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THE BELGIAN THERMAL REACTOR PLANT (BTR)

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The plant design is based on the use of a heterogeneous pressurized light water reactor having a heat output of 43000 kilowatts at full power. The primary plant is pressurized at 2000 pounds to prevent boiling in the core during normal operation.

Steam is produced at 520 psia for driving a 3000 rpm, 50 cycle turbine-generator having an output of 11,500 kilowatts.

The Reactor - The core of the reactor consists of fixed fuel elements fabricated from slightly enriched uranium. The uranium is in the form of an oxide and is clad with zirconium.

The uranium oxide is compressed into small cylindrical pellets, which are sintered and then ground to close dimensional tolerances. The oxide density is above 90 per cent of theoretical density. The final pellet dimensions are approximately 0.3" by 0.3". The pellets are loaded into zirconium tubes having a wall thickness of 0.03 inches and a length of 18 inches. Zirconium plugs welded into the end of the tubes completely seal the fuel rod.

The fuel rods are assembled into a rod bundle that is approximately 5 x 5 x 18 inches. The rods are welded to end plates containing small openings that permit water flow between and parallel to the individual rods. Three rod bundles are assembled into a 54 inch long fuel subassembly. The bundles are held together by four zirconium rods that extend the full length of the subassembly. The zirconium rods are located at each of the four corners of the subassembly and are welded to the fuel bundle end plates. One fuel rod is omitted at each corner of the fuel bundles to provide space for the zirconium rods. Transition pieces are fastened to each end of a fuel subassembly to permit supporting the subassembly in a 2 1/2 inch circular opening in a bottom stainless steel plate and a correpsonding opening in a top hold-down plate. The primary coolant flows through the center of the transition pieces. The total length of a subassembly is 66 inches, including the end pieces.

The core consists of 32 subassemblies, and contains approximately 2000Kg of uranium having an enrichment of about five per cent. The actual enrichment has not been established and may be significantly higher or lower than this figure. The core is being designed for a calculated life of 7000 hours at full power.

The reactor is controlled by 12 neutron absorbing rods. The rod material has not been fixed, however a cobalt alloy, Haynes-25, is being considered. Rod extensions will be used to avoid water holes within the core when rods are withdrawn. The rods will be controlled by mechanisms located on the reactor vessel closure. The two arm collapsible and the fixed roller nut mechanisms are being considered.

The reactor core is located in a reactor vessel having an inside diameter of 58 inches and an overall height of 17 feet. The vessel will be made of carbon steel clad with type 304 stainless steel. The vessel has a full diameter closure that has to be removed during refueling operations. The present design is based on a gasketed head with provisions for seal welding.

Water at 492 degrees enters the reactor vessel through two 12 inch nozzles located above the top of the core. The coolant flows down through the reflector and thermal shield regions and then up through the core. The coolant velocity in the core is about 10 feet per second, and the total flow is 5,000,000 pounds per hour. Water leaves the vessel at 518°F through a single 16 inch nozzle.

The Coolant System - The coolant leaving the reactor vessel is carried to a single vertical steam generator through a single 16" pipe. The steam generator is approximately 5 feet in diameter and 27 feet high. The coolant is returned to the reactor vessel through two 12 inch pipes. One 6250 gpm canned motor, 50 cycle pump and one check valve are located in each of the 12 inch pipes. No main stop valves will be provided.

With the adopted primary loop arrangement, a very large percentage of the impedance to coolant flow is common to the two pumps. In case one pump is lost, due to pump or power supply difficulties, the coolant flow decreases to 70-80 per cent of the flow with two pumps in service. By comparison, the one pump flow in a two loop plant is only 50-60 per cent of the flow with two pumps. The higher single pump flow with the adopted design has two distinct advantages. First, more time is available to decrease the reactor output if a pump is lost during full-power operation. This is important because a reactor core is operated at a high power output per unit volume, and damage to the core can result if its heat output is not reduced following a reduction in coolant flow. The time available to reduce the reactor output depends on the magnitude of the reduction in coolant flow.

The second advantage of the higher single-pump flow is the larger permissible continuous plant output with one pump out of service.

The omission of main stop valves in the reactor plant eliminates the most probable cause of a cold water accident. In a two-loop plant with main stop valves, it is possible to operate the plant with the valves closed in one loop. If this loop is returned to service, by opening the main stop valves, cold water can be introduced into the reactor. This increases the reactivity of the core and can produce a hazardous condition.

In the adopted design all of the water in the primary coolant system is maintained at about the same temperature, thus avoiding the most probable cause of the cold water accident. It is proposed to have small openings in the check valves, and to maintain a small flow through the 12 inch pipe even when a check valve is closed. This flow will be sufficient to maintain temperature in the pipe. This not only eliminates the possibility of an accident when the check valve opens, but also minimizes thermal stresses in the system by minimizing temperature differences.

Pressure Control System - The pressure control system consists of a pressurizer vessel containing a two-phase mixture of steam and water, replaceable immersion heaters, and provisions for spraying coolant into the steam during positive pressure surges. It also contains spring loaded and electrically operated relief valves which vent to the flash tank. The pressure control system is designed to maintain the normal operating pressure of 2000 psia at the reactor outlet during steady state operation. The system must also accommodate coolant thermal expansion and contraction and limit the fluid pressure fluctuations to an allowable range at the reactor outlet during temperature excursions resulting from normal power transients.

Coolant Purification System - To maintain a low concentration of impurities in the coolant system, it is necessary to circulate approximately 10 gpm of coolant through a purification system. The purification system reduces the impurities in the water in the coolant system to below two parts per million. This high purity assures a low residual radioactivity which allows personnel to enter the reactor plant enclosure in a minimum time following a shutdown of the plant. It also reduces fouling of the various components associated with the coolant system.

Purification is accomplished in a mixed bed demineralizer which operates on a by-pass circuit off the coolant system and across the head of the coolant pump. To avoid resin decomposition this demineralizer requires a water temperature of no more than 130°F with a desired temperature of 120°F. To cool the coolant system water to 120°F and not throw away the heat from this 0.1% of the main coolant flow a regenerative heat exchanger is used. This exchanger cools the water to approximately 200°F. A non-regenerative heat exchanger is used to then cool the water to 120°F for the demineralizer and provide a thermal difference for the regenerative heat exchanger.

Coolant Charging and Volume Control System - A coolant charging and volume control system is used initially to fill the coolant system with demineralized low pressure water and to then provide high pressure water for coolant water volume DECREASES that are of too great a magnitude to be handled by the pressure control system. For large magnitude water volume INCREASES the coolant charging and volume control system discharges water to maintain the coolant system's water volume. This system also provides low pressure water for flushing the demineralizer.

The initial filling of the coolant system with cold demineralized water from the demineralized water storage tank is accomplished with a low pressure centrifugal pump of 100 psig and 120 gpm capacity in approximately one-quarter hour.

As the plant is started the water in the coolant system is heated and expands and must be released or excessive pressure will be built up. The system releases the excessive volume of water to the flash tank where the water is brought to atmospheric pressure and then dumped into the waste-disposal system.

During periods when the plant is being shutdown the coolant water temperature is reduced and the water volume shrinks. This requires more water than can be provided from the pressurizer vessel of the pressure control system, to be added so as to maintain the coolant system pressure of 2000 psia. Water is added by positive displacement high pressure feed pumps discharging through a filter to valves which determine where the water is to be added or used. The rate of release and addition is about 5 gpm which is about 15% of the coolant system volume, per hour. The charging and volume control system also provides water of 3750 psia for hydrostatic tests of the coolant system and its associated systems.

The water, which is supplied to the coolant system by this charging system, is taken from the turbine electric plant condensate storage tank through a demineralizer and deaerator to purify it. The purified water is stored in a demineralized water storage tank which is covered with an inert gas blanket of hydrogen.

Coolant Loop Evacuation System - To avoid contaminating the coolant with dissolved air during the filling operation, the system is evacuated. A portable vacuum pump is used. Connections are made to any high points where air could be trapped. These connections consist of manually operated, capped valves with a small section of pipe installed downstream. During plant operation this section of pipe is capped and seal welded.

Corrosion Inhibitor System - A gas is introduced into the coolant system as a means of reducing the rate of corrosion of the metal surfaces in contact with the coolant. This gas is injected into the water entering the coolant system from the coolant purification system. High pressure cylinders and manifolds are provided to store the gas and control its rate of injection into the make-up lines.

Sampling System - The sampling system is designed to determine physical and chemical properties of the coolant and the steam from the steam generator. Such things as conductivity, pH, concentration of suspended and dissolved solids, radioactivity, and quantity of dissolved gases can be checked. Sample connections are made to the pressurizer vessel, discharge of the make-up pumps, the purification system, the coolant loop and the steam side of the steam generator. Radioactive material handling techniques are required for these samples.

Component Water Cooling System - The reactor shield tank, coolant pumps, control rod drive mechanisms and certain heat exchangers require cooling. Cooling water is obtained through the turbine condenser hot well and the system is designed to operate independent of auxiliary power, if necessary.

Waste Disposal System - The design of an adequate disposal system for radioactive wastes from the plant cannot be carried out properly until complete information is available on the finalized plant design and site. Therefore, the radioactive waste disposal system, as proposed, includes only the facilities needed to collect and store the normal radioactive liquid wastes until they can safely be diluted and discharged.

Gaseous wastes are drawn from the pressurizer vessel and from the flash tank. The relatively small amount of gas is passed through a condenser and a charcoal filter and piped to the decontamination area where it is diluted with fresh air while being discharged from the stack.

The ion exchangers in the coolant purification system will become highly radioactive. When the resin is exhausted, it must be removed from the shell, placed in containers and disposed of in a suitable manner.

Reactor Shutdown Cooling System - A reactor shutdown cooling system is provided to dissipate the reactor decay heat during the following conditions:

1. Normal overnight shutdown
2. Extended shutdown
3. Fuel replacement
4. Loss of all electric power during normal plant operation

Fuel Handling Equipment - The fuel elements of the reactor core continue to produce both heat and intense gamma radiation after the plant has been shut down. Therefore, when fuel subassemblies are removed from the reactor, they must be cooled and the operators shielded from radiation throughout the operations of removal, handling and storage. Underwater fuel handling has been selected as the best method for three reasons:

1. Water provides adequate cooling without interfering with the mechanical handling of the core subassemblies.
2. Water provides the necessary radiation shielding, but still permits guidance of tools by direct visual observation.
3. Water is inexpensive and easily handled.

The top of the reactor vessel opens into the bottom of an unloading tank. During normal plant operation, this tank is empty. During the fuel replacement operation, it is filled to sufficient depth to assure at least 15 feet of water above the top of a fuel subassembly which has been raised clear of the reactor vessel.

The subassemblies are removed individually with a long-handled tool in conjunction with an overhead crane. The subassemblies are than placed in a deep water storage pit until such time as they can be sent to a reprocessing plant.

Reactor Plant Enclosure - The reactor plant enclosure surrounds that part of the reactor plant which contains the hot high pressure coolant. Its purpose is to prevent the escape of vapor and gas or fission products to the atmosphere in the remote possibility of a break or leak in the high pressure equipment.

The volume of the plant enclosure is dependent upon the energy stored in the coolant and the maximum pressure which can be tolerated in the enclosure. The enclosure for this plant is sized so that the coolant volume of 400 cubic feet and the contents of the steam generator can, in the event of a rupture, flash to an equilibrium mixture of water, steam, air and gas without exceeding a pressure of 33 psig. This is accomplished by a vertical cylinder with a spherical head, 42 feet in diameter and 90 feet in overall height.

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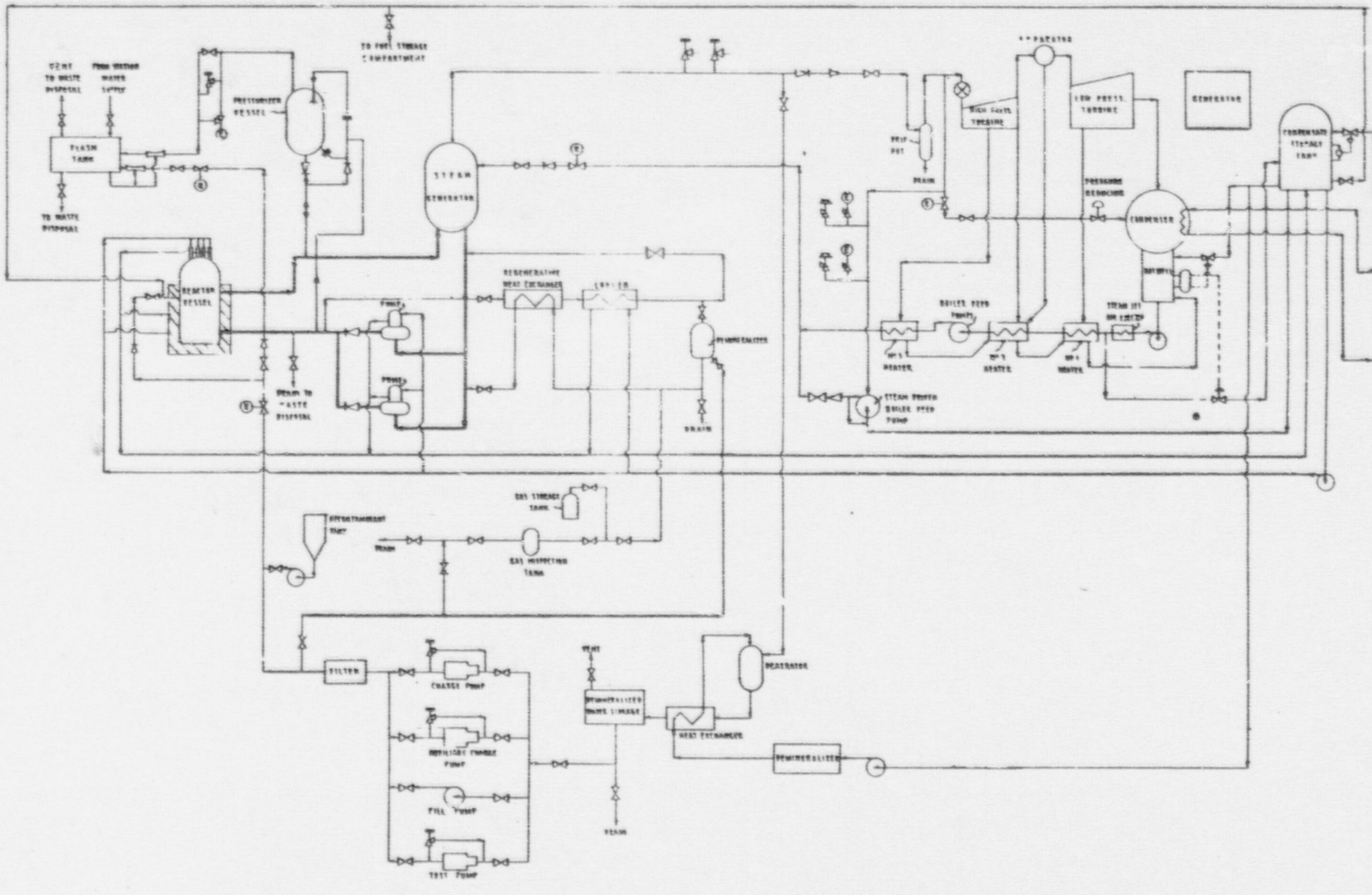
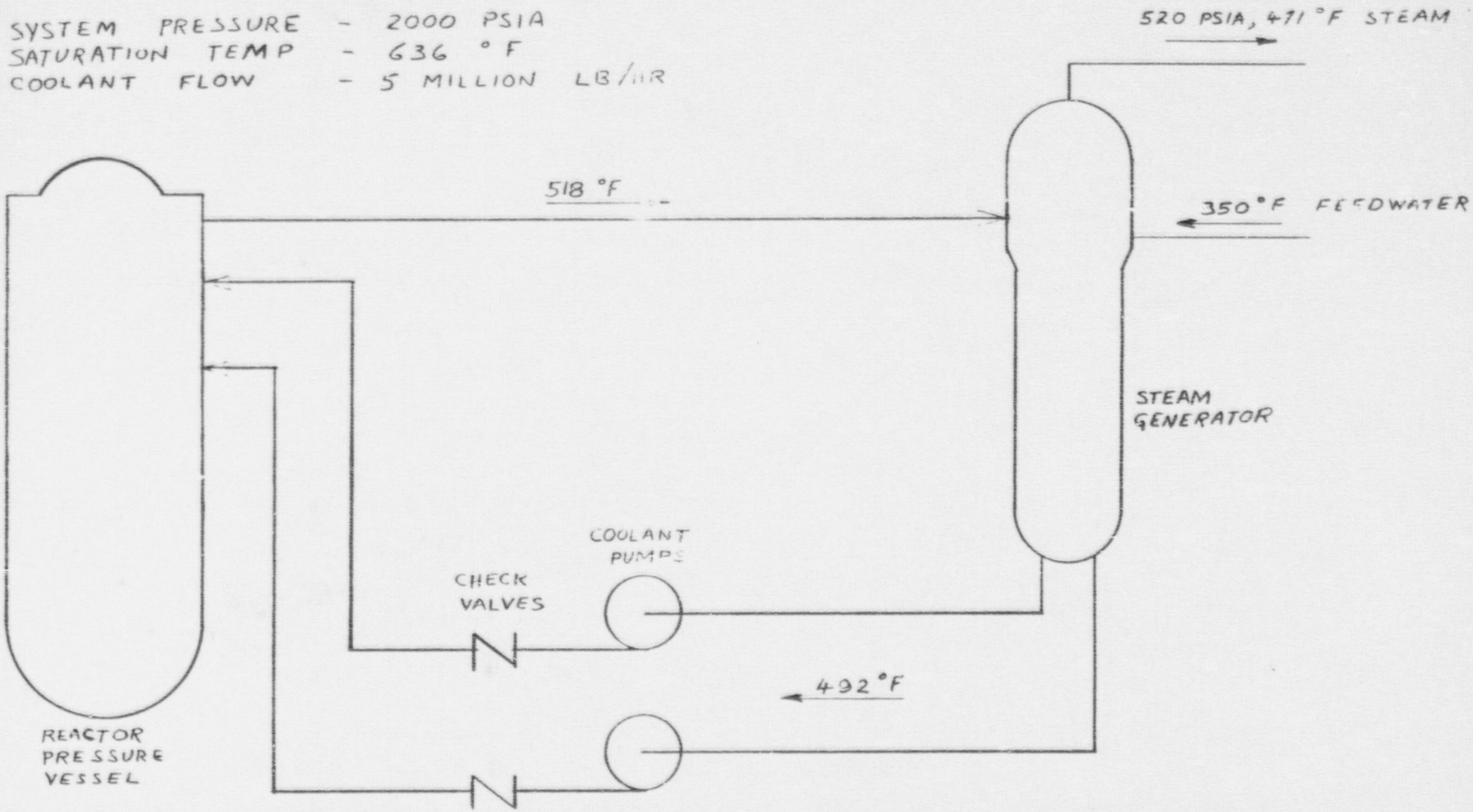


PLANT FLOW DIAGRAM



REACTOR VESSEL AND COOLANT LOOP