Reactor Boiler and Auxiliaries - Course 133

MAIN CIRCUIT CONSIDERATIONS

The properties of many possible heat transport fluids have been considered and there are an even larger number of heat transport systems that can be used with them. However, there are many principles that apply equally well to several systems. All heat transport systems can be classified as either indirect or direct cycles. In the indirect cycles, heat from the reactor is used to produce steam in a boiler or heat exchanger outside the reactor. The heat may be transported from the reactor by water, organic liquids, gases or liquid metals but the heat transport systems have many similarities.

In the direct cycle steam is produced in the reactor and boiling water, steam or fog would be the heat transport fluid.

Indirect Cycle Systems

The basic heat transport system used with an indirect cycle is shown in Fig. 1. The primary loop is a closed loop consisting of a steam generator, or boiler, a circulating pump and associated pipes and valves. The heat transport fluid is circulated through the reactor to the steam generator and back to the reactor. The fluid transports the heat from the reactor to the steam generator where it is used to boil ordinary water to produce steam. The suction of the circulating pump is at the outlet of the steam generator because the heat transport fluid is coolest at this point. This decreases the probability of cavitation occurring in the pump due to the lower suction pressure. Although this is the basic heat transport system used with an indirect cycle, additions or modifications may be required depending on the heat transport fluid used. These will be discussed under the following headings.

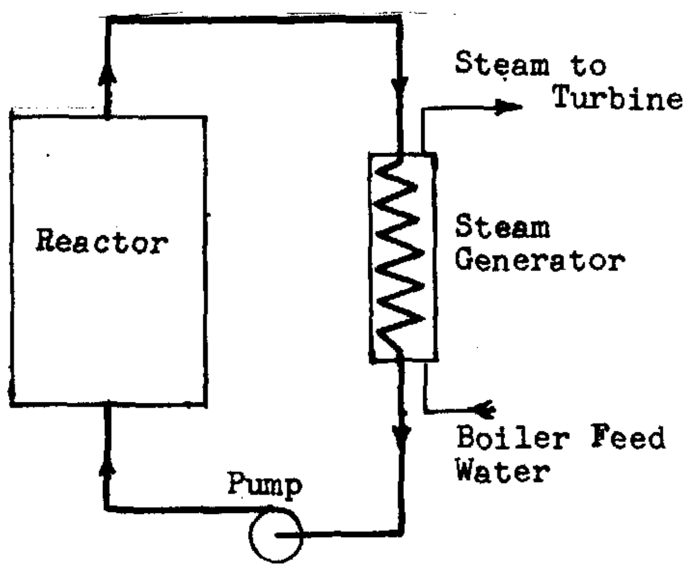


Fig. 1

(a) Pressurized Water Systems

Pressurized light water systems generally use the pressure vessel concept, in which the water, as both moderator and heat transport fluid, is in one common system. Many use the simple type of loop, shown in Fig. 1, with perhaps two or more such loops associated with each reactor as shown in Fig. 2. Two or more steam lines from separate steam drums feed into one turbine. The number of loops will be determined by the reactor power and the possible capacity of pumps and steam generators.

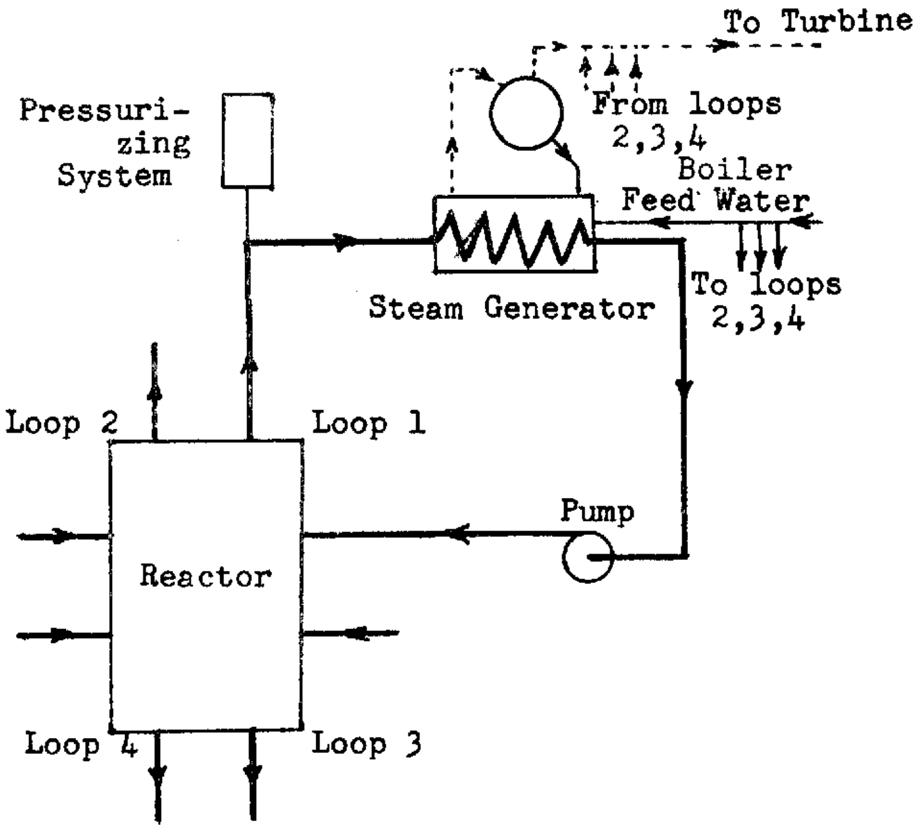


Fig. 2

A pressurizing system is required to maintain the loop pressures at 1500 to 2000 psig. Normally only one such system is required for all the loops.

In a pressurized heavy water reactor, such as the Swedish R-3/ADAM reactor, using the pressure vessel concept, the heat transport - moderator system arrangement is the same as that described above.

This type of multiloop system permits the station to operate with one loop out of service. It is likely, therefore, that valves will be installed in each loop so that the steam generator and the circulating pump can be isolated for maintenance. Such valves, if remotely controlled, could also be used to isolate one loop if leaks developed in it. If each loop is separately shielded, as in the Shippingport reactor, maintenance can be carried out on the isolated loop while the reactor is operating.

There are two types of pressure tube reactors. In both types the moderator used is heavy water, which is kept separate from the heavy water heat transport fluid. The pressure tubes or fuel channels can be vertical, as in the Carolinas Virginia Tube Reactor, or they may be horizontal as in the CANDU type. The vertical pressure tube system would use the primary loop system discussed above because it is a simple system and nothing more complicated is required.

In the CANDU system, advantage is taken of the fact that the fuel channels are horizontal, to use bi-directional fuelling. Since fuel moving is carried out against the direction of flow, the heavy water heat transport fluid is arranged to flow in opposite directions in adjacent channels. One of two arrangements are now possible as shown in Figs. 3 and 4. In the system shown in Fig. 3, the fuel channels, in which the flow is from right to left, feed through feeder pipes to a common header. The flow from left to right, through the reactor channels, passes into another outlet header. The flow from both headers pass through a common line, to the steam generator and thence, to the circulating pumps. The outlet of the pumps is fed to two inlet headers. One inlet header feeds the fuel channels in which flow is from right to left, and the other inlet header feeds the channels in which flow is from left to right. In effect the left-to-right and right-to-left reactor flows are in parallel and one loop only is required if it can cope with the required heat removal rate. If the heat removal rate is too high, then several steam generators can be placed in parallel and several pumps used in parallel. However, if the flow rates require prohibitively large pipe lines, two or more such loops would be necessary.

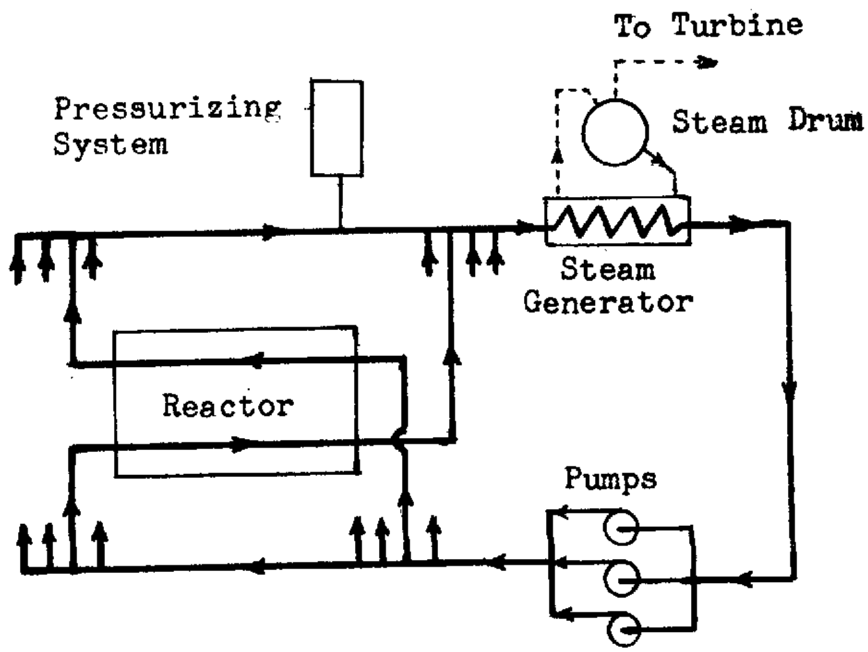


Fig. 3

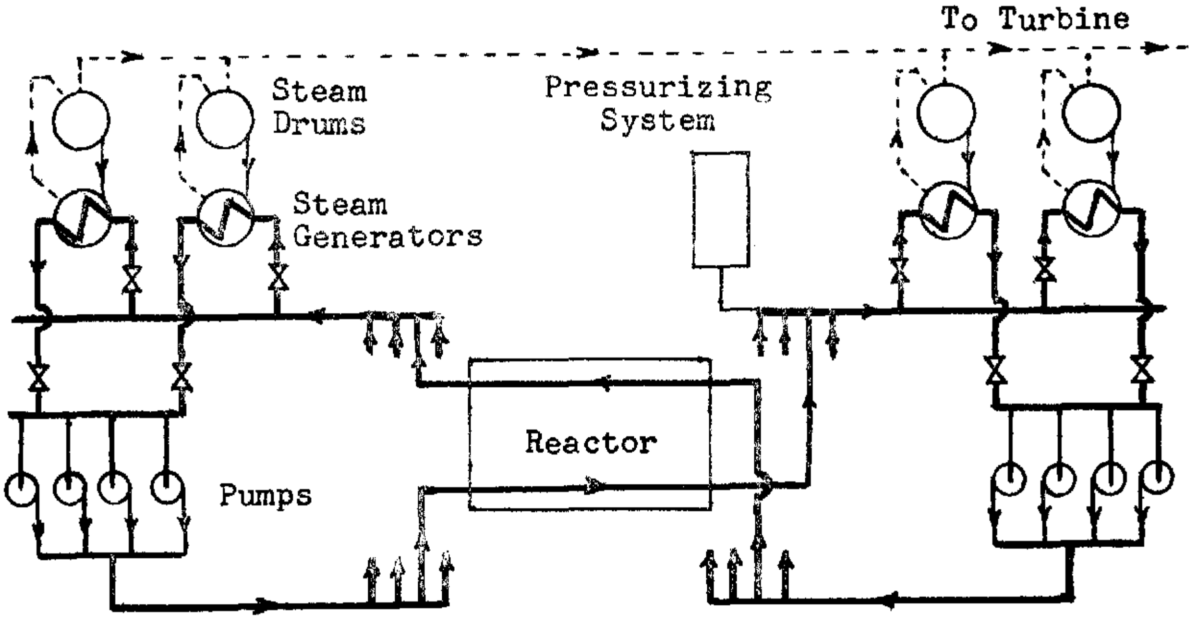


Fig. 4

Figure 4 shows an alternative arrangement. Here the right-to-left heavy water flow passes through feeders to outlet headers to the left of the reactor. These outlet headers feed one or more steam generators in parallel. The water from the outlet of these steam generators returns through pumps to the left side inlet headers of the reactor. Feeder pipes then carry the water to the fuel channels in which the flow is from left-to-right. The water is reheated as it passes through the reactor and feeds through the right side outlet headers, through one or more steam generators in parallel, through the pumps and back to the right side inlet headers. The cycle is then repeated. In effect the left-to-right and right-to-left reactor flows are in series in the one loop. There are, essentially, two heat sources and two heat sinks in the loop. Additional heat removal capacity can be installed by multiplication of steam generators and circulating pumps in the same loop. However if the heat removal rate required results in flow rates which require prohibitively large pipes, more loops would be necessary.

If multiple steam generators, pumps or loops are used, valves would probably be installed for isolation of steam generators, pumps or loops.

There are several principles and equipment considerations which apply to all pressurized water systems :-

1. The most important principle that must be applied is that IT MUST BE POSSIBLE TO REMOVE HEAT FROM THE FUEL AT ALL TIMES.

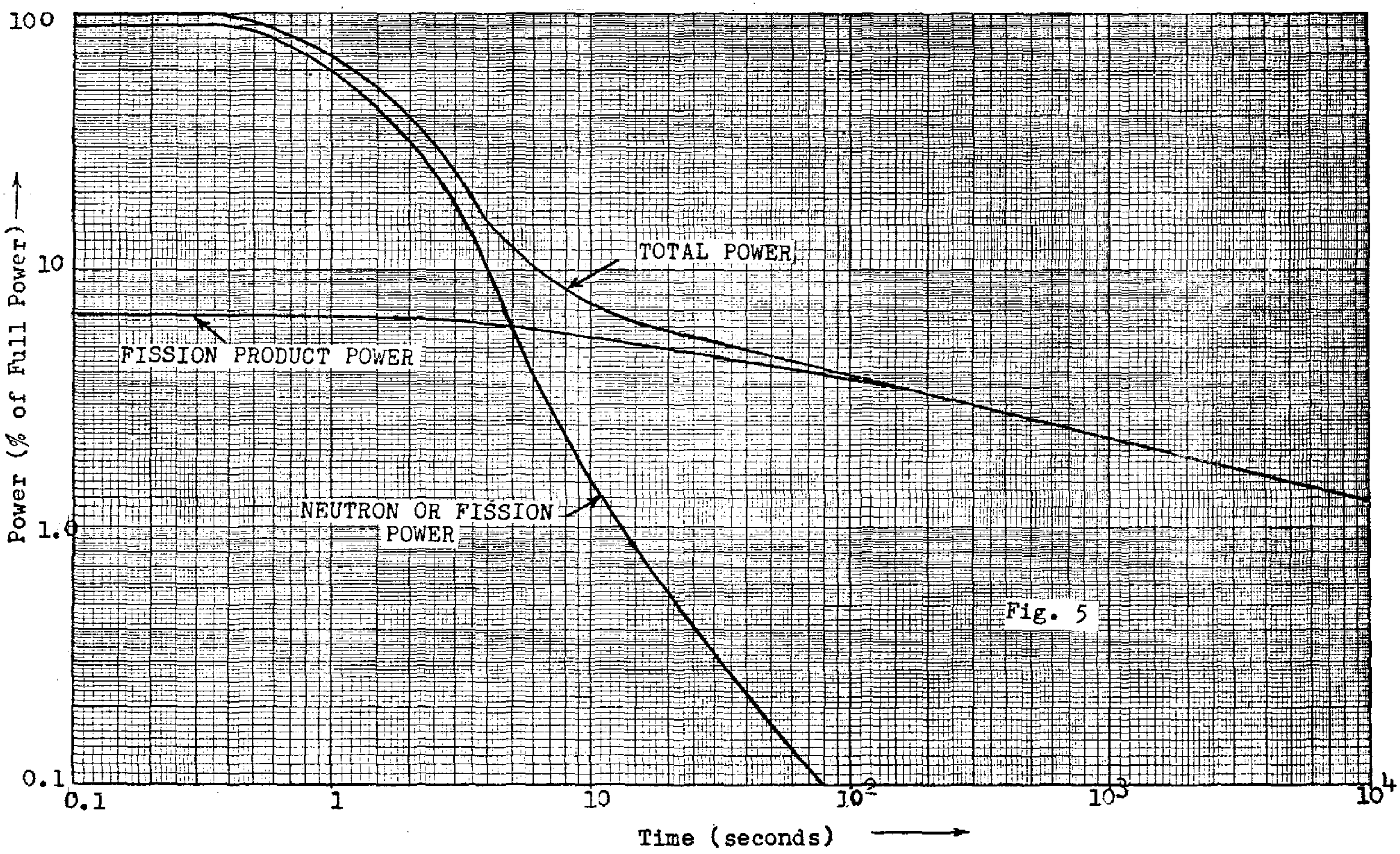
   Heat is produced in the fuel by fission of fissile material and by decay of fission products. Over 6% of the total heat production is by decay of fission product, as shown on the extreme left of the graph in Figure 5. Figure 5 also shows how the total reactor thermal power decreases, following a reactor trip. There is an initial rapid decrease to about 6% or 7% of full power in 10 or 20 seconds. Thereafter the decrease is slow because most or all of the heat is produced by fission product decay. If this heat is not removed, even during reactor shutdown, the temperature rise in the fuel would cause fuel sheath rupture or, possibly, melting of the fuel, sheath and fuel channels.

   There are many consequences of this heat removal requirement, some of which apply directly to the main heat transport circuit. The reactor is placed at a lower point in the system than the steam generator so that in the event of loss of circulating pumps, heat will be transported from the fuel to the heat sink by natural convection or thermosyphoning. This method of heat removal should be sufficient to remove a maximum of about 6% of full reactor power. To ensure that thermosyphoning is available at all times when an alternative heat removal system is not in use, an interlock would prevent isolation of all the steam generators or interruption of main circuit flow, unless an alternative system was first made available. It must be realized that thermosyphoning can only lower the heat transport fluid temperature to about 250°F because the water in the steam generators require a temperature of 212°F or higher to boil and, thus, provide a heat sink. An alternative method of heat removal is required for temperatures below this value.

   If there is insufficient flow through the heat transport system due to loss of one or more pumps, a reactor trip normally occurs. However thermosyphoning cannot cope with the required heat removal for perhaps 20 seconds or more. It is, therefore, necessary to fit the pumps with flywheels so that a sufficiently long pump run-down time is ensured to provide the forced convection required to remove the heat generated during this period of time.

   Further consequences of the heat removal requirement will be considered as they apply to the auxiliary systems.

2. The use of multiple loops, steam generators or pumps increases the reliability of the system. The heat removal rate or flow requirements may dictate the use of multiple loops or multiple



100
10
1.0
0.1
0.1
1
10
10²
10³
10⁴
Power (% of Full Power) ⟶
Time (seconds) ⟶
TOTAL POWER
FISSION PRODUCT POWER
NEUTRON OR FISSION POWER

Fig. 5

components because large enough steam generators and pumps are either unavailable or only available at a prohibitive price. Nevertheless the system reliability is increased by using more than one loop, more than one steam generator or more than one pump, in parallel and this may well be a major consideration. If one loop or one steam generator becomes defective it can be isolated and sufficient excess capacity built into the remaining loops or steam generators to allow operation at full or slightly reduced power.

One or more pumps would be installed as standby pumps so that they can be used to replace defective pumps. Such a changeover of pumps could possibly be made while the reactor continued to operate and it would have to be possible during the poison override time following a reactor trip. With such an arrangement, check valves are required in the pump outlet lines to prevent backward rotation of the stationary pumps. A limited flow of system water might be required, through the stationary pumps, to keep them at or near system temperature. This would avoid stresses in the pump casing on pump changeover.

3. The circulating pump suctions are connected to the outlet of the steam generators which will be at the lowest temperature in the system. This decreases the probability of the water flashing to steam, at the lower pressure, and causing vapour locking of the pumps.

4. **Decomposition of the water is suppressed by addition of hydrogen (or deuterium). It is not then necessary to provide degassing and recombination facilities.**

Equipment considerations, in pressurized water systems, are as follows:-

1. Pumps

Parallel pump operation is again required and pump requirements will, therefore be similar to those for the moderator system. Large flow centrifugal pumps with medium discharge pressures and non-drooping head-flow characteristic curves, would be used. Because of the high pressures and temperatures in the heat transport system the leakage problem is much more severe than in a separate low pressure--low temperature moderator system. Leakage in the pumps, in the U.S. pressurized light water reactors, is minimized by using the canned rotor pumps previously discussed. However, because of the high capital cost of canned rotor pumps, leakage in the CANDU heavy water systems, have been minimized by using shaft sealed pumps. When such pumps are used, double high-pressure shaft seals must be used, the space between the seals being bled off to a collection system. The alternative is to seal the shaft with throttle bushings backed up by low-pressure mechanical seals to retrict

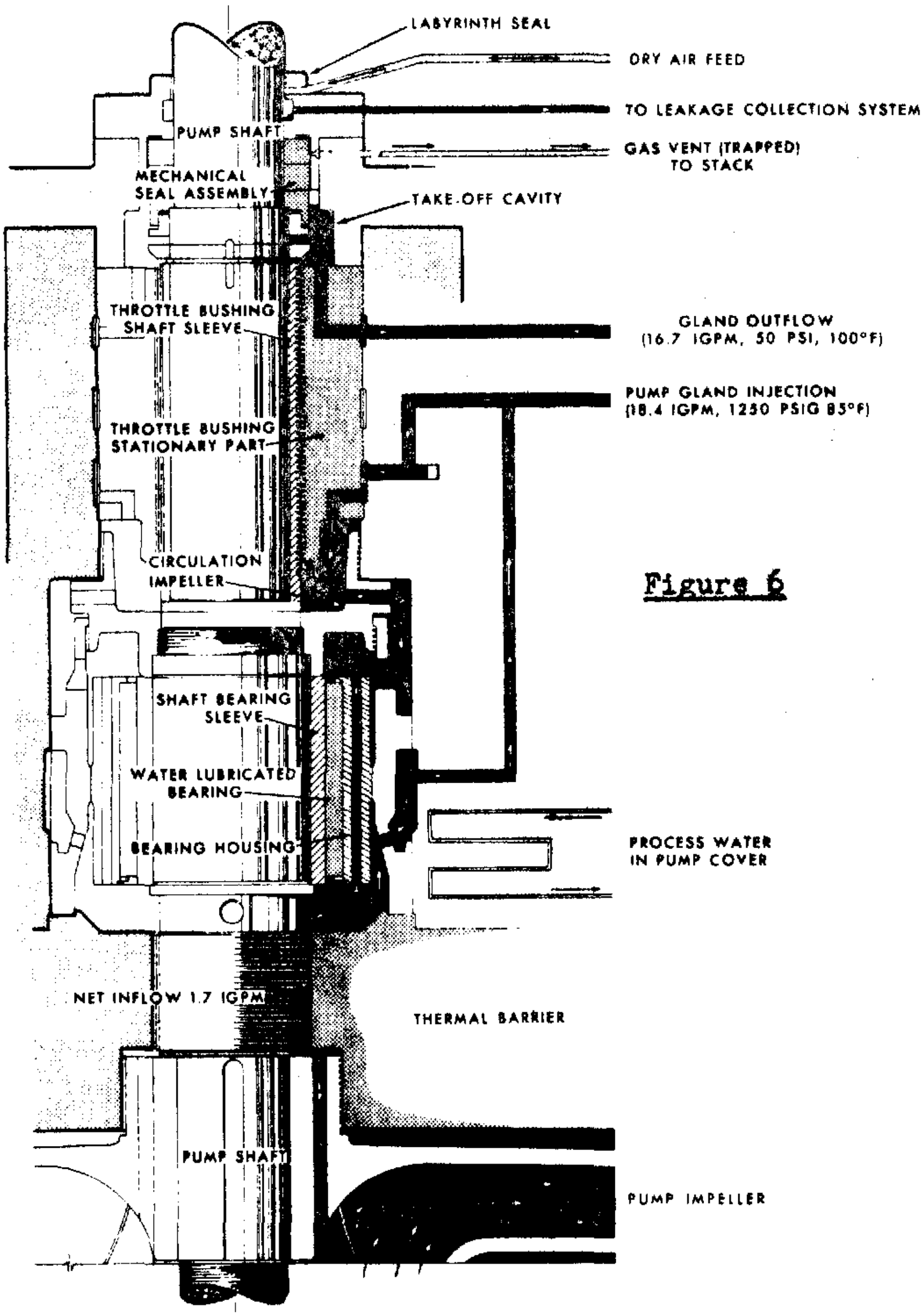


Figure 6

leakage. Such an arrangement is used in the pump shown in Fig. 6, which is the type of pump used at Douglas Point G.S.

It may be seen, from Figure 6, that cooling of the seal chamber is required. Because of the lower pressure at the pump suction, it is possible that dissolved gas may come out of solution inside the pump casing. Provisions are, therefore, required for effective venting of the pumps particularly prior to starting them. Such a venting system would feed into the collection system.

The pump bowl and casing would probably be made of cast stainless or chrome steel to reduce erosion problems.

2. Steam Generators

In the steam generators or boilers heat is transferred from the heat transport fluid to ordinary water, which is boiled to produce steam for the turbine. The most common type of steam generator is the U-type tube-and-shell heat exchanger with steam

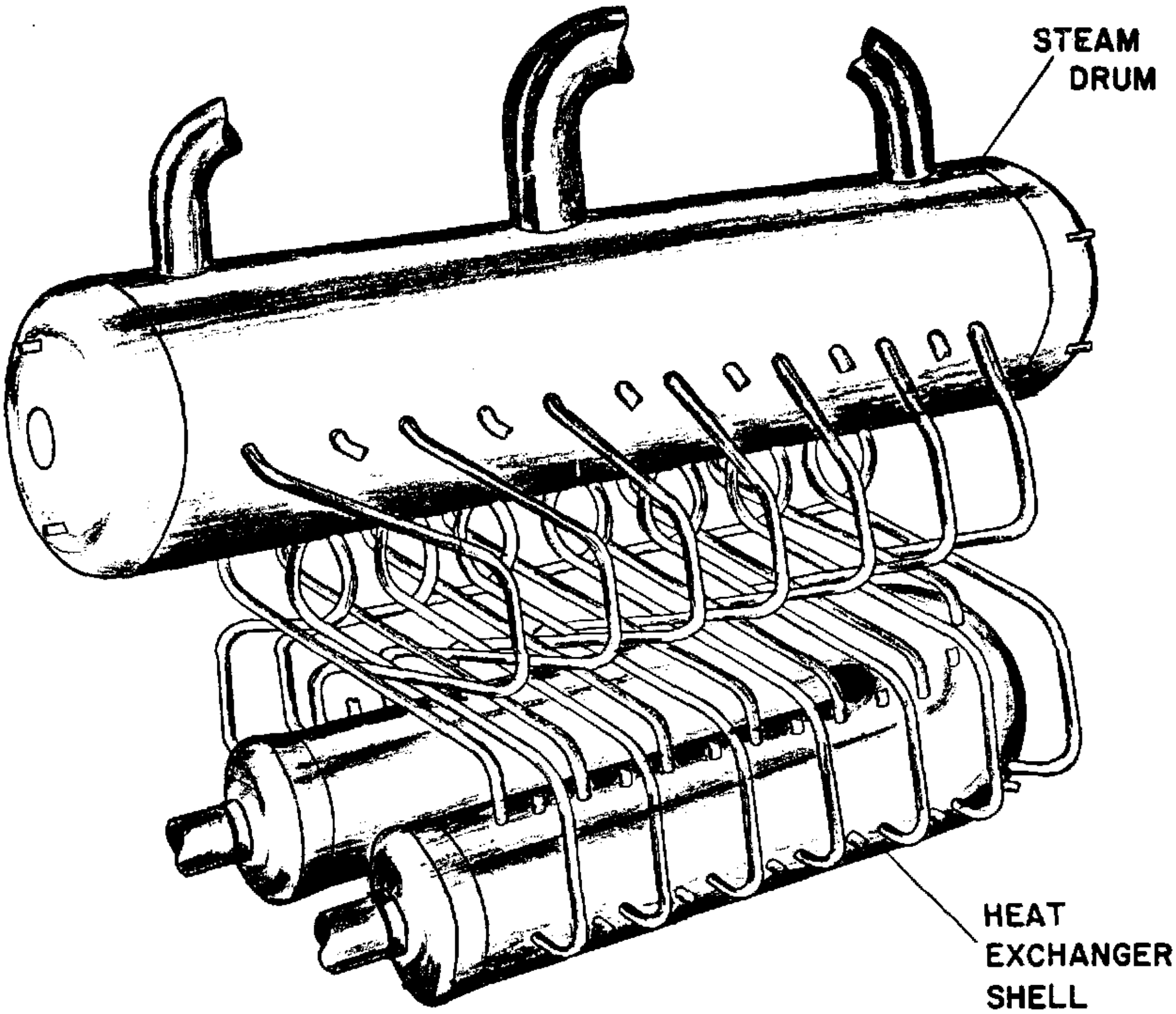


Figure 7

drum. The heat exchanger may be of the horizontal type shown in Fig. 7 or the vertical types in Figs. 8 & 9. The steam drum may be separate from the heat exchanger and there may be several heat exchangers associated with one steam drum. One steam generator in Douglas Point G.S., has ten heat exchangers, of the type shown in Fig. 8 with one steam drum.

Water at saturation temperature flows from the steam drum, through the downcomers and into the bottom of the heat exchanger. It boils in the heat exchanger and the steam enters the drum through the risers. The steam and water are separated in the steam separators and dry saturated steam passes to the turbine.

On the other hand an integral heat exchanger and steam drum may be used. Such a unit, 12 of which are used in Pickering G.S., is shown in Fig. 9. This integral arrangement is considered more economic and easier to transport and install.

Recirculation takes place inside the shell in an annulus formed by the outer shell and an inner shell which prevents the downcoming water from flowing directly onto the tubes. The lower part of the boiler is a preheater section and the baffles are used to prevent unacceptable thermal stresses in the tube sheet at the preheater.

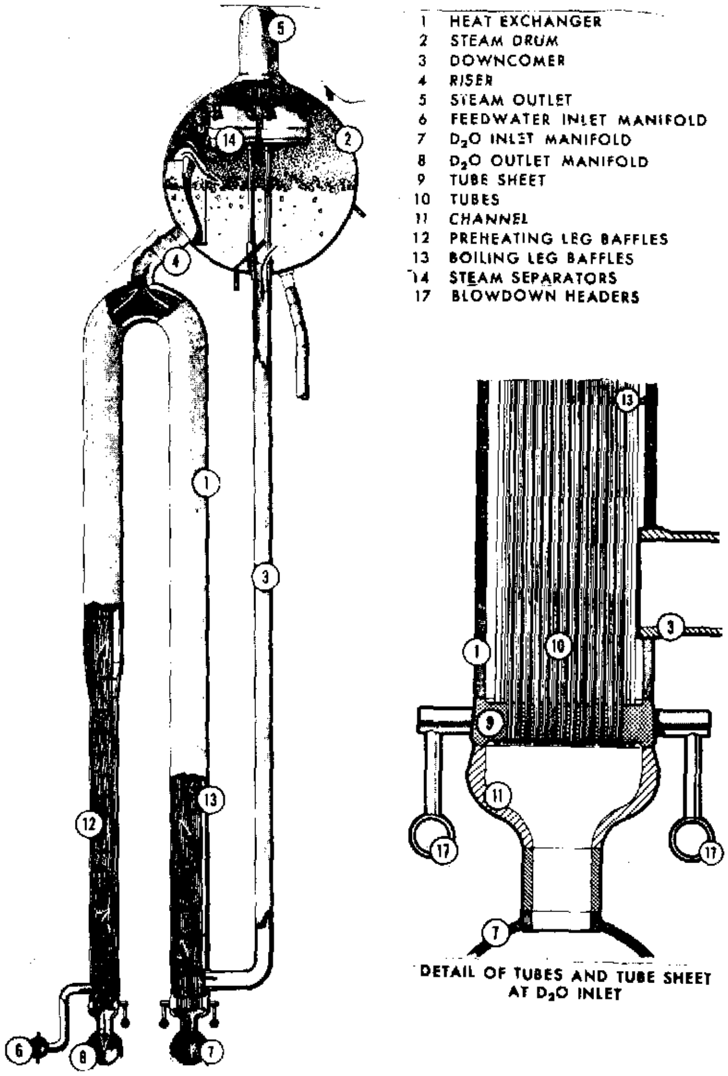


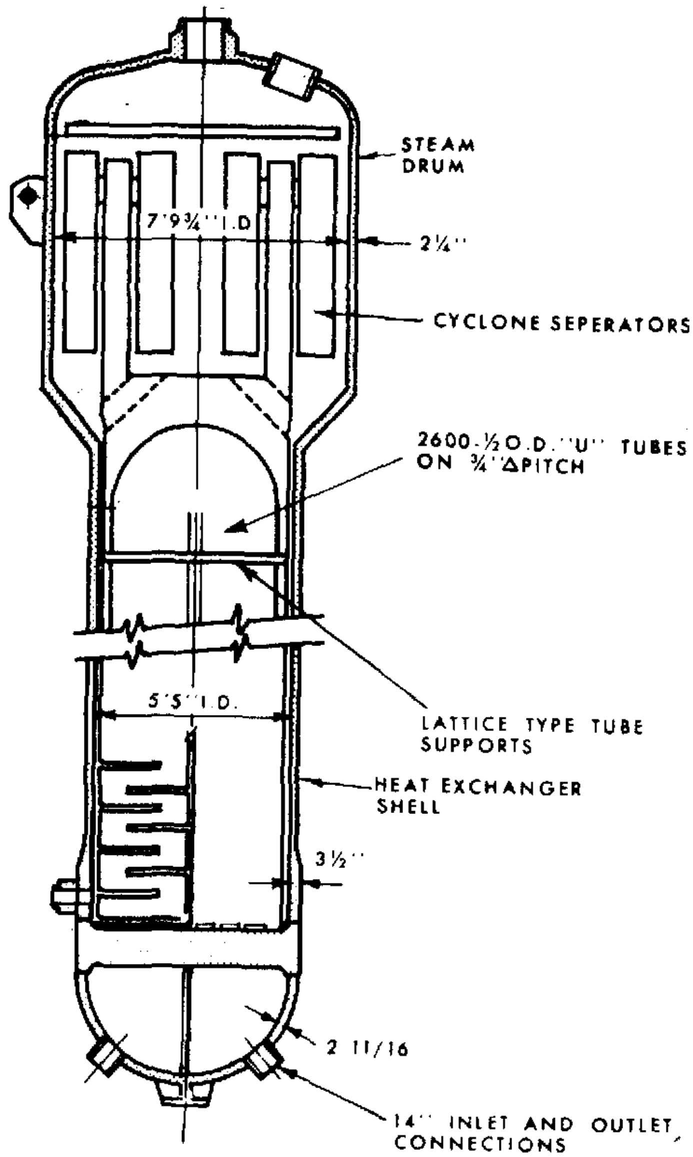
Fig. 8

In all three types the heat transport fluid, which is at a higher pressure than the light water, will pass through the tubes. The tubes will be made of a material, such as Monel or Inconnel, which is free of stress corrosion. The tube to tube-sheet joints are rolled or expanded and back-welded helium tight to reduce leakage to a minimum, particularly in a heavy water system. The tube sheets would also be of Monel or Inconnel or carbon steel clad with such metals. The shell side and the steam drum, with their associated risers and downcomers would be of carbon steel. The unit would be of welded construction in accordance with the ASME Boiler Construction Code, Section VIII for Unfired Pressure Vessels, and the requirements of the Tubular Exchanger Manufacturer's Association and the appropriate Provincial or State regulations.

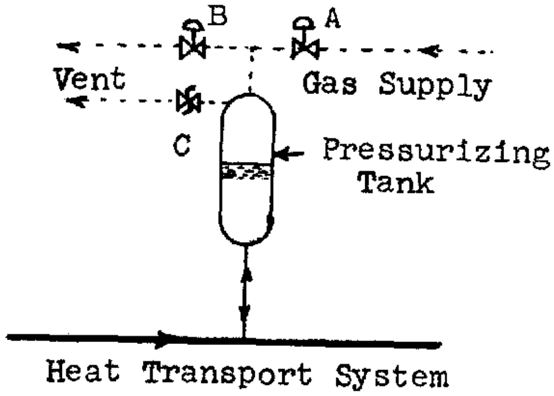
The steam generator will have welded blowdown and blowoff connections and either the steam drum or the main steam line from the drum will have relief valves to avoid overpressurization.

3. <u>Pressurizing System</u>

One of three methods can be used to pressurize the heat transport system. The simplest method is that illustrated in Fig. 10. A pressurizing tank is connect to the system so that the tank is about half full of system water. The tank is also connected to a pressurized gas supply through a valve A. This valve, A, opens when the system pressure drops below a predetermined set point.



<u>Fig. 9</u>



<u>Fig. 10</u>

If the system pressure increases above a preset value, the valve B opens to vent the tank. A relief valve, C, prevents overpressurization if B fails closed or if the pressure rise is too rapid.

A more commonly used method of pressurization is that shown in Fig. 11. Again a pressurizing tank is used and connected to the system so that it is about half full of water. Electric heaters are immersed in the water and are used to heat the water until the vapour pressure in the upper part of the tank is equal to the desired system pressure. The heaters are then controlled with heat transport pressure signals so that they maintain this pressure within narrow predetermined limits. It is possible that a spray system may be incorporated in such a tank for rapid depressurization of the system, if required, by condensation of the vapour. The water supply for the sprays would be taken from a point, in the heat transport system, at the highest pressure, such as at the discharge of the circulating pumps. The supply to the sprays would be controlled by valve A, which would be remotely operated. It is possible to continuously control the pressure in the tank, by using the sprays, if valve A is controlled by the system pressure. However, this tends to degas the water in the system which would lead to hydrogen removal from solution. The relief valve, B, prevents overpressurization of the system.

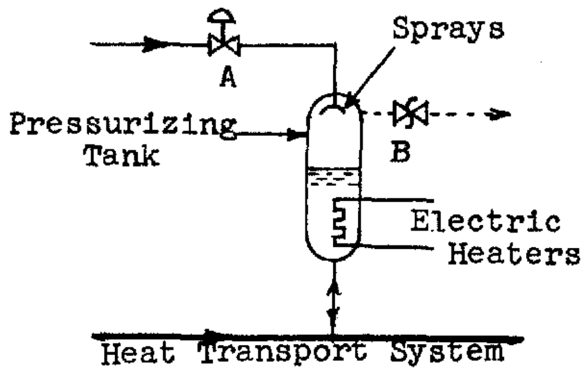


Fig. 11

In both the above methods of pressurization, the pressurizing tank will be at the highest point in the system. The pressurizing tank would be of carbon steel and manufactured according to the appropriate ASME code for unfired pressure vessels.

In the third method of pressurization the system is "solid" ie, there is no gas or vapour space above the system fluid. Use is made, instead, of the natural compressibility of the water and a bleed and feed system is used as shown in Fig. 12.

Changes in pressure will occur in the system particularly during warming up (swell) or cooling down (shrinkage) of the system. If the pressure increases above a predetermined set point, valve A opens allowing bleed-off of water from the system, through the cooler, to the storage tank. The rise in level, in the storage tank displaces the cover gas into a suitable container. Valve

A closes as soon as the correct pressure is attained. If the pressure in the system falls below a predetermined set point, valve B opens, allowing inflow or feed of water from the storage tank into the system. The feed pump, which produces this inflow, must have a discharge pressure in excess of the system pressure. The compressibility of water, at about 1250 psig and 560°F, is such that the net addition of 1 cu. ft. of water to the heat transport system raises the pressure by about 50 psi.

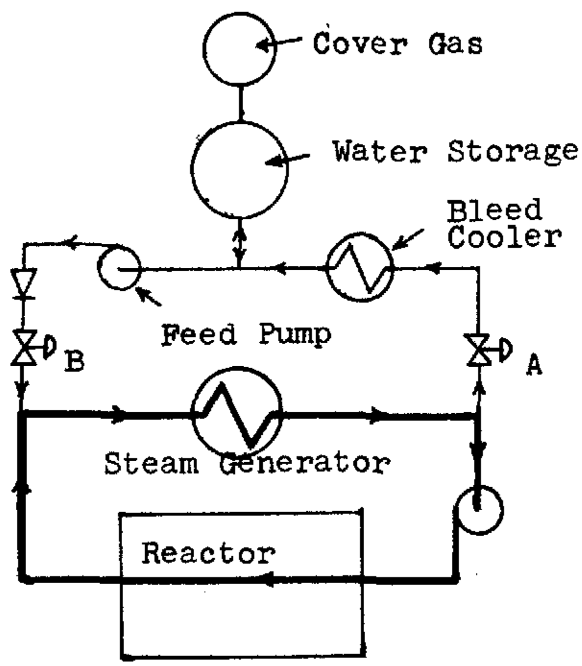


Fig. 12

It may be considered necessary to keep the feed pump operating continuously, in which case a small steady bleed from the system may be allowed which is balanced by an equal steady feed into the system. As may be seen later such an arrangement could be used as a purification circuit as well.

4. Piping and Valves

Since the heat transport system transfers heat from the fuel to the steam generator, it could contain fission products should a fuel sheath fail. The fuel sheath may be regarded as the primary fission product containment. It is imperative, therefore, that the heat transport system, which is the secondary containment, be reliable with a minimum of leakage out of it. With heavy water as the heat transport fluid, there is an additional economic reason for maintaining minimum leakage and a further reason is that of preventing the escape of tritium. Because of the high pressures and temperatures involved, reduction of leaks becomes a major problem.

Pipes would likely be manufactured from carbon steel such as ASTM A-106 grade B standard. The system must be of welded construction complying with either the requirements of the ASA B31.1, Code for Pressure Piping or, as in the case of large headers, with Section V111 of the ASME Boiler and Pressure Vessel Code for Unfired Pressure Vessels. Conditioning of the system will be required, by circulating water at 300°F through the system, in order to cover the pipe inner walls with a protective oxide and, thus, reduce corrosion.

Types of valves will be determined in the same way as for the moderator system. The valve bodies will, however, be made from carbon steel. Large valves will be provided with double stem seals and the inter-seal space drained to a closed collection system. A minimum number of small valves should be used and they should either be glandless types or double stem seals should be used.

Again the piping and equipment arrangement should be such as to minimize heavy water holdup but the congestion should not be such as to make maintenance so difficult that accidental spillage becomes more likely. Means must be provided for inserting isolating gas bags in the lines and for draining equipment or pipe sections.

(b) Gaseous System

Reactors using gas as the heat transport fluid can be divided into two groups:-

1. The "low" temperature systems which operate at temperatures below 1000°F because they generally use natural uranium metal and carbon dioxide gas. The alpha to beta transition in uranium restricts the fuel temperature to below 1220°F (660°C) and the gas temperature is kept below 1000°F because of the occurrence of a CO_2 - graphite reaction above this temperature.

The gas pressure used in the heat transport system is generally around 100 psig to 400 psig. Pressurization of the system is not, therefore, a major problem except in so far as it affects the fabrication of the very large pressure vessels which are used. Multiple heat transport loops are used and the only significant difference between pressurized gas and pressurized water systems is in the design of the heat exchangers. The heat transport outlet temperature is around 650°F to 750°F and these temperatures permit some degree of superheating of the steam. The heat exchangers are usually of the tube and shell type with finned tubes to improve the heat transfer characteristics. Each heat exchanger is fitted with economizer, evaporator and superheater stages for both high pressure and low pressure steam. Typical heat exchanger arrangements are shown in Figures 13 and 14.

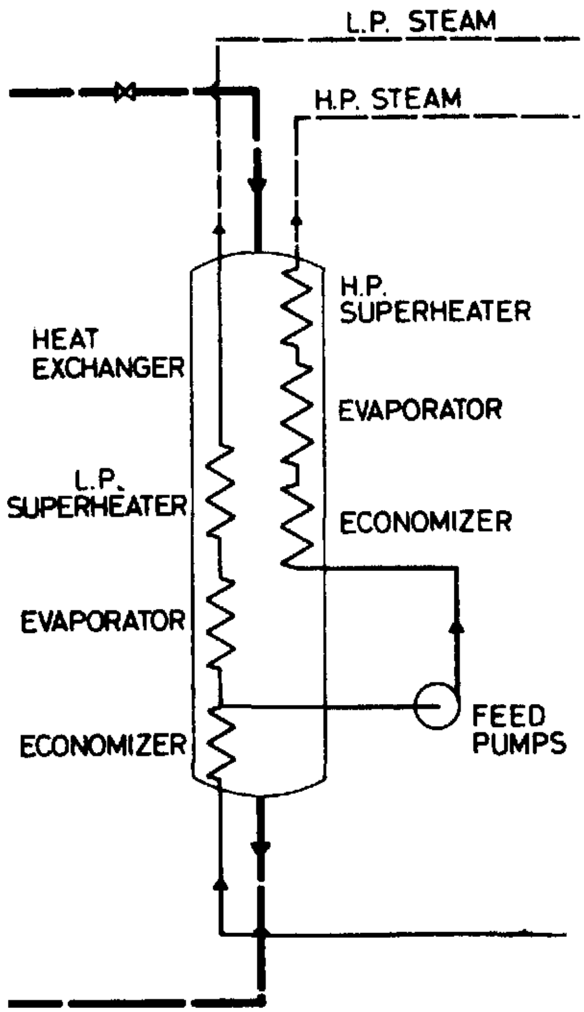


Fig. 13

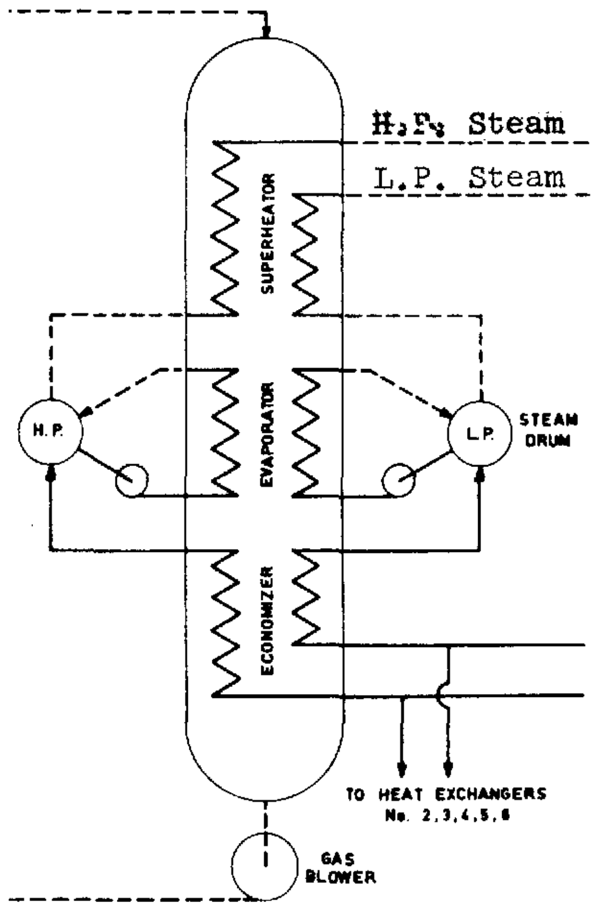


Fig. 14

2. The high temperature reactors which operate above 1000°F. These all use enriched uranium, generally as UO_2 and the fuel sheaths are made from stainless steel, zirconium, hastalloy, inconnel or graphite. The best heat transport fluid is helium since the CO_2 - graphite reaction still restricts the allowable CO_2 temperature. The higher temperatures permit a greater degree of steam superheating but the heat exchanger arrangement would probably be similar to those used with "low" temperature systems.

(c) Organic Liquid Systems

The major advantages of using organic liquids as heat transport fluids are the low pressures required in the system, even at temperatures up to 800°F, and the degree of steam superheating that can be obtained with these higher heat transport temperatures. Because of the low pressures involved (less than 200 psig) pressurization of the heat transport system may be achieved by simply applying gas pressure to the free surface of the liquid in the reactor itself or in an external surge tank. Alternatively pressurizing pumps can be used.

No hazardous chemical reaction occurs between organic liquids and water, and, therefore, the heat can be transferred directly from the primary organic circuit to boil the feedwater. An arrangement similar to that shown in Figure 15 would be used, with an evaporator, or boiler, and superheater. Both evaporator and superheater would be constructed of carbon steel and both would probably be of the shell-and-tube type.

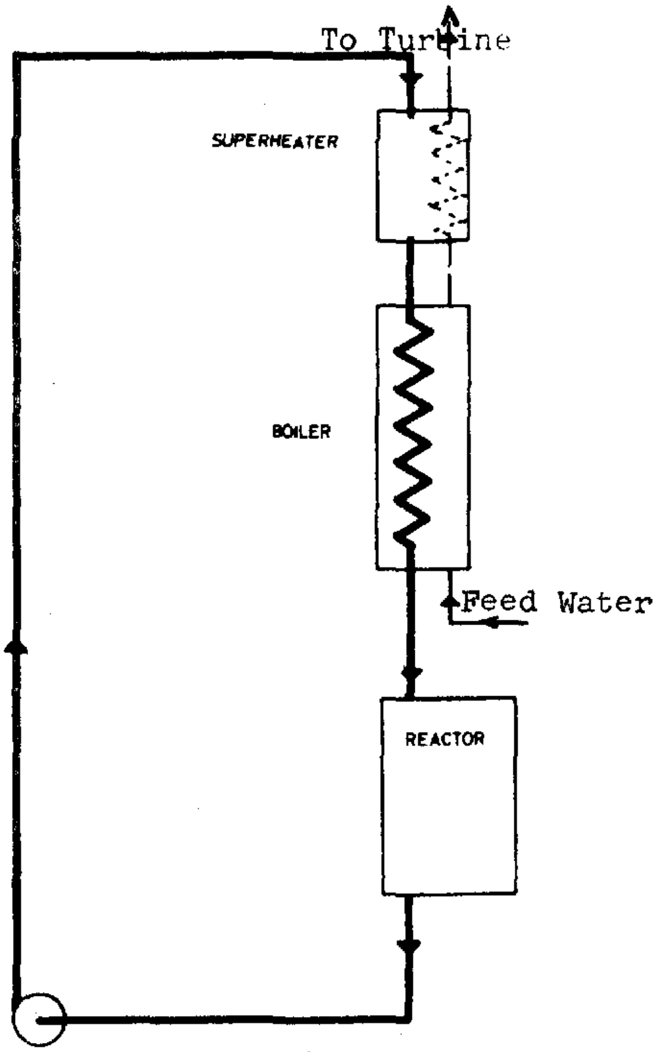


Figure 15

In the boiler the organic liquid would be on the tube side whereas, in the superheater, the steam would flow in the tubes and the organic liquid would be on the shell side. The boiler would have an internal steam separator to minimize water carry-over to the superheater.

Conventional "hot oil" pumps can be used to circulate the organic liquid round the heat transport system.

(d) Liquid Metal Systems

The extraordinary heat transfer properties of liquid metals make them attractive as heat transport fluids, particularly in fast reactors where the poor moderating properties of sodium, for example, make it particularly suitable. No pressurization of the system is required and the only pressurization which is likely to occur would be due to the circuilating pump discharge pressure or any static heads in the system. Liquid metals are capable of operating at the high temperatures required to generate superheated steam for modern turbines. The two most extensively used liquid metals are sodium and a sodium-potassium eutectic. The former is probably the better heat transport fluid but the latter is liquid at room temperature whereas traceheating would be required with sodium. There are two major problems when using either of these hot liquid metals to produce steam from water:-

1. The liquid metal systems are highly radioactive because of the formation of sodium - 24.

2. These liquid metals react violently with water.

Because of these problems, two circuits are used, as shown in, Figure 16. The primary liquid metal circuit, which is radioactive, transports heat from the fuel to an intermediate heat exchanger where it is used to heat a secondary fluid which is also a liquid metal.

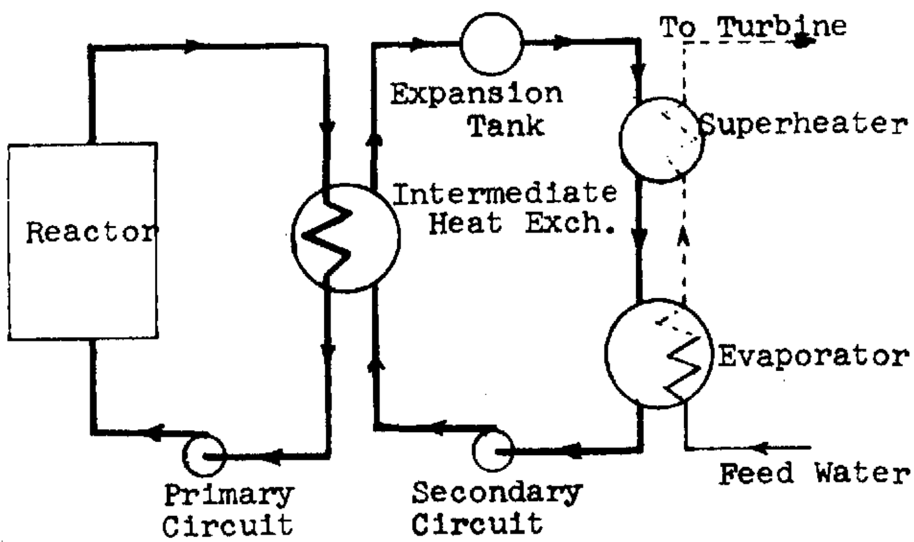


Fig. 16

The secondary circuit, normally not radioactive, has an evaporator and superheater to produce superheated steam. Both evaportator and superheater may be incorporated in the same steam generator. If mercury is used as the secondary fluid, there will be no reaction between it and the water in the steam generator. The evaporator and superheater could then be conventional tube-and-shell type exchangers with water or steam on the tube side.

If liquid sodium or sodium-potassium eutectic is used in the secondary loop, reaction between the secondary fluid and the water must still be prevented in the event of a tube failure. This is accomplished, as shown in Figure 17, by using double-walled tubes and double tube sheets. The liquid metal will then be on the shell side with water and steam in the inner tubes. The annular space between the double walls and the space between the tube sheets is filled with mercury or helium. This intermediate fluid prevents contact between the liquid metal and the water in the event of a tube failure and also acts as a monitoring fluid for detecting tube failures.

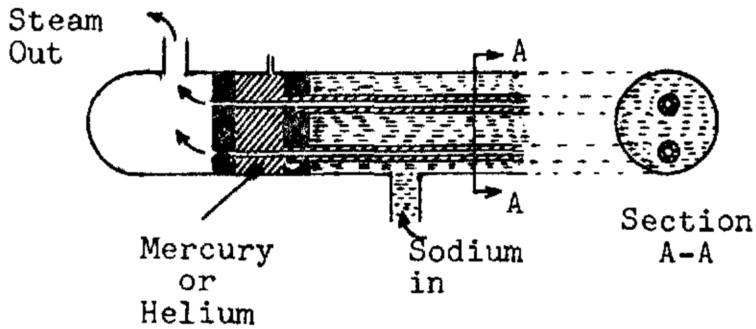


Figure 17

The intermediate heat exchanger, the evaporator and the superheater would probably be made of stainless steel.

The circulating pumps used with liquid metals may be centrifugal mechanical pumps similar to conventional pumps of this type. Leakages along the shaft can be reduced by having a liquid free surface inside the pump with a cover gas. Leakage of the cover gas is prevented with oil-filled, double-face shaft seals.

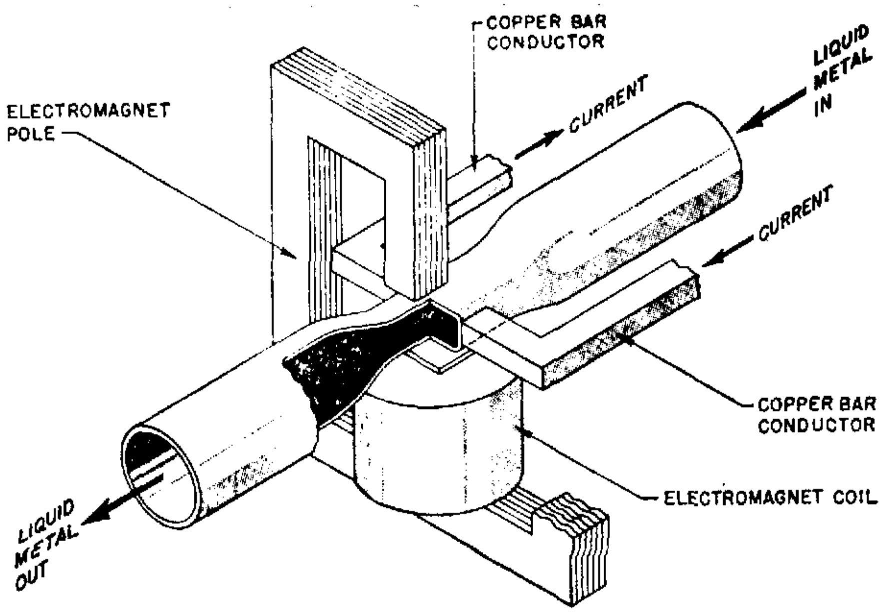


Figure 18

Alternatively a freeze-seal is formed on the shaft by freezing the sodium leaking along the shaft.

Advantage can be taken of the electrical conductivity of liquid metals to force it to flow along a pipe under the influenze of a magnetic field. The "electromagnetic" pump, shown schematically in Figure 18, results. A current is passed, through the liquid metal, in a direction perpendicular to a magnetic field. The liquid metal, being a current-carrying conductor, is exerted upon by a force which moves it along the pipe. The advantage of such an arrangement is that there are no moving parts except the fluid being circulated. However such pumps have low efficiencies and are, usually, only used on small lines where flow is occasional.

Direct Cycle Systems

In direct cycle systems the heat transport fluid is also the thermodynamic heat engine fluid which passes into the turbine. This fluid can be steam produced in the reactor and used to drive a steam turbine or it can be a gas which is heated up in the reactor and then passes to a gas turbine. Such heat engine fluids can be produced by a number of different heat transport systems:-

(a) Boiling Water Systems

Boiling water systems can, of course, be used in an indirect cycle in the same way as the pressurized water systems. The direct cycle however offers some advantages, which have already been discussed, and most boiling water reactors use the direct cycle. The simplest boiling water system is the "single" cycle system shown in Figure 19. Steam, produced in the reactor, passes to a steam drum which contains separators to remove entrained water from the steam. Dry saturated steam then passes to the turbine and the separated water is circulated back to the reactor. The feed water return is passed directly to the reactor, or flows to the steam drum where it mixes with the water in the drum and is returned to the reactor.

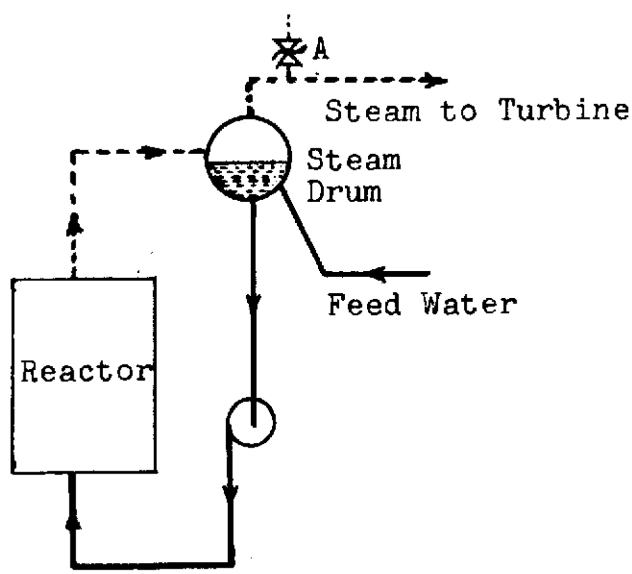


Figure 19

Several such loops may be required depending on the reactor power. In a pressure tube boiling water reactor, the steam from several fuel channels would feed into one steam drum and again several such steam drums may be required depending on the rating of the reactor.

No pressurizing equipment is required. The steam pressure produced depends on the rate at which steam is produced and the rate at which it is passed into the turbine. The steam pressure will rise until the two balance. Steam pressure can be increased further by increasing the rate of production, (i.e. increasing reactor power), or decreasing rate of flow into the turbine. The normal operating pressures are about 500 psia to 1000 psia and are, generally lower than in the pressurized water systems.

Piping and equipment requirements will be similar to those in pressurized water systems. Overpressurization is prevented by means of safety valves such as A.

In the "dual" cycle system, shown in Figure 20, the reactor heat is carried off partly as steam and partly as hot water. The hot water is used to produce steam in a secondary steam generator either by flashing or by boiling feed water. The steam produced in the secondary steam generator is at a lower pressure than the primary steam and goes to intermediate stages of the turbine. This cycle improves the control characteristics of the reactor and results in a more stable system.

Figure 21 shows a modification of this "dual" cycle system which is used in the Dresden Station. Secondary steam, at a lower pressure than the primary steam generator. The heat required to boil the water is obtained from the water separated from the primary steam in the primary steam drum. The turbine governor is set to control the output of this inter-

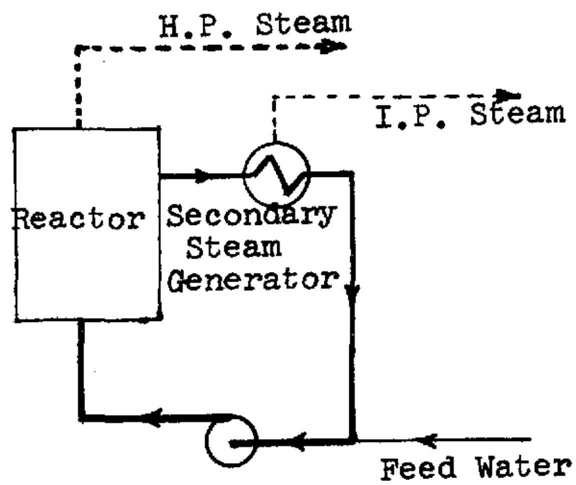


Figure 20

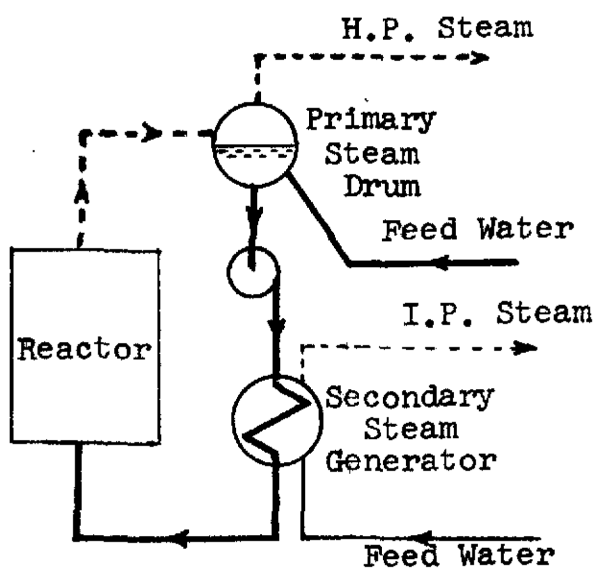


Figure 21

mediate pressure steam so that primary steam pressure does not vary with change in load.

The boiling superheat reactors use a "single" cycle system which is even simpler than that shown in Fig. 19. Superheated steam is obtained by passing steam, generated in the outer section of the reactor, through a central superheating region of the same reactor. No separators or steam drums are, therefore, required and the steam is passed directly into the turbine. The feedwater return from the turbine is pumped directly into the reactor.

(b) Fog Systems

The heat transport system, using fog as a heat transport fluid, is very similar to that using the boiling water system. Figure 22 illustrates such a system. The fog is produced by mixing some of the steam from the separator outlet with water, which was separated from this steam. The fog, as it passes through the reactor, is converted into steam. Entrained water is removed in the separator and saturated steam passed to the turbine. The steam content at the inlet to the reactor is about 15% to 25%. As heat is added to it, in the reactor, the steam content increase to 50% to 60% steam.

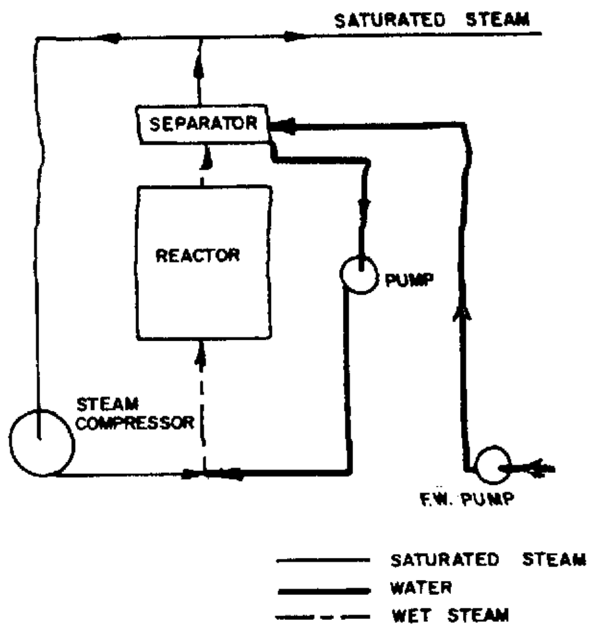


Figure 22

(c) Gas Turbine Systems

If high temperatures can be attained in a gaseous heat transport fluid, the gas can be passed directly into a gas turbine. This gives a similar advantage to that obtained with superheated steam. A direct cycle is used which does not require steam separators or steam generators.

ASSIGNMENT

1. Explain (a) Why, in a pressurized water system, the reactor is placed at a lower point in the system than the steam generator.

(b) Why the circulating pumps in such a system are fitted with flywheels.

2. What are the advantages of using multiple loop systems or multiple steam generators and pumps in a single loop?

3. Explain two methods of pressurizing water systems that are in common use.

4. What is the basic difference between a pressurized water and a pressurized gas heat transport system?

5. Explain the similarities and the differences between heat transport systems using organic liquids and liquid metals.

6. Describe one special design feature of steam generators or superheaters used with liquid metals.

7. Explain the essential difference between the "single" and "dual" direct cycles and the advantages of using the latter.

A. Williams