PRESSURIZED WATER REACTOR DESCRIPTION

INTRODUCTION

Nearly all the power reactors in the United States are water reactors, that is, the reactor coolant is ordinary water - not heavy water. There are two types of water reactors:

1. The pressurized water reactor (PWR) in which the reactor is cooled by water under considerable pressure so that the average energy of the water leaving the reactor is less than the energy required to boil the water at this pressure. In this system, the high pressure water is conducted to heat exchangers, which are usually known as steam generators, where steam is produced by boiling of water on the low pressure side of the steam generators.

2. The boiling water reactor (BWR) in which the coolant water is allowed to boil in the reactor; in this type, the steam is usually sent directly to a turbine for electric power generation.

PWR OVERALL DESCRIPTION

Figure 1 shows a simplified diagram of a PWR system for electric power generation. The left-hand loop or "primary loop" or "nuclear steam supply system" is the portion that utilizes the nuclear fuel to produce steam. The right-hand or "secondary loop" includes the turbine generator, condenser, feed pump and piping.

The nuclear steam supply system is made up of five principal parts:

1. The nuclear reactor which consists of a pressure vessel containing the reactor core (including fuel assemblies and control rods). The fission chain reaction occurs in this core, producing heat that is removed by the pressurized-water coolant.

2. The steam generators where the water coolant from the reactor transfers its heat through tubes to generate the steam for the turbines.

3. Piping to deliver the water coolant to and from the reactor and the steam generators.

4. Pumps to circulate the water coolant.

5. A pressurizer to maintain the coolant water at a pressure high enough to prevent boiling, and to accommodate volume changes in the coolant.

PRIMARY SYSTEM OPERATION

During the operation of the nuclear plant, water is heated in the core through the energy released by the fission process. This water flows out of the pressure vessel and through the reactor coolant piping (hot leg) to the steam generator. Hot water enters the steam generator through the inlet nozzle at the top of the steam generator. The water then is forced through Inconel tubes which provide a mechanism for heat transport to the secondary (steam) side of the generating unit.

The primary water flow in the steam generator is counter to the secondary water and steam flow. As the tubes traverse the steam generator from top to bottom, they are initially surrounded by steam. The hot water heats the steam above the temperature where the steam would still contain some moisture. The primary water, flowing through the tubes, passes into the region in the steam generator where the heat being transferred through the tube metal causes the scondary side water to boil forming steam. This transfer of heat causes the primary water to give up the energy which was gained in the reactor core and enter the lower end of the steam generator cooled.

The cooled water then flows through two reactor coolant pipes up to the reactor coolant pumps. Each cold leg, or section or reactor coolant piping which is transporting cooled primary water, contains a reactor coolant pump. The reactor coolant pumps provide the fluid power to overcome the frictional flow losses experienced in the piping, through the core, and in the steam generator tubes and the pumps.

The pump returns the cooled water back to the reactor vessel where it flows down the inside of the reactor vessel, around the core barrel, then up through the core support structure to the fuel elements to be heated again.

The arrangement of the components is illustrated schematically in Figure 2. An elevation and plan view of the components of Figure 2 are illustrated in Figures 3 and 4.

Two separate pathways exist for the cooling of the primary water, the production of steam and the return pumping of cooled water to the core. Each pathway or loop consists of the associated reactor coolant piping, steam generator and reactor coolant pumps.

THE REACTOR VESSEL

The heart of the reactor is the core where the chain reaction occurs in the nuclear fuel and the heat is removed by the coolant. The reactor, along with all other parts of the plant, must be capable of delivering the designed full-power output. This means that the coolant flow must remove the heat generated by the core without overheating at any point. The design must also accommodate expeditious start up, instantaneous shutdown and the operator's requirements for rapid changes of load. Pressurized water reactors lend themselves readily to these requirements.

Figure 5 is a vertical sention of a modern pressurized water reactor vessel for electric utility application. Its principal components are:

1. The reactor vessel which encloses the reactor core and makes it possible to contain the desired coolant pressure.

2. The core consisting of fuel assemblies and control rods.

3. The thermal shields which absorb radiation emitted from the core, and reduce gamma and neutron energy absorption in the pressure vessel wall.

The reactor pressure vessel consists of a cylindrical shell, a bottom spherically dished head which is welded to the shell and a closure head which is held in place by 60 closure stud/nut assemblies. The vessel is constructed of low alloy carbon steel; the internal surfaces are clad (lined) with stainless steel.

The reactor vessel is provided with nozzles to accept the reactor coolant piping, two hot legs and four cold legs, two core flooding system nozzles from the Emergency Core Cooling System and nozzles to accept the control rod drive mechanism assemblies.

The reactor vessel closure head is bolted to the lower part of the vessel during operation. Redundant metallic seals, compressed by the bolting force, prevent any leakage through this mating surface.

The core support structure contained within the reactor vessl provides stability and support to the fuel assemblies from hydraulic and thermal forces by guiding the flow of water. The upper internals are also supported by the reactor vessel. These components also provide flow guidance as well as guiding the control rods into the fuel assemblies. All internal core structures are fabricated from materials such as stainless steel, which are resistant to corrosion in the primary water.

SYSTEM PIPING

The reactor coolant piping is carbon steel lined with stainless steel. The piping is sized to provide maximum transport of water consistent with other plant requirements such as space, pumping ability and mechanical ability to satisfy design requirements. All piping joints are welded including joints to the reactor vessel, reactor coolant pumps and the steam generators. Provisions are made to periodically inspect these joints as well as each component in the system.

STEAM GENERATORS

The steam generators are vertical shell-and-tube type heat exchangers where, as described previously, the primary water is wholly contained within the tube while secondary water (feed water) is admitted on the shell side, (that portion outside the tubes but contained by the steam generator carbon steel outer vessel).

Primary water flows from the top, down the tubes and back through the lower channel head to the cold leg piping. The steam generators supplied by B&W are designated as once-through steam generators since the primary water flows through in one direction from the core. (Other PWR NSSS suppliers provide steam generators in which the water flows through tubes shaped like inverted U's.)

The secondary feedwater enters the steam generator through a nozzle on the shell and is evenly distributed around the cylindrical shell by a distribution box. This allows even flow of feedwater through the steam generator.

Steam leaves the secondary or shell side through two pipes, since the volume of steam is much greater than the corresponding volume of water. These pipes carry the steam to the turbine through a series of valves.

REACTOR COOLANT PUMPS

The reactor coolant pumps are centrifugal pumps driven by 9,000 horsepower electric motors. The solid shaft connecting the motor to the pump impeller could be a source of leakage of primary water since the pump casing is part of the primary piping by virtue of its being welded in place. Three mechanical sealing mechanisms are provided on each pump shaft in order to minimize any potential leakage. These seals use water at a high pressure as a sealing fluid against the leakage of the primary system water.

In the event that pump operation were suddenly interrupted, flywheels are provided on the pump motors to continue the rotation of the pumps so that flow in the loops does not suffer a rapid decrease. These flywheels allow the coastdown of the pump to continue to promote flow to the core.

After stopping operation, mechanisms on the pump motor shaft prevent flow through a loop in a reverse direction from moving the pump impeller. These anit-rotation devices lock the pump in position until unlatched during the pump startup.

THE PRESSURIZER

Volumetric changes in the amount of water in the primary system occur whenever plant operation causes temperature or pressure in the system to change. In order to accommodate these changes, a pressurizer is connected between a hot leg and the cold leg of one of the two reactor coolant system loops. The pressurizer is essentially a tank which is filled partly with steam and partly with water which is hotter than the other water in the system. As the volume increases in the primary circuit, the water surges from the connected hot leg into the pressurizer, concurrently steam may be condensed to provide space for the water and maintain the system pressure. As pressure decreases, water leaves the pressurizer and more steam is formed to take the place of the water thus the pressure is also held constant. Electric heaters and a water spray are provided in the pressurizer to accomplish the pressure-volume compensation.

THE CORE

The active core utilized for power production is composed of 177 fuel assemblies. Each fuel assembly consists of fuel rods, guide tubes for the control rod assemblies and an instrument tube. The particular location in the core of a fuel assembly determines if a control rod or an instrument assembly is part of the fuel assembly. Fuel assemblies are designed to provide favorable nuclear, thermal and hydraulic characteristics. The fuel assembly must be designed to promote the nuclear fission process in its design. Also, once the fission has occurred in the fuel pin, it must be designed so that the energy released to the fuel pin can be removed by the cooling water. Finally, the fuel assembly must be designed to minimize the resistance it presents to moving water so that pumping requirements are minimized.

Control rod assemblies inserted in the fuel assembly provide short term nuclear control of the fission process. The control rods are guided into designated assemblies by guide tubes. In addition to the neutron absorbing control rods, soluble boron is added to the primary water to further control the nuclear reaction during different stages of the core life.

Control rod assemblies enter the fuel assembly from the top. During operation, magnetic jacks are used to position the control rods according to desired power output. If a quick shutdown of the nuclear reaction is required, the magnetic field can be released and the control rods drop by gravity into the fuel assembly.

Instrument assemblies enter the fuel from the bottom and are used to provide information on core power levels and temperature through flux instruments and through thermocouples. In addition, instrumentation outside the reactor vessel is also used to monitor the nuclear reaction.

In addition to the primary system which has been discussed at length, there are auxiliary systems, connected to the primary system for the performance of specific functions. These auxiliary systems are discussed briefly below.

MAKE-UP AND PURIFICATION SYSTEM

Impurities in the reactor coolant must be kept at a low level to minimize surface fouling and to assure maximum plant availability. This is usually accomplished by a makeup and purification system. A portion of the water from the reactor coolant circuit is continuously removed through the letdown cooler, passed through a purification demineralizer to remove impurities other than boron, and stored in a makeup surge tank from which it is returned to the reactor coolant system, as required, to maintain the pressurizer level. The capacity of the surge tank must accommodate changes in the volume of water resulting from load changes without requiring discharge of the radioactive coolant.

In most PWR systems, low temperature water is injected continuously into seals (e.g., pumps) to prevent outward leakage of coolant. The water leaking into the reactor coolant at these seals is removed continuously through the makeup and purification system. The out-leakage at the seals is returned to the makeup surge tank through separate coolers. Major components of the makeup and purification system are preferably located outside the reactor building for access during plant operation.

Chemical addition and sampling operations are required to alter and monitor the concentration of various chemicals in the reactor coolant and auxiliary systems. The chemical addition and sampling system provides for the addition of boric acid for reactivity control, materials such as lithium hydroxide for pH control and hydrogen or hydrazine for oxygen control. The addition of chemicals is usually accomplished through the makeup surge tank. Means are provided for taking samples from the reactor coolant system.

DECAY HEAT REMOVAL SYSTEM

The Decay Heat Removal System is utilized during the transition to shutdown to provide cooling of the decay heat generated in the core. The system is piped to the hot legs and removes the warmed water after the RCS is reduced in pressure and temperature. Heat exchangers provide cooling of the primary water by service water. The primary water is then pumped back to a cold leg for further use in the RCS.

EMERGENCY CORE COOLING SYSTEM

The Emergency Core Cooling System uses existing plant components for the most part to provide cooling of the fuel in the event of an accident. The Makeup system pumps comprise the High Pressure Injection system using borated water from the Borated Water Storage tank as the initial cooling water source.

The Decay Heat Removal Pumps form a low pressure ECCS to be utilized once the primary side pressure has fallen. The Decay Heat Removal Pumps also use the Borated Water Storage Tank as the initial source of cooling water but can also use the water existing in the reactor building sump as a source of water for circulation. The Decay Heat Removal Heat Exchangers would cool this water prior to its re-entry to the Reactor Coolant System.

The Core Flood tanks act as a static system for rapid cooling of the core at low pressures. These pressurized tanks will empty their contents into the reactor vessel, through the core flood nozzle once RCS pressure has fallen below the level of the flood tanks.

The Primary System as well as the Emergency Core Cooling System are designed for the intended service for the plant lifetime as well as accident loads and transients, earthquakes and cyclic loads due to pressure and temperature using conservative design standards as suggested by the American Society of Mechanical Engineers and the NRC Regulatory Guides.

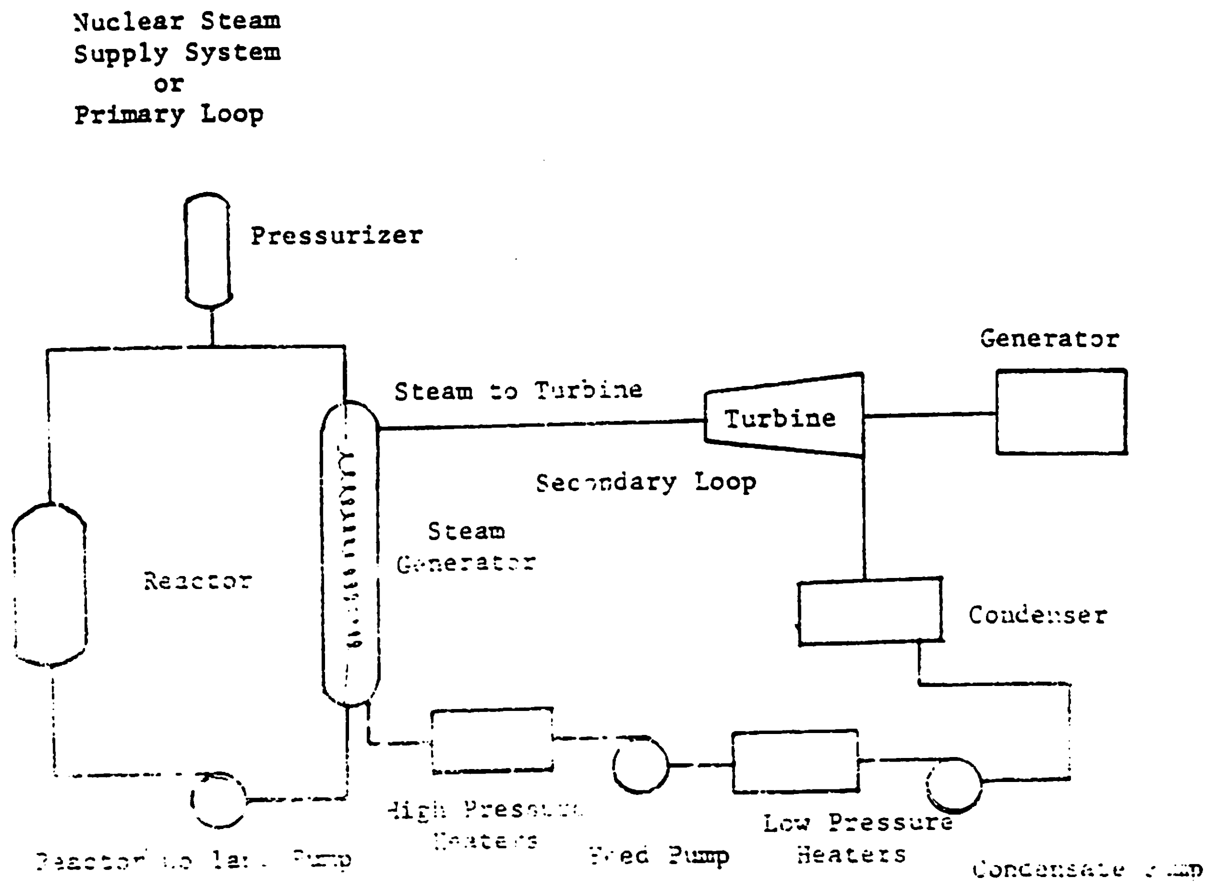
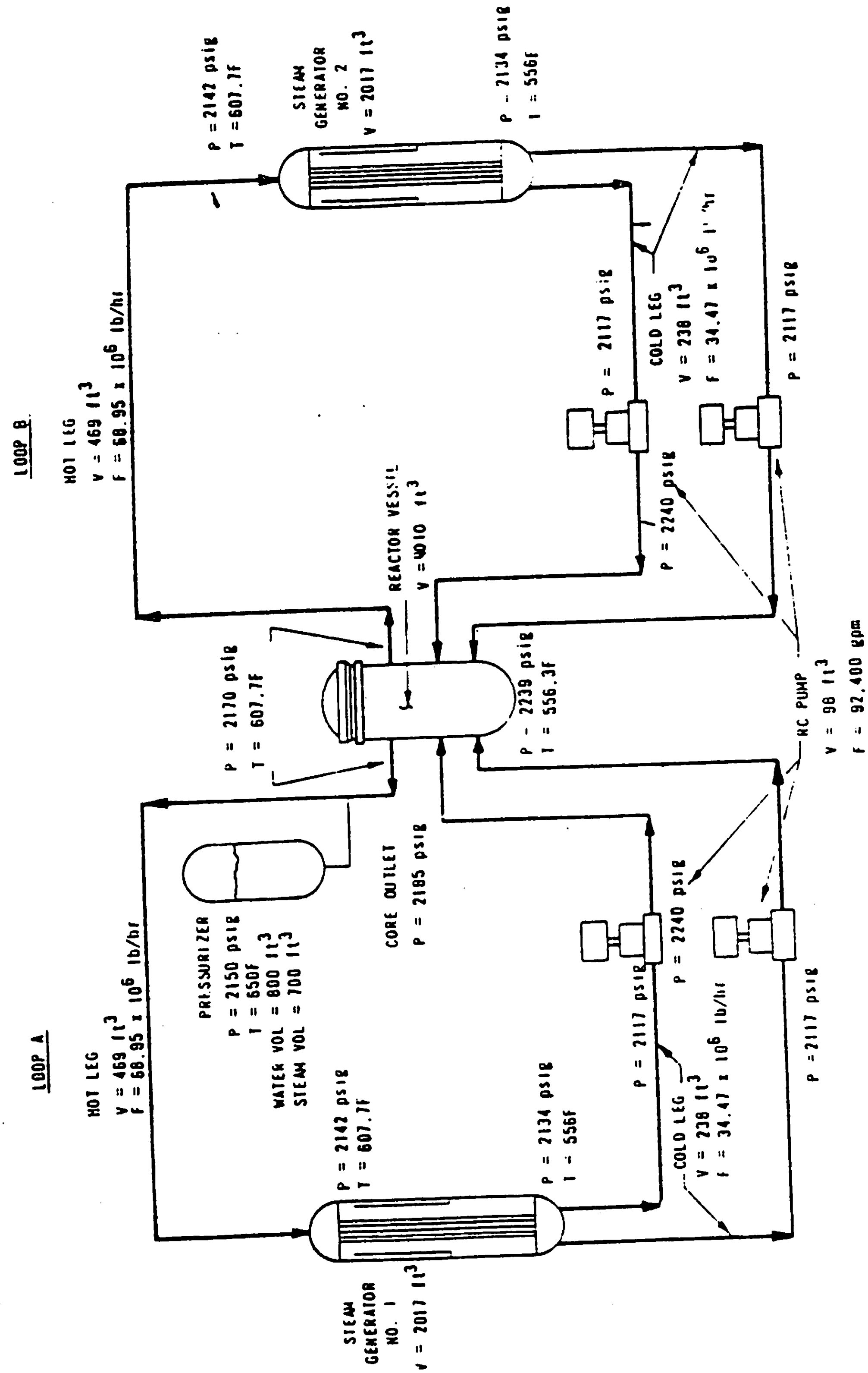


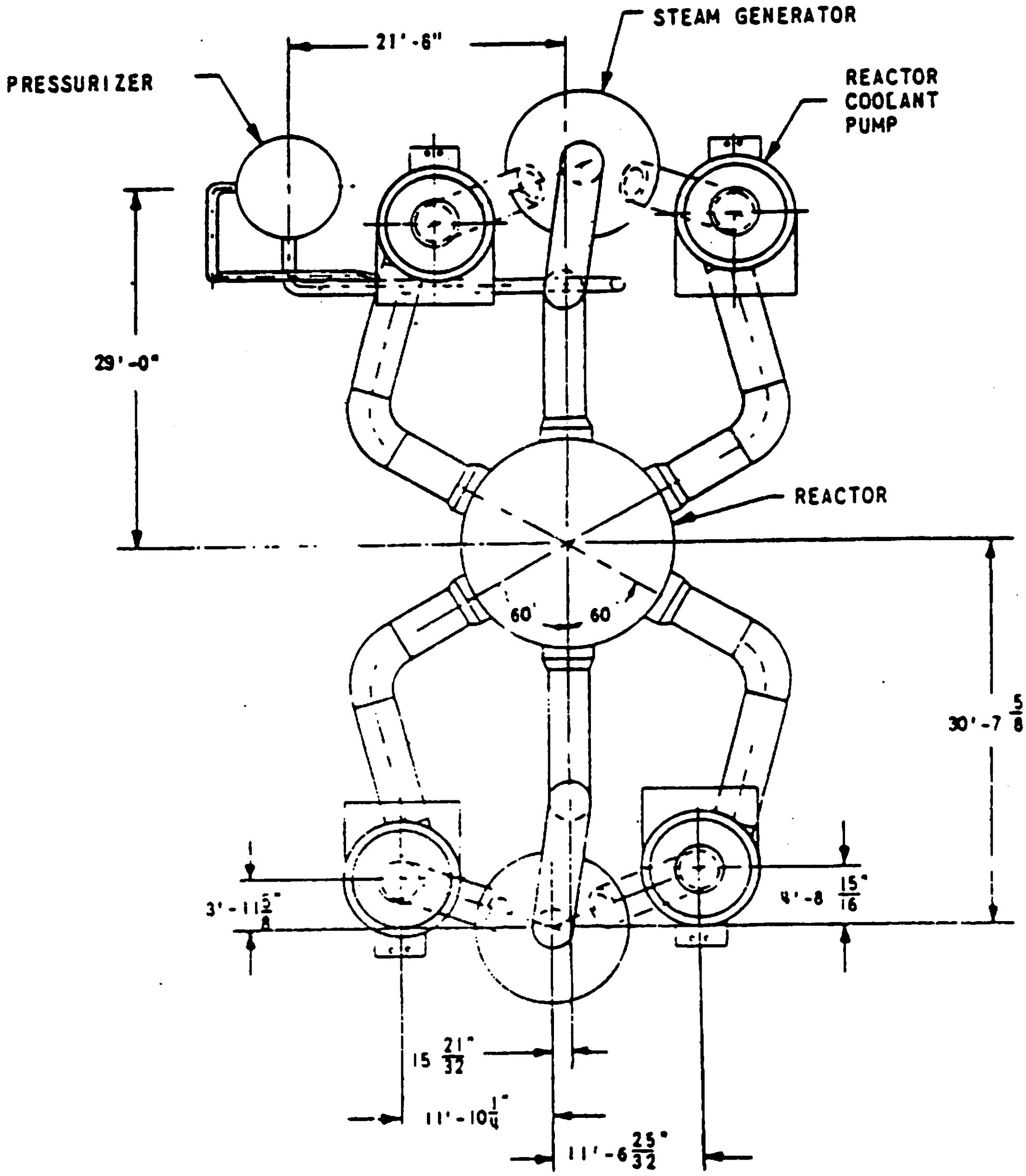
Fig. 1 Diagram of pressurized water reactor system.



REACTOR COOLANT SYSTEM FLOW DIAGRAM
AT FULL POWER STEADY STATE CONDITION

THREE MILE ISLAND NUCLEAR STATION UNIT

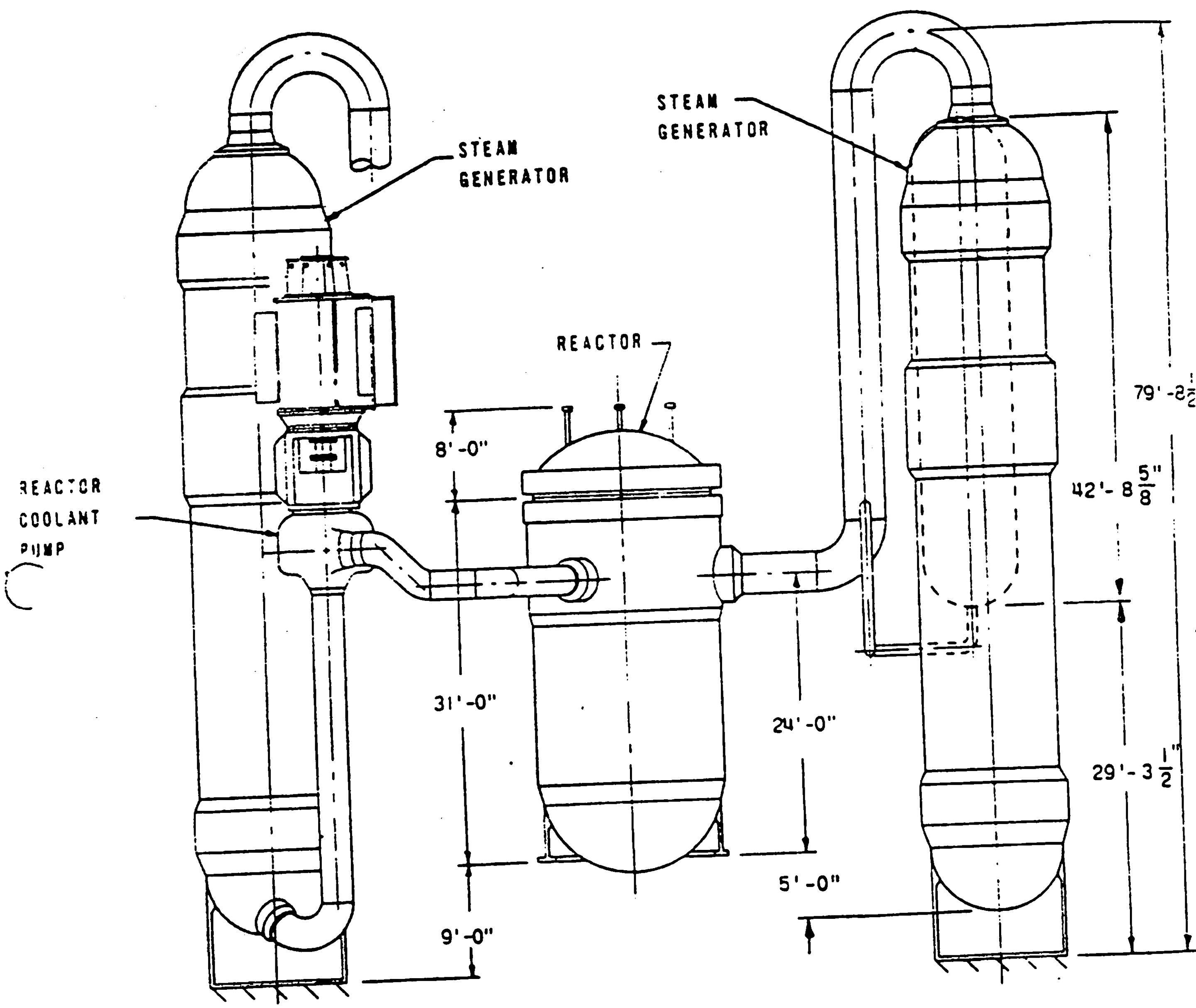
FIGURE 2



REACTOR COOL NT SYSTEM ARRANGEMENT - PLAN

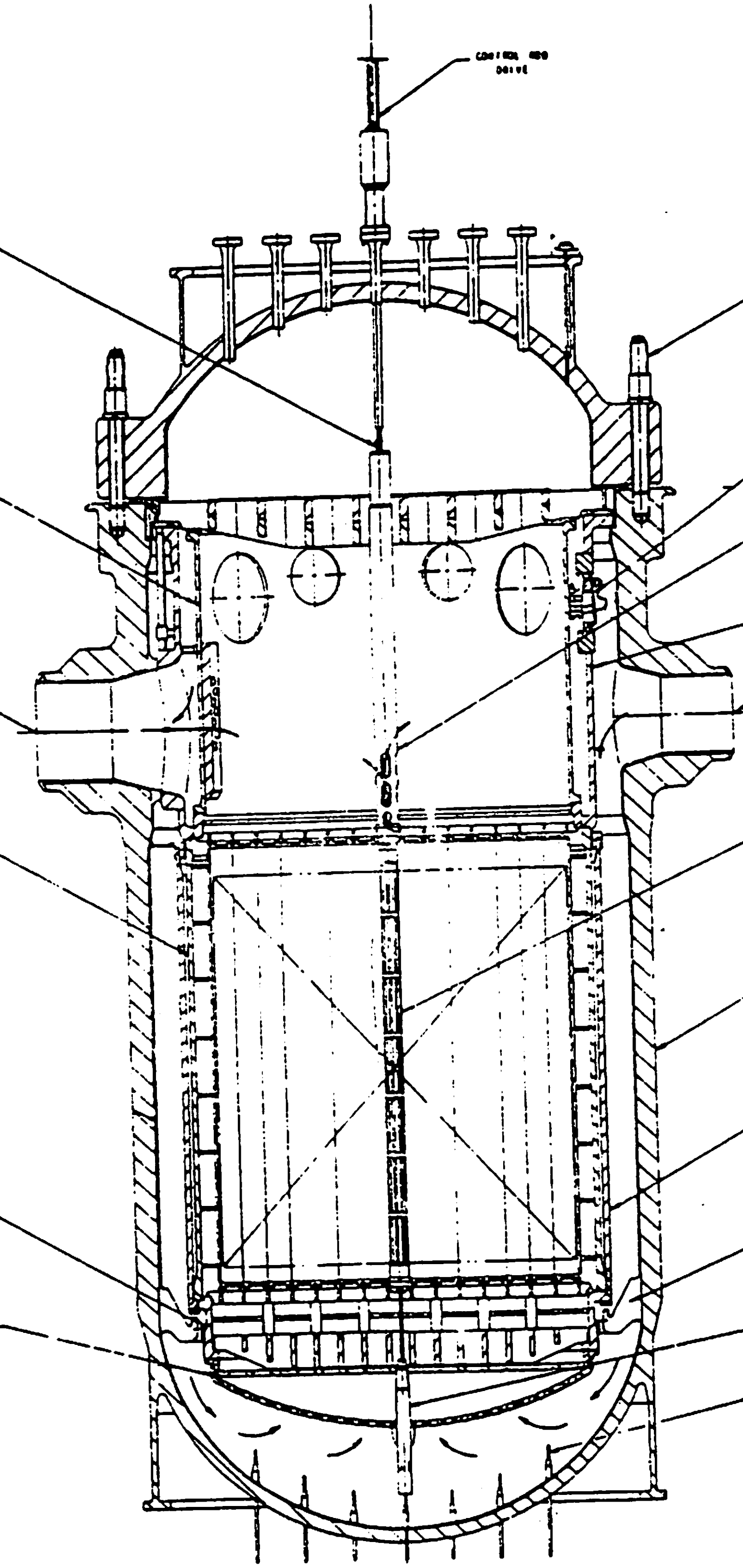
THREE MILE ISLAND NUCLEAR STATION UNIT

FIGURE



REACTOR COOLANT SYSTEM ARRANGEMENT - ELEVAT
THREE MILE ISLAND NUCLEAR STATION UNIT 2

FIGURE 4



NOTE: Surveillance Specimen
Holder Tube Not Shown

REACTOR VESSEL & INTERNALS-GENERAL ARRANGEMENT

THREE MILE ISLAND NUCLEAR STATION UNIT 2

FIGURE 3