
Spent resin sluicing	1	150 (34)	250 (76)	240 (1.66)	250 (121)	30 (22)	Horiz.	46 (1170)	3600	
Reactor coolant drain tank	2	150 (34)	250 (76)	240 (1.66)	250 (121)	30 (22)	Horiz.	46 (1170)	3600	

TABLE 1 Continued.

Pump	Number per plant	Flow, gpm (m^3/h)	Head, ft (m)	Design pressure, lb/in^2 (MPa)	Design temp., °F (°C)	Driver hp (kW)	Shaft	Length or height, including driver, in (mm)	Speed (nominal), rpm	Notes
Boric acid transfer	2	100 (22.7)	200 (61)	150 (1.03)	200 (93)	15 (11)	Horiz.	45 (1140)	3600	
Boron recycle evaporator feed	2	100 (22.7)	200 (61)	150 (1.03)	200 (93)	15 (11)	Horiz.	45 (1140)	3600	
Boron injection recirculation	2	20 (4.5)	100 (30.5)	240 (1.66)	200 (93)	3 (2.2)	Horiz.	18 (460)	3600	Canned
Spent fuel pit skimmer	1	100 (22.7)	50 (15.2)	150 (1.03)	200 (93)	3 (2.2)	Horiz.	42 (1070)	1800	
Refueling water purification	1	200 (45)	200 (61)	150 (1.03)	200 (93)	30 (22)	Horiz.	52 (1320)	1800	
Waste processing system	5	100 (22.7)	200 (61)	150 (1.03)	200 (93)	15 (11)	Horiz.	45 (1140)	3600	
Gas decay tank drain	1	10 (2.27)	90 (27)	150 (1.03)	180 (82)	3 (2.2)	Horiz.	15 (380)	3600	
S. G. blowdown—spent resin sluice	1	110 (25)	165 (50)	150 (1.03)	100 (37)	15 (11)	Horiz.	39 (990)	3600	

Source: Westinghouse Electric.

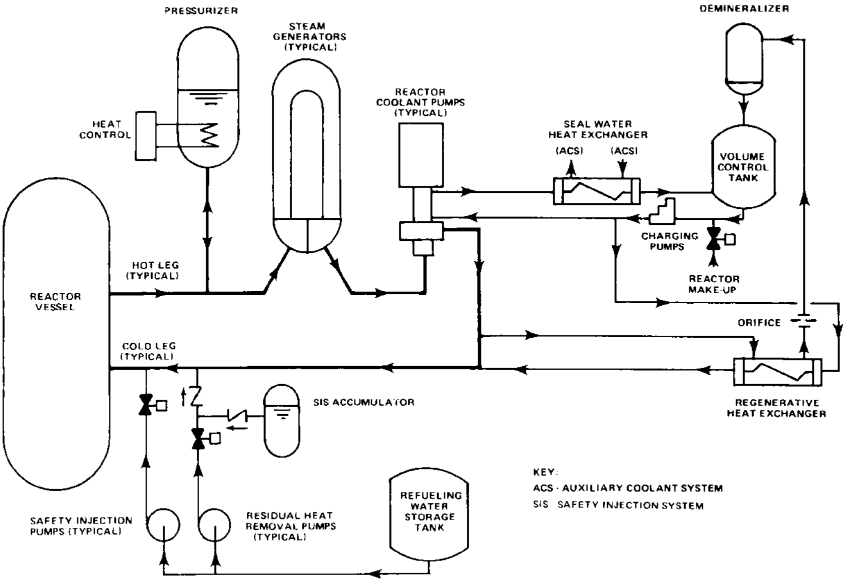

FIGURE 1 Flow diagram for pressurized water reactor coolant system (Westinghouse Electric)

All of the pumps and vital equipment associated with pipe rupture (that is, the emergency core cooling system) is supplied with diesel generator electrical power backup. If needed, the diesel generators will accept the various pump loads sequentially at intervals of a few seconds until all needed equipment is on line.

Other pumps serve other systems. *Spent fuel pit pumps* provide the necessary cooling of the fuel elements that have been removed from the reactor. Resin beds, which are a part of the water purification system, are flushed to a storage tank by *spent resin sluicing pumps.* An evaporator package, partly for removing boron from the primary water, is supplied by *recycle evaporator feed pumps. Chilled water pumps* supply the boron thermal regeneration system. Similarly, other pumps, some not listed in Table 1, support auxiliary systems.

BWR Plants In boiling water reactor (BWR) plants, active boiling takes place in the nuclear core and steam is piped to the turbogenerator (Figure 5). Typical reactor water conditions are 1000 lb/in^2 gauge (6.895 MPa) and 550°F (288°C). In the United States, the plant is usually arranged with a low-leakage containment vessel completely surrounding a dry well and a pressure-suppression pool (Figure 6). The containment vessel is a cylindrical steel or concrete structure with an ellipsoidal dome and a flat bottom supported by a reinforced concrete mat. The containment forms a security barrier and prevents the escape of radioactive products to the atmosphere if an accident should occur.

Table 2 shows the principal pumps used in BWR plants together with significant characteristic data.

To assure a high reactor flow rate and to avoid local areas of core overheating, internal *jet pumps* have been used in all but the earliest U.S. BWR plants. These jet pumps are driven by large-volume, medium-head *recirculation pumps.* Variable flow rate is achieved either by flow control valves or by variable-speed motors driven by motor generator sets. The latest designs employ a flow control valve. The use of jet pumps decreases the size of the external loop piping and pumps and provides a core reflood capability in the event of pipe rupture. The main recirculation pumps are not required for emergency cooling. In

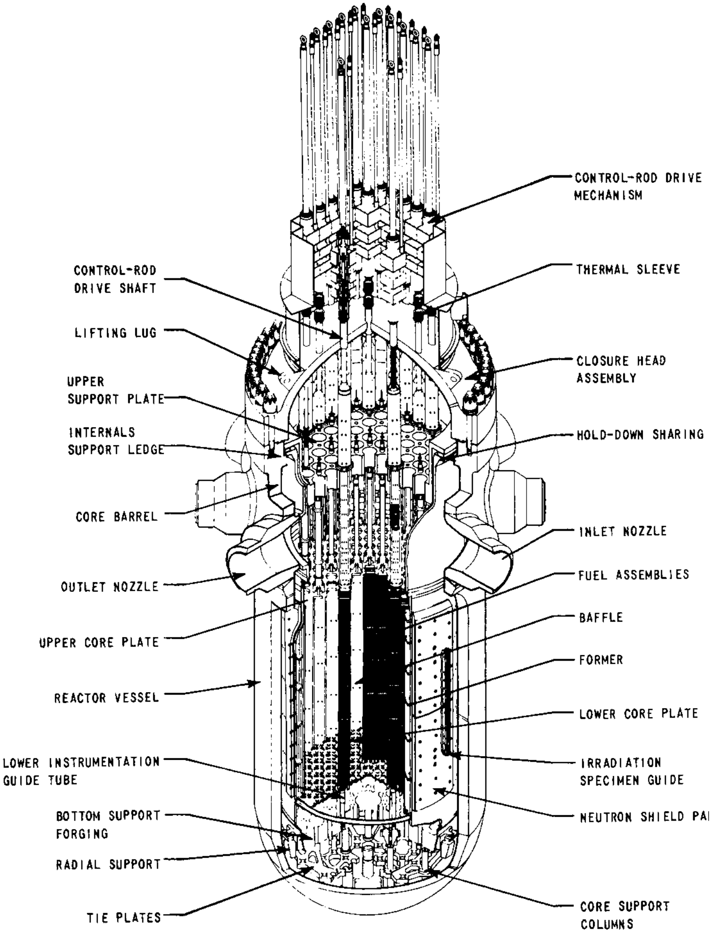

FIGURE 2 PWR reactor vessel (Westinghouse Electric)

normal operation, the recirculation pumps operate in conjunction with the jet pumps, which are wholly contained in the reactor vessel. The purpose of the jet pumps is to increase the flow from the recirculation pumps at reduced head for reactor cooling. The jet pumps have no moving parts. In addition to their normal service, they also play a role in the natural circulation of the reactor water during emergency cooling.

Several subsystems operate in support of the recirculation system, and each contains one or more pumps. *Reactor water cleanup pumps* are used in a filter-demineralizer system to remove particulate and dissolved impurities from the reactor coolant. This system also removes excess water from the reactor. The control rods are operated hydraulically with water pressure provided by the *control rod drive pumps.* The pumps are located in an auxiliary building, and the fluid is piped to the control rod drive units, which are posi-

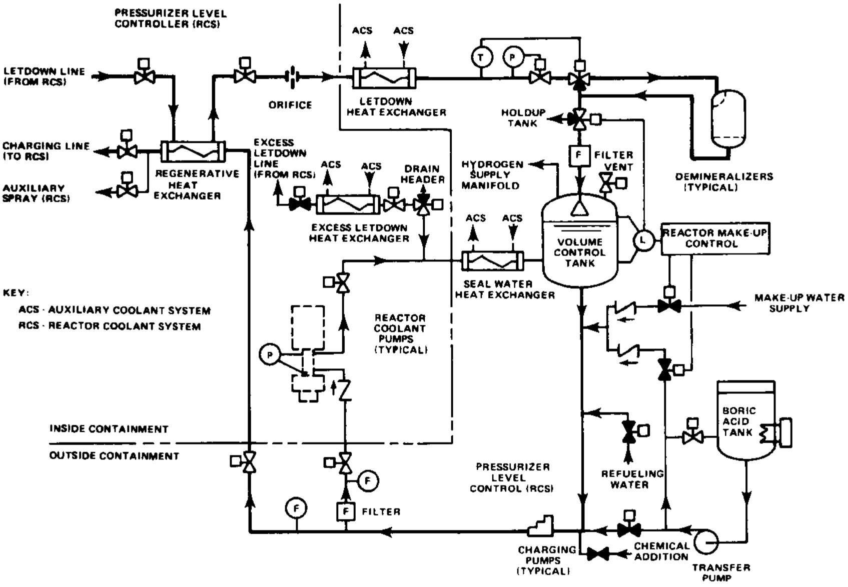

FIGURE 3 Flow diagram for chemical and volume control system (Westinghouse Electric)

tioned directly under the reactor vessel. For those components that require constant cooling, such as the recirculation pump motors and other equipment located in the containment, auxiliary, fuel, or radwaste buildings, *closed cooling water pumps* furnish the necessary flow. These pumps are located in an auxiliary building to permit ready access for servicing if needed. The system is closed so it can be isolated from an ultimate, usually raw water, heat sink, such as a river, lake, or ocean.

To cool the fuel stored under water in the fuel building and the water in the upper containment, separate *fuel pool cooling pumps* are provided in an independent system.

The emergency core cooling system is in reality an array of subsystems providing the necessary features, including redundancy, to protect the core in case of a significant malfunction. The high-pressure core spray system uses a vertical *high-pressure core spray pump,* motor-driven but backed by a diesel generator in event of loss of electric power. This pump, a single unit, provides the initial response when a small pipe breaks or an equivalent malfunction occurs. Should this system be inadequate to maintain reactor water level, the reactor vessel is automatically depressurized and the *low-pressure core spray pumps* supply additional capacity. As an added safeguard, the *RHR pumps* are used in a secondary-mode operation to inject cooling water directly into the reactor vessel. If steam should enter the containment region, the *RHR pumps* operate in another mode—as containment spray pumps—and are manually operated to condense the steam and thus reduce any potential pressure buildup in the containment. The *RHR pumps* function when needed to limit the temperature of the water in the suppression pool. The turbine-driven *reactor core isolation cooling pumps,* in a redundant and independent system, inject cool water into the reactor vessel. The *standby liquid control system pumps* inject boron solution into the reactor for alternative shutdown.

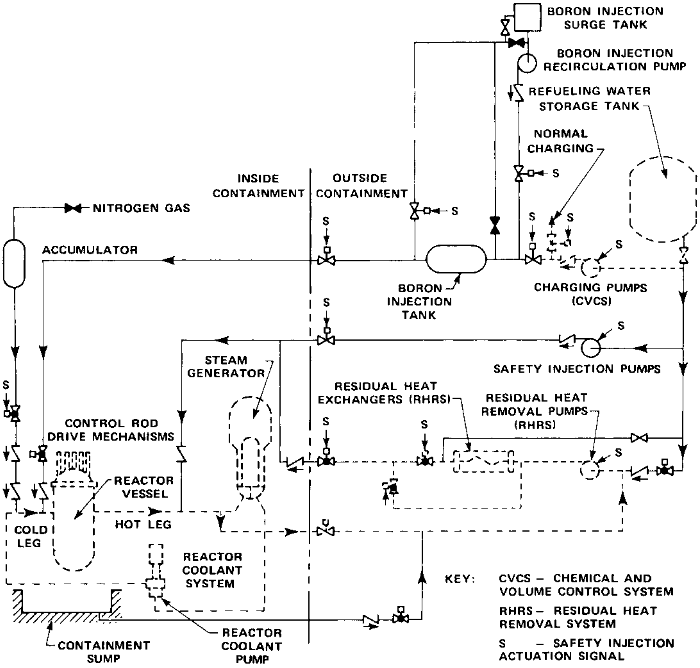

FIGURE 4 Flow diagram for safety injection system (Westinghouse Electric)

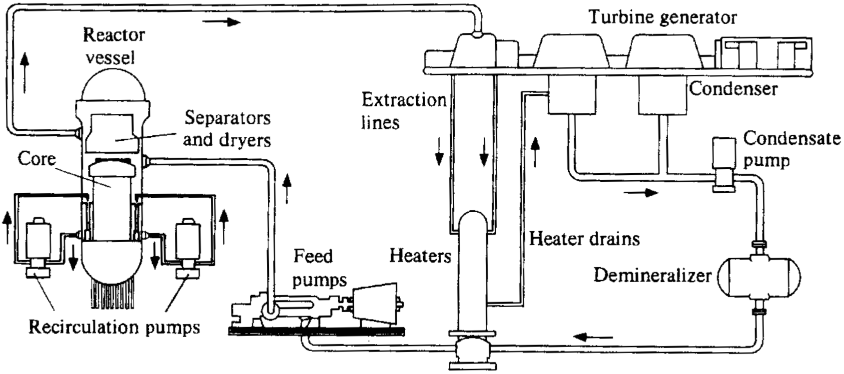

FIGURE 5 Boiling water direct cycle reactor system (General Electric)

Additional Equipment In addition to these systems, a number of support systems exist, most of which require some form of pumping. Without attempting to describe their systems, there are, for example, pumps for feedwater, condensate, chilled water, booster service, condenser service, demineralized water transfer, condensate transfer, dry-well drain, containment drain, concentrated borated water tank, water leg, precoat, radwaste, and sample station.

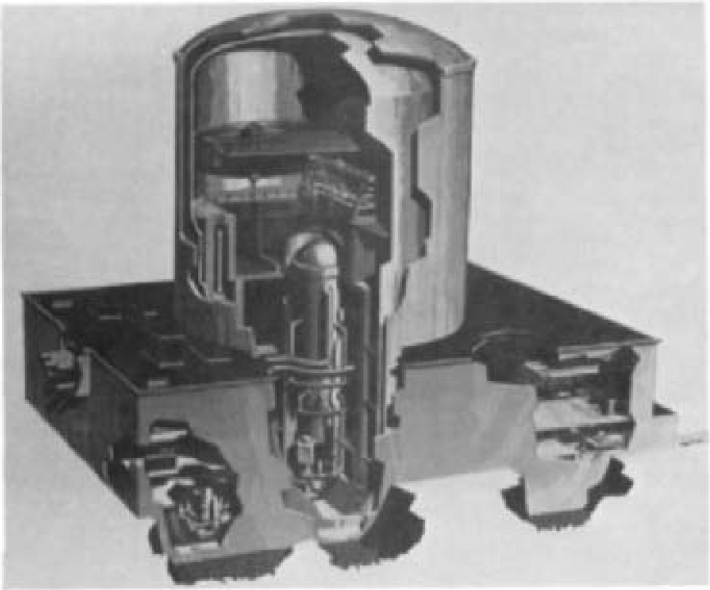

FIGURE 6 BWR containment and reactor vessel, showing one of two external recirculation pumps (General Electric)

MAIN COOLANT PUMPS

The term *main coolant pumps* as used here includes both the *recirculation pumps* in BWR plants and the *reactor coolant pumps* in the primary systems of PWR plants. As shown typically in Figures 7, 8, 9, and 10, main coolant pumps use a vertical shaft with the impeller at the bottom and a drive motor coupled to the top end of the shaft.

Bearings Main coolant pumps are usually single-bearing units, although one manufacturer provides a second guide-and-thrust oil-lubricated bearing just below the coupling. Within the pump, hydrodynamic water-lubricated bearings are conventionally used (one supplier using a hydrostatic type). The hydrodynamic bearing generally consists of a hardened sleeve journal shrunk on the shaft and a carbon-lined bearing with some type of self-aligning feature. Bearing diametral clearances are approximately 1.5 mils per inch of bearing diameter (0.0015 mm per millimeter). This rather large clearance is desirable because of thermal transient conditions. Where carbon bearings are used, a cooling mechanism must be provided because the carbon is not suited to long exposure in a hot environment. Many methods are available to accomplish this.

With bearings adequately sized and operating in clean water, virtually trouble-free performance can be expected even with relatively frequent starts and stops.

The hydrostatic, or pressurized, bearing is used where it is not convenient or desirable to provide bearing cooling, for the hydrostatic bearing can be designed to operate in reactor temperature water. Usually it will be larger than its hydrodynamic equivalent and somewhat more sensitive to starting because of the metal-to-metal rubbing that occurs until rotative speed has built up a small pressure to provide a water film clearance. At normal operating speed, however, a hydrostatic bearing will have a significantly larger lubricating film than a hydrodynamic bearing and can tolerate larger particulate matter without wear.

An exception to the previous discussion occurs in both German and Swedish BWR designs, where the recirculation pumps are inverted and inserted directly into the bottom

TABLE 2 Typical nuclear pump parameters in BWR plants

Pump	Number per plant	Flow, gpm (m^3/h)[a]	Head, ft (m)	Design pressure, lb/in^2 (MPa)	Design temp., °F (°C)	Driver hp (kW)[a]	Shaft	Length or height, including driver, in (mm)	Speed (nominal), rpm	Notes
Recirculation coolant	2	44000 (9993)	760 (231)	1675 (11.55)	575 (302)	8000 (5970)	Vert.	240 (6096)	1800	
RHR service water	4	7300 (1658)	115 (35)	150 (1.03)	150 (65)	300 (224)	Vert.	200 (5080)	900	
RHR	3	8520 (1935)	275 (84)	450 (3.10)	212 (100)	900 (670)	Vert.	350 (8890)	1800	
High-pressure core spray	1	1465 (333)	2600 (792)	1600 (11.03)	212 (100)	3000 (2240)	Vert.	500 (12700)	1800	
Low-pressure core spray	1	6000 (1363)	280 (85)	550 (3.79)	212 (100)	1750 (1310)	Vert.	400 (10160)	1800	
Closed cooling water	2	2040 (463)	110 (34)	150 (1.03)	212 (100)	60 (45)	Horiz.	100 (2540)	1800	
Reactor core isolation cooling	1	700 (159)	2600 (792)	1500 (10.34)	212 (100)	800 (597)	Horiz.	123 (3124)	4000	Turbine-driven variable-speed
Fuel pool cooling and cleanup	2	600 (136)	300 (91)	150 (1.03)	150 (65)	75 (56)	Horiz.	95 (2413)	1800	
Reactor water cleanup	2	150 (34)	500 (152)	1400 (9.65)	560 (293)	50 (37)	Horiz.	78 (1981)	3600	

TABLE 2 Continued.

Pump	Number per plant	Flow, gpm (m^3/h)[a]	Head, ft (m)	Design pressure, lb/in^2 (MPa)	Design temp., °F (°C)	Driver hp (kW)[a]	Shaft	Length or height, including driver, in (mm)	Speed (nominal), rpm	Notes
Control rod drive hydr. system	2	95 (22)	3500 (1067)	1750 (12.07)	150 (65)	300 (224)	Horiz.	168 (4267)	1800	
Standby liquid control	2	40 (9)	2800 (853)	1400 (9.65)	150 (65)	40 (30)	Horiz.	60 (1524)	1800	Reciprocating pumps
Jet	20	10000 (2271)	80 (24)	N.A.	575 (302)	N.A.	Vert.	250 (6350)	N.A.	
Waste evaporator	2	9000 (2044)	50 (15)	50 (0.35)	274 (134)	150 (112)	Horiz.	120 (3048)	720	
Resin tank precoat	1	255 (58)	85 (26)	150 (1.03)	150 (65)	10 (7.5)	Horiz.	65 (1651)	1800	

[a] Vary depending on reactor power rating.

Source: General Electric.

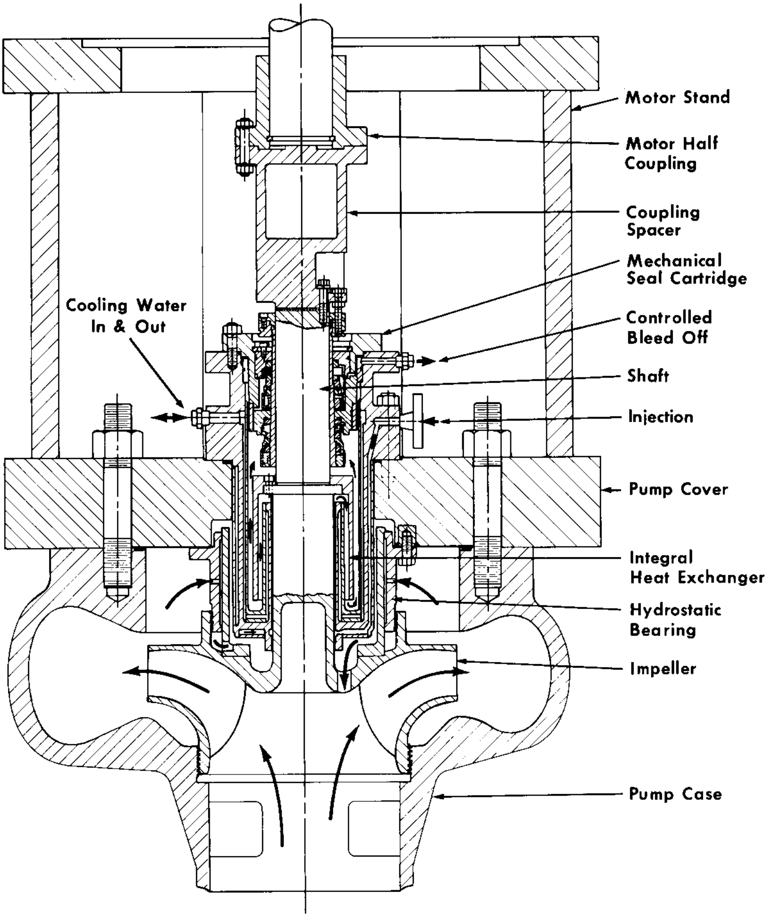

FIGURE 7 Main coolant pump (Flowserve Corporation)

periphery of the reactor vessel and use wet winding motors. There are no jet pumps. Flow is varied by changing motor speed with solid-state power supplies, one for each recirculation pump.

Seals Pump seals are invariably of the pressure-balanced type because of the high pressures involved. Several suppliers use pressure breakdown techniques to distribute the pressure either equally or in some desired proportion between two or more seals in series (Figure 11). The technique is analogous to that of a potentiometer, where particular voltages may be obtained by selecting the proper point along an electrical resistance. Also, as with a potentiometer, the flow through the primary resistance path must exceed the tapoff flow in order to maintain the system stability. For pressures in PWR systems, three series seals are frequently used (with each seal taking one-third of the overall pressure), and with lower-pressure BWRs, two series seals are usually sufficient. A margin of safety is built into the systems such that pump operation can be continued even if one of the series seals fails.

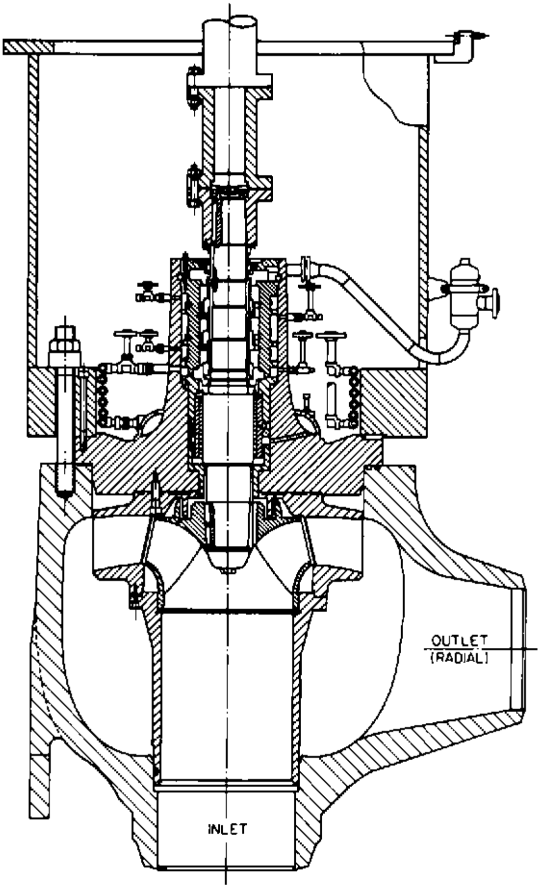

FIGURE 8 Main coolant pump (Sulzer Pumps)

In addition, a safety seal may also be installed as a backup. At least one manufacturer uses a high-pressure ceramic seal with a carbon seal backup followed by a vapor seal. Main coolant pump seals are usually supplied with reactor-grade water through a seal injection system. The advantage of using injection water is that it can be temperature-controlled and filtered. Most pumps, however, can be operated without it for at least reasonable time periods.

PRINCIPAL TYPES OF PUMPS

Most of the pumps in nuclear service are one- or two-stage centrifugal motor-driven pumps. Both vertical and horizontal types are used. Charging, safety injection, feedwater, and other high-head pumps are usually multistage motor-driven centrifugal units. Some requiring high power are turbine-driven. Double-suction designs are frequently used for RHR pumps, where service requires operation at low available NPSH. Reciprocating

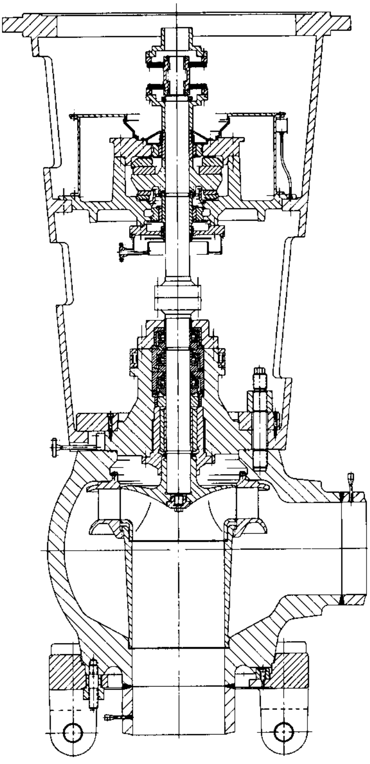

FIGURE 9 Main coolant pump (CE-KSB Pump)

pumps find limited service in nuclear plants for make-up flow, seal injection flow, or chemical mixing service. Canned pumps are frequently used in subsystems where their zero-leakage capabilities can be exploited.

Figure 12 shows a multistage centrifugal pump used in charging and safety injection service.

Figure 13 illustrates a reciprocating pump often used for charging and hydrostatic test service. It is rated at 98 gpm (22 m^3/h) at 5800 ft (1768 m) head. In Figure 14, a vertical multistage unit is shown. This type of unit is common in heater drain service. Figure 15 shows a single-stage pump of a type used in many service functions in a nuclear plant. Typically, its flow is 75 gpm (17 m^3/h) with a developed head of 235 ft (71.6 m) at 3500 rpm.

SPECIAL REQUIREMENTS FOR NUCLEAR SERVICE PUMPS

It is in the area of special requirements that nuclear service pumps differ most widely from commercial products. These special requirements, described in greater detail later, far exceed the requirements of the general industrial field and illustrate the strong emphasis placed upon pressure integrity and pump operability.

Nuclear-grade pumps are designed, built, inspected, tested, and installed to rigid standards of the U.S. Nuclear Regulatory Commission, the American Society of Mechanical Engineers, the American National Standards Institute, and other regulatory agencies,

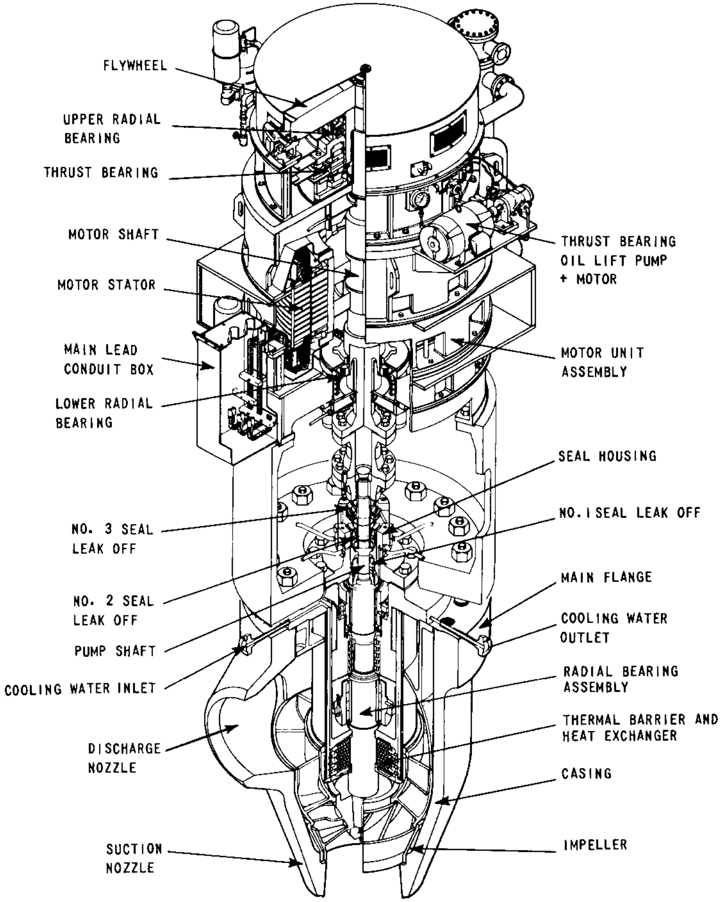

FIGURE 10 Main coolant pump (Westinghouse Electric)

such as state and local jurisdictional bodies. Established rules can be divided into two distinct categories: (1) those controlling integrity of the pressure-retaining boundary and (2) functional considerations.

The hydraulic design of nuclear pumps is the same as that of pumps in conventional service. For recirculation and reactor coolant pumps, a radial discharge is preferred by some users because it tends to simplify certain aspects of the plant design.

Vibration characteristics of pumps in nuclear service are especially important because of the relative inaccessibility of the equipment for checking and servicing and because safety requirements permit only limited outage of pumps; otherwise, the plant must come to standby condition.

An analytical or experimental determination of lateral and torsional natural frequencies is routine for most pump-driver combinations, and occasionally a transient analysis may be required.

Design under ASME Code Rules Under the rules established by the ASME Boiler and Pressure Vessel Code, Section III (Nuclear Components), the owner, such as the plant

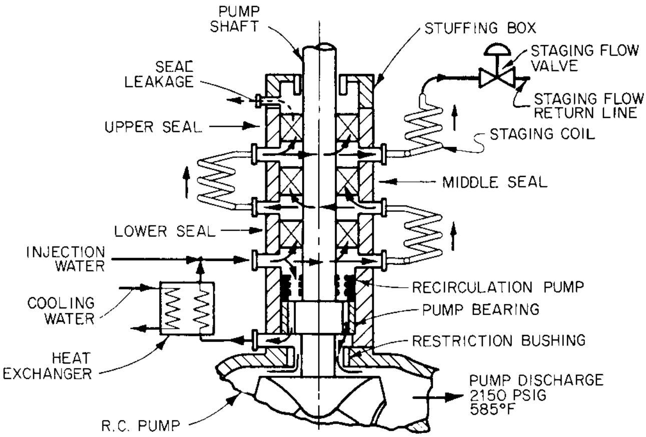

FIGURE 11 Flow schematic for a reactor coolant pump seal (Sulzer Pumps)

designer or public utility, either directly or through an agent, prepares a design specification for a specific pump, which in code terms is a component. This specification must be approved by a licensed Professional Engineer and list the applicable ASME Code Year and Addenda.

The manufacturer builds the pump to the design specification. Verification is provided through the combined efforts of the material supplier, manufacturer, insurance inspector, and state and local enforcement agencies.

The design specification requires compliance with the rules of the code with regard to the design of the pressure boundary and, in addition, includes supplementary requirements prescribed by the owner. Other standards are invoked as applicable to meet the safety and environmental requirements of the U.S. Nuclear Regulatory Commission. Functional needs may be included, and the code class to which the pump is to be built must be identified.

There are three ASME code classes for pumps. For the most critical service, a Class 1 pump is specified. Class 2 represents a pump serving a less critical system, and Class 3 is the lowest-class pump for nuclear service. It is the owner's responsibility to establish the pump class, with guidance provided by the Nuclear Regulatory Commission and the manufacturers.

For the pressure boundary evaluation, a Class 1 pump, by code rules, receives the most detailed analysis using verified and validated modern design techniques. These techniques must be supported, if necessary, by experimental stress analysis, and a certified Design Report must be submitted to the customer to document adherence to the code. Fatigue analysis of critical portions of the pump may be required, and behavior under all plant conditions, including accident, must be evaluated. Class 2 pumps require less analysis, but a certified Design Report is still required, documenting compliance with the customer's specification and the code. For Class 3 pumps, even wider latitude of design is permitted, but a certified Design Report must still be submitted to the customer. All three classes of pumps are to receive an ASME N-stamp by a qualified pump manufacturer upon successful completion of design, manufacture, inspection, test, and document review.

Additionally, nuclear service pumps are usually examined in design for thermal steady-state and transient conditions, behavior under seismic disturbances, conditions of nozzle loadings imposed by system piping, means of support, and accessibility for service, in-service inspection, and replacement.

Rules for quality control during material procurement, manufacture, and test are also contained in the code. Nondestructive examination and document control are detailed, and

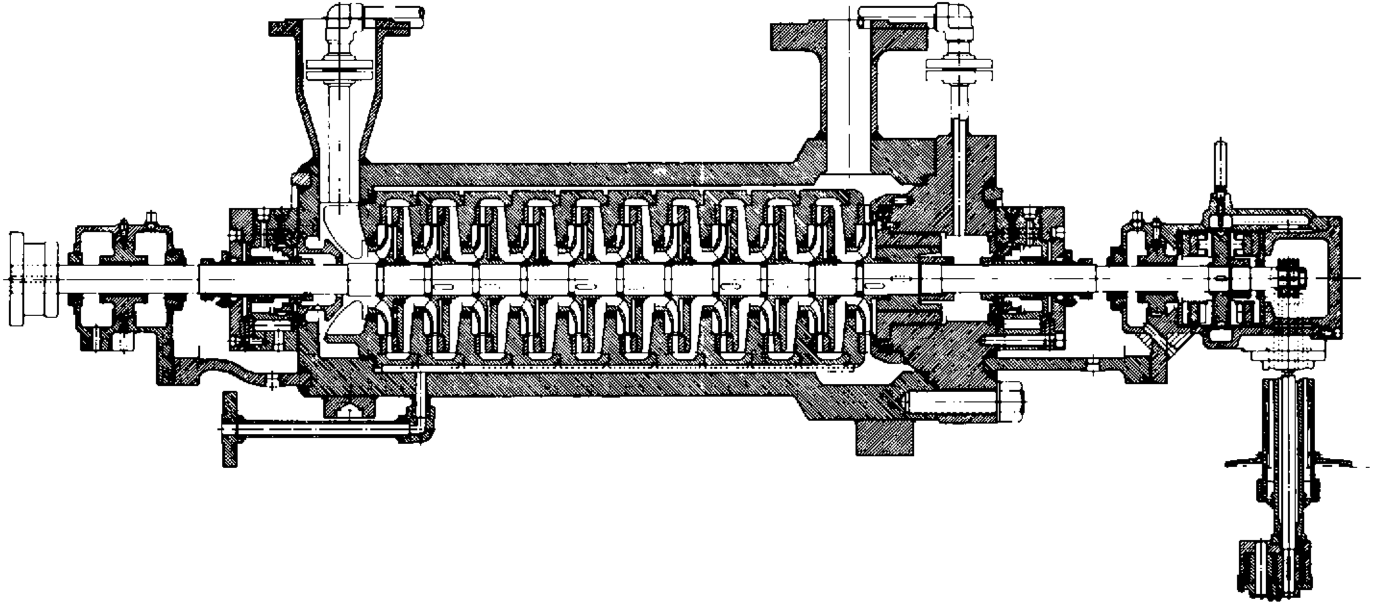

FIGURE 12 Pump for PWR charging and safety injection service (Flowserve Corporation)

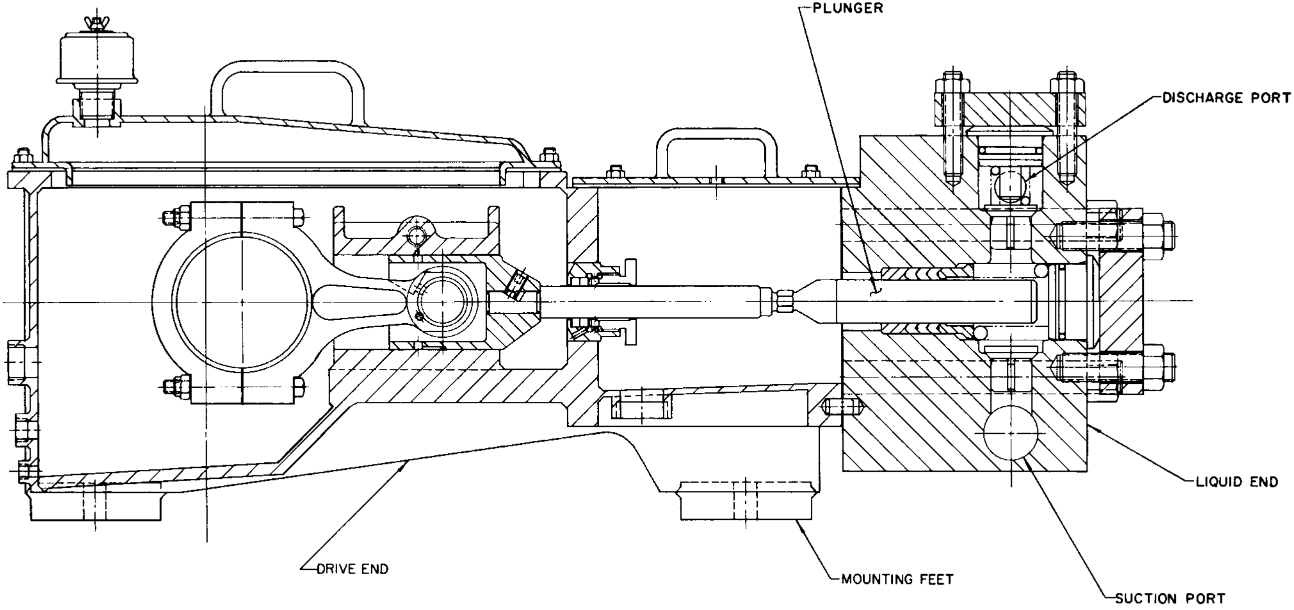

FIGURE 13 Reciprocating pump for nuclear service (Gaulin)

FIGURE 14 Vertical multiple-stage pump (Flowserve Corporation)

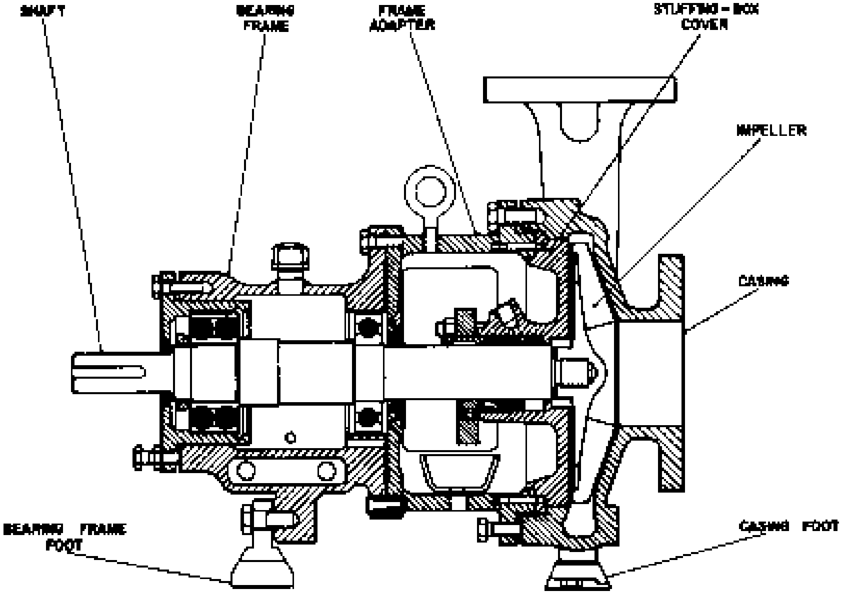

FIGURE 15 Single-stage pump used for many service functions in a nuclear plant (ITT/Gould Pumps, Inc.)

a quality assurance program requiring a formal procedure manual must be prepared and implemented by the manufacturer. Periodic surveys by the ASME verify adherence to code rules. Local jurisdictional authorities provide day-to-day inspection services as required by the manufacturer.

Design of Noncoded Parts Parts of the pump that are not classified as pressure boundary items or attachments to the pressure boundary are not covered by the ASME code. The owner's design specification may describe applicable requirements for these non-pressure parts, referencing other documents or excluding use of certain objectionable materials. If the pump is in critical service or is needed in emergency situations, certain ANSI standards may be invoked. Accompanying these rules will be extensive quality assurance and documentation to demonstrate compliance.

MATERIALS OF CONSTRUCTION

Material Limitations When pumps built to ASME standards are required, materials for the pressure-retaining parts must be selected from a list approved by the ASME. Section III (Nuclear Components) of the ASME Boiler and Pressure Vessel Code lists these materials, their allowable stresses, and the examination requirements that must be applied to ensure their suitability.

Typical Materials Examples of acceptable materials for pressure-retaining boundary parts are shown in Table 3. They are suitable for all three ASME code classes; however,

TABLE 3 Materials for pressure-retaining boundary parts

Carbon steel	
Castings	SA-216, Gr WCA, WCB, WCC
Forgings	SA-105, Gr I, II
Plate	SA-515, Gr 55, 60, 65, 70
Bolting	SA-193, Gr B6, B7, B8, B16
Stainless steel	
Castings	SA-351, Gr CF8 (304), CF8M (316)
Forgings	SA-182, Gr 304, 316, 321, 347
Plate	SA-240, Gr 304, 316, 321, 347
Nonferrous	
A limited number of nonferrous materials are permitted.	

other acceptable materials may be restricted to use for a particular class. Hazardous and porous materials are generally avoided, as are materials such as cobalt, which, though normally harmless, may become hazardous from radioactive considerations (see following text). Cobalt content is often limited in large stainless steel parts but is usually permitted in concentrated form of small areas, for example, where hard-facing is required.

Materials of construction should not be affected by the usual decontamination chemicals.

Nonpressure boundary parts may be made of conventional materials but will usually require the buyer's approval. Certain elastomers, such as ethylene propylene, which has good radiation stability, are excellent for seal parts. Many fine grades of carbon-graphite are available for water-lubricated bearings and for mechanical seal facings.

CONSIDERATIONS OF RADIOACTIVITY

Radioactivity may become a serious consideration in the design of nuclear pumps because of the need for servicing the equipment. The water used in the primary system becomes contaminated with metallic elements through solubility, corrosion, and erosion. When circulated through the core region, the metallic elements become radioactive because of interaction with neutrons. These radioactive contaminants may, if soluble, remain in solution in the water or, if unsoluble, plate out on metal surfaces or become lodged in "crud traps," such as fit interfaces, screw threads, porous base metals, extremely rough surfaces, cracks, and certain types of weld configurations, such as socket welds. In one case, for instance, a pump impeller returned for overhaul defied attempts at decontamination until it was discovered that a repair had been made to a presumably integral wear ring by undercutting and shrinking on a new ring. The interface was barely perceptible, but once it had been found and the ring had been removed, the impeller was readily decontaminated.

Soluble contaminants are most easily removed by providing the pump with complete drainage features; that is, leaving no internal pockets that are not naturally drainable. Ease and speed of parts replacement are, therefore, also important items of design because they reduce the length of time service personnel are exposed to radiation.

The Nuclear Regulatory Commission (NRC) provides specifications detailing the allowable radiation exposure to personnel. Any pump that produces radioactivity at rates that would exceed these limitations must either be repaired at a facility licensed to handle contaminated material or be decontaminated prior to being sent to a conventional repair shop.

After prolonged service in a nuclear plant, pumps may emit radioactivity at a rate in excess of 2 to 50 rem/hr, far in excess of the NRC limits. Therefore, provisions to decontaminate nuclear pumps becomes an important design characteristic. Although not all nuclear pumps operate in highly radioactive environments, these pumps will usually require some degree of decontamination before they can be freely handled and repaired.

SEISMIC DESIGN

The ASME code requires that a seismic analysis be performed on all classes of nuclear pumps. Refer to Subsection 9.14.2 for more detailed information on this subject.

TESTING

Hydrostatic Testing Hydrostatic testing in accordance with ASME code rules is conventional except that specific documentation is required.

Performance Testing Performance of nuclear pumps is verified by procedures common to non-nuclear pumps. In addition, however, it may be necessary to demonstrate pump performance under some emergency condition, such as loss of cooling water or seal injection water. Also, a test under simulated total-loss-of-power conditions may be required, in which the reactor coolant pump must coast safely to a stop and withstand loss of both cooling and seal injection water for a finite time.

Periodic Testing The ASME code, under its rules for in-service inspection (Section XI), requires periodic testing of certain pumps installed in a nuclear plant. The pumps affected by these rules are those associated with the safety systems and those that may be required to function during an emergency or a reactor shutdown. Examples of such pumps are those for core spray, residual heat removal, boron injection, and containment spray. If pumps cannot be tested in their usual circuit, they must be supplied with bypass loops that can be valved off.

The field testing procedure involves obtaining a baseline set of values for head, flow, speed (if variable), vibration, inlet pressure, and bearing temperatures. The flow quantity that sizes the bypass loop is not specified in the code, but in the practical sense, the flow must be adequate to prevent overheating of the pump and overloading of the bearings. Also, because it is an off-design point, consideration is given to the potential for rough operation due to impeller internal recirculation and possible low-flow cavitation damage. Code rules call for a five-minute running period every three months and longer periods where it is necessary for bearing temperatures to stabilize. If the differences between periodic operating data and baseline data exceed permissible limits, the cause for the differences must be sought and corrected. Record-keeping is therefore a significant part of pump in-service testing.