

Reactor Boiler and Auxiliaries - Course 133

MODERATOR SYSTEM & EQUIPMENT CONSIDERATIONS

With solid moderators, such as graphite or beryllium, no circulation of the moderator is possible. Furthermore, any heat removal, from the moderator, that may be required is accomplished by conduction through to the heat transport system. Therefore, no system, as such, is associated with solid moderators.

In reactors using light water or organic liquids as the moderator, the same material is also used as the heat transport fluid, and the two systems are common. In such cases the pertinent considerations are those appropriate to the heat transport system. Some heavy water moderated reactors, such as the Halden reactor in Norway and the R3/ADAM reactor in Sweden, are also pressure vessel reactors which are in the same category.

It is only when the moderator system is separated from the heat transport system that the moderator system and equipment requires particular consideration. Such a separation only exists in the pressure tube type of reactor using heavy water as the moderator and the discussions in this lesson will be confined to this type of system. Many of the principles involved would apply equally well to other fluids if they were used, as moderators, in a pressure tube reactor.

Basic Requirements

The main purpose of the heavy water moderator system is to maintain the reactor critical by thermalizing the neutrons released at fission. In order that it continues to do this effectively, the desirable neutron properties of the moderator must be maintained. This will involve treatment of the moderator in such a way that:

- (a) The corrosion product concentration is kept to a minimum.
- (b) The temperature is prevented from rising.

Removal of impurities, in the form of corrosion products or other dissolved or suspended solids, is also desirable to avoid them becoming radioactive and preventing access to the system components, especially during reactor shutdown. It is also easier to maintain low corrosion product concentration if corrosion in the system is prevented as far as possible. This means that:

- (a) The materials used in the system must be compatible with heavy water.
- (b) The pH of the water must be carefully controlled to suit the materials used.

For the reactor to remain critical, it may be necessary to be able to vary the moderator level in the reactor, particularly if the reactor is to be partially or completely regulated by varying the moderator level. A protective system will operate to shutdown or trip the reactor quickly, should certain variables, such as reactor neutron power, exceed some predetermined level. Reactor shutdown is conveniently accomplished by removing the moderating material or by inserting neutron absorbers into the core. It may, therefore, be necessary to empty the moderator from the reactor into a storage tank, as the primary and only method of shutting down the reactor or as a backup to some other means of reactor shutdown.

Since the moderator is contained in the reactor vessel, or calandria, thermal stresses in the vessel can only be avoided or controlled by keeping the moderator temperature within certain limits. It is also necessary to prevent the moderator from boiling and this must be done without applying much pressure to the system so as to avoid having to use a pressure vessel and high pressure piping and components.

The moderator is very likely to be used for other purposes as well. It may well be used to cool absorber rods, booster rods, and even calandria support rods. It is likely to be used for spray cooling in the calandria or dump tank when this is required. Provisions may be necessary for heavy water exchange between the moderator and the heat transport systems either on a normal operational basis or under emergency conditions. The moderator system would also be the source of water for dousing sprays in such areas as the reactor vault and fuelling machine rooms. Heavy water is also supplied to the blower seals or jet exhausters that would be required if a cover gas system is used.

The basic requirements of the moderator system can, therefore, be summarized as follows:

- (a) Means must be provided to remove heat from the heavy water moderator so that its temperature may be controlled.
- (b) Some method is required to maintain the purity and/or pH of the heavy water.
- (c) A storage tank is required with provisions for transferring heavy water from the calandria to the storage tank and from the storage tank to the calandria. The same equipment would enable the moderator level in the calandria to be raised or lowered.

- (d) The necessary piping and valves must be installed so that heavy water can be transferred from the moderator system to the auxiliary systems such as spray cooling, absorber and booster rod cooling and the dousing sprays. Exchange of heavy water between the moderator and heat transport systems must be arranged and the necessary piping, valves and connections installed.
- (e) Provisions are required for removal and addition of heavy water from or to the system and for the addition of liquid neutron poisons.
- (f) The piping and equipment in the system must be made of a material compatible with heavy water and the calandria material. Alternatively the surfaces in contact with the heavy water must be compatible.
- (g) Heavy water leakage must be kept to a minimum. Pipe and fitting joints, valve stem packing and seals must be such as to ensure this. Not only does reduction of heavy water losses result in lower operating costs, but it also reduces the tritium hazard to station personnel.
- (h) The arrangement of equipment and pipes in the system must be such as to minimize heavy water holdup. This reduces the capital cost of the heavy water required. However, this should not result in such a congested layout that maintenance of equipment and heavy water handling becomes very difficult. Accidental losses of heavy water are then more likely and the savings on heavy water holdup might be partly offset by increased operating costs.
- (i) Choice of equipment must be such as to ensure maximum reliability of the system at all times.

Moderator Heat Removal

Heat is generated in the moderator by neutron scattering and radiation absorption. Additional heat is transferred, to the moderator, from the heat transport system. The moderator may also be used to cool booster and control rods. The total heat produced in or transferred to the moderator is about 7% of the total heat produced in the reactor. Thus, in a 20 Mwe station, such as NPD G.S., requiring 82 Mw of thermal generation, the total heat produced in or transferred to the moderator is 5.6 Mw. In a 200 Mwe station, such as Douglas Point G.S., this increases to 50 Mw of heat. If this heat was allowed to accumulate in the moderator it would soon boil. It is, therefore, necessary to remove this heat and keep the moderator at a temperature below its boiling point. The moderator can not, therefore, be allowed to be stagnant in the reactor vessel but must be circulated through a circuit external to the reactor in which the heat is removed.

The simplest type of heat removal circuit, shown in Figure 1, consists of a pump, a heat exchanger or cooler and the connecting pipes. A considerable amount of heat must be removed from the moderator, particularly in a 500 Mwe unit. It seems uneconomical, therefore, to transfer this heat to cooling water, which is later discharged to a lake or river.

Unfortunately the moderator temperature is only 120°F to 180°F and it is not practical to use heat energy, at such a low temperature, for, say, building heating. However, serious consideration has been given to using this moderator heat for turbine condensate reheat. The heat exchanger would then replace a low pressure feedwater heater normally heated by steam extracted from the turbine. However, the moderator heat has, to date, been merely removed in a conventional heat exchanger.

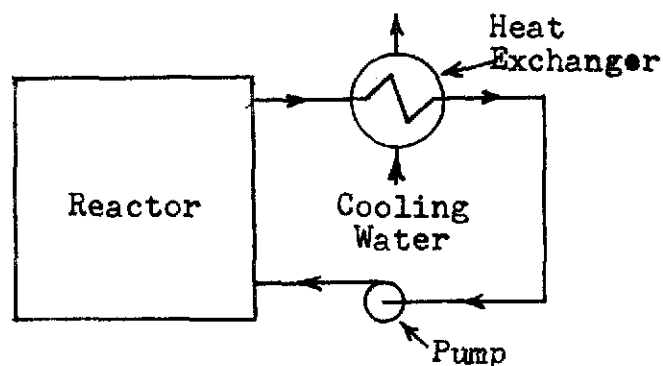


Fig. 1

The basic circuit is rarely as simple as that shown in Fig. 1. Greater reliability is normally ensured by having more than one pump, operating in parallel, as shown in Fig. 2. Multiple heat exchangers may also be used as in Fig. 3.

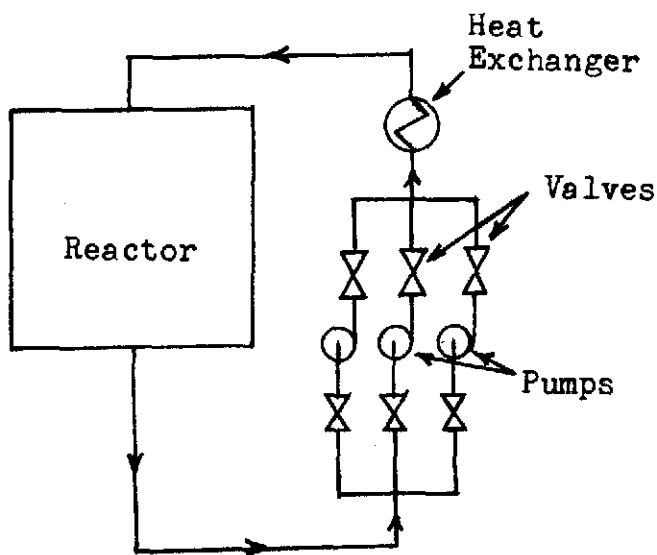


Fig. 2

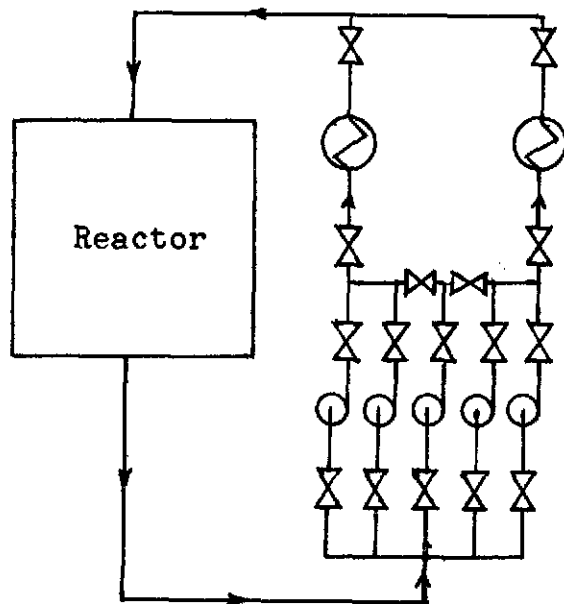


Fig. 3

In Fig. 2, two of the three pumps may be required for normal operation with the third acting as a standby pump in case one pump becomes defective. In Fig. 3, two pairs of pumps may be normally operating with the centre pump acting as a standby for either pair. On reactor shutdown, the moderator sprays are still cooling the calandria walls and tubes and the booster and control rod cooling is still required. For example, in a 200 Mwe unit, 4 Mw of heat must still be removed from the moderator when the reactor is shut down and 5 Mw must be removed if the booster rod has been recently used. So, in Fig. 3, only two of the five pumps may be required and only one heat exchanger. In Fig. 2 the different heat removal requirements would be allowed for by changing the cooling water flow.

It may now be seen that valves are required in the circuit for pump isolation and interconnection and, possibly for heat exchanger isolation.

The requirements for the various pieces of equipment in the circuit are as follows:

(a) Pumps

Parallel pump operation is required in this type of system. To reduce the number of pumps which are required, large flow, medium discharge pressure, centrifugal pumps are used. These are located at a point low enough in the system to provide the required net positive suction head. They must not be placed at a point where the suction static head is so high that special pump casings would be needed to withstand the pressure. Pumps with drooping head:flow characteristic curves should not be used for parallel operation. The pump curve should rise continually from full capacity to zero flow.

As shown in Fig. 4, a drooping pump curve intersects a given head at two different points. The pump with the continually rising curve will operate steadily at the one point but the pump with the drooping curve will tend to "hunt" between the two points at the same head. This is likely to cause serious damage to the system.

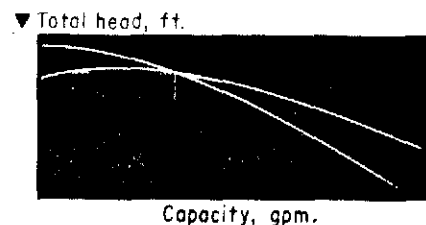


Fig. 4

The hydrostatic pressure in the moderator system is low compared with that in the heat transport system. However, it is high enough to cause heavy water leakage problems. Heavy water leakage in the pumps can be minimized by the use of one of two types of pumps. Canned rotor pumps as shown in Fig. 5, are pumps in which the motor is inside the pressure boundary of the system. A thin layer of metal separates the oil immersed stator windings from the system fluid. The leakage problems, in such

a pump are similar to those encountered with flanges and are much less severe than with the alternative shaft-sealed pumps.

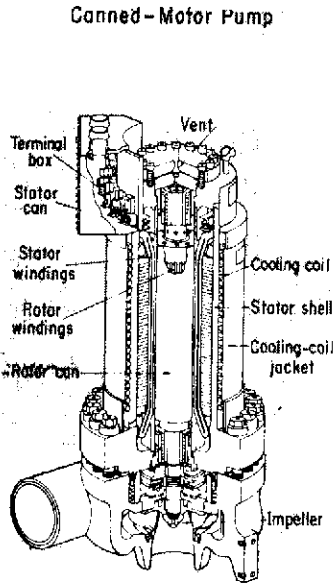


Fig. 5

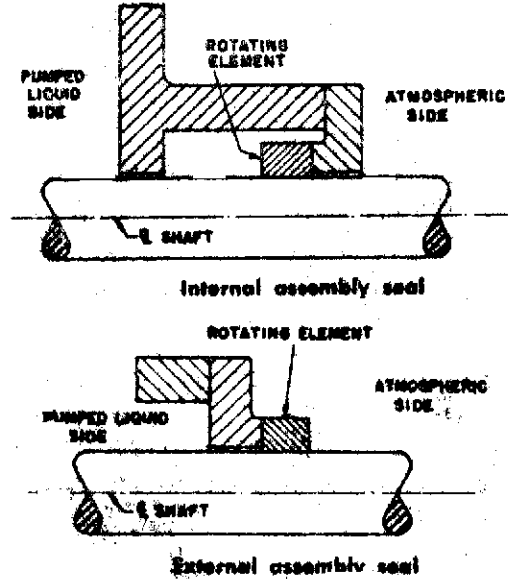


Fig. 6

However, canned rotor pumps are also much more expensive. The mechanical shaft seal pump uses a sealing device which forms a running seal between flat, precision-finished surfaces. The seal is made between a hard face made of stellite and a carbon face as shown in Fig. 6. The rotating sealing surface is carried on the pump shaft and this bears against the other stationary face. Double seals may be used, the space between the seals being bled off to a collection system. However in a moderator pump it may be sufficient to back up the seal with a labyrinth restriction and a bleed-off to the collection system, or simply allow any leakage through the seal to pass to the collection system. Such a collection system recovers the heavy water with little or no downgrading and also prevents the spread of radioactive contamination.

The parts of the pumps which are in contact with the heavy water should be of stainless steel.

(b) Heat Exchangers

Tube-and-shell type heat exchangers are suitable in this type of system. The U-tube type heat exchanger, shown in Fig. 7, simplifies expansion problems and reduce the number of tube sheet joints.

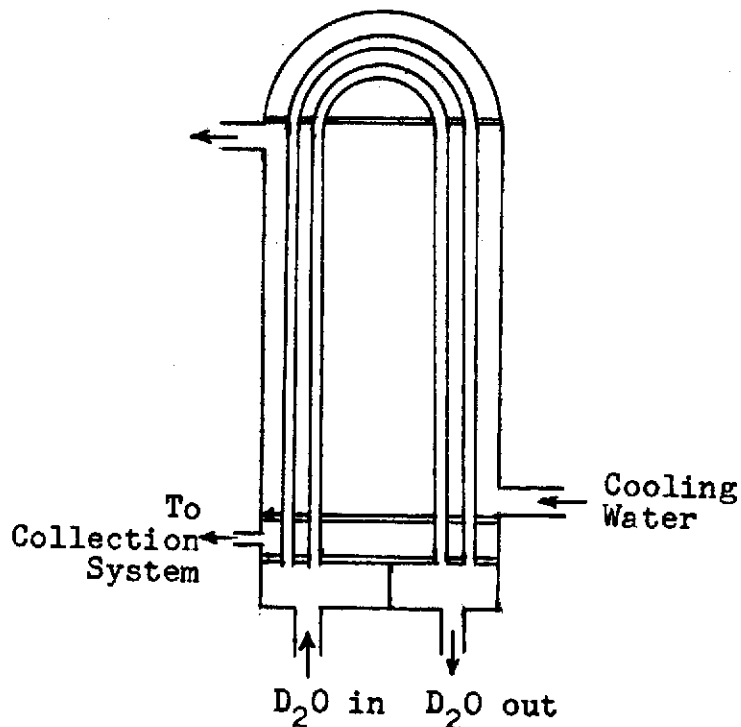


Fig. 7

would involve hundreds of thousands of dollars in upgrading costs and unit down time. A system for detecting radioactive nuclei, in the cooling water leaving the heat exchanger, would indicate D_2O leakage into the cooling water.

The tube material would probably be inconnel or some copper-nickel alloy, whereas the shell would be made of carbon steel.

In order to maintain moderator cooling at all times the cooling water supply has to be very reliable. Should the normal process water supply fail an alternative source of cooling water must be available.

(c) Valves

Moderator system operating conditions are generally below $200^{\circ}F$ and 100 psig. The radiation levels, around the equipment, are probably only moderate. The valve sizes required may be as large as 10" or 12" or as small as $\frac{1}{2}$ ". The choice of valve will depend partly on the function of the valve, ie, a globe valve might be used where flow control is required whereas a gate valve might be preferred where it is used for isolation. Other factors, such as prices, heavy water holdup and friction losses, are also considered before a particular type of valve is chosen.

Heavy water holdup is reduced by passing the heavy water through the tubes and the cooling water on the shell side. Double tube sheets are used to reduce leakage and the space between the tube sheets is drained to the collection system.

The moderator pumps maintain the heavy water at a higher pressure than the cooling water. This ensures that any leakage that does occur will be from the heavy water to the cooling water. The loss of D_2O incurred while a leakage point was located would perhaps cost a few thousand dollars whereas the downgrading of the whole of the moderator as a result of cooling water inleakage

In NPD G.S. all the large isolating valves are gate valves but for Douglas Point G.S. a calculation, based on the above factors, was made to compare gate and globe valves with butterfly valves. The comparison indicated a significant economic advantage of the wafer type butterfly valves in the larger sizes. Consequently, rubber-lined wafer type butterfly valves were chosen for valves 6 inches and larger. Development tests showed that the leakage past the vane was acceptable and that the operation of the valve was satisfactory. The shorter length also made them more suitable for use in a congested layout.

Saunders rubber or neoprene diaphragm seat valves are generally used, in smaller pipelines, where the radiation damage to the diaphragm does not prohibit their use. If the radiation damage to the diaphragm is likely to be severe all metal diaphragm or globe valves would be used.

Consideration must be given to heavy water leakage along the valve stem. Metal bellows, of the type shown in Fig. 8 can be used to seal the valve stem but these are not really required in low pressure systems. A more likely approach is the use of double stem packing seals with an inter-seal drain to a closed collection system. It may not even be necessary to have a stem leakage connection. In Douglas Point G.S., for instance the smaller diaphragm valves have V-notches bonnets with a stem O-ring outer seal. The bonnets have vent plugs through which periodic leakage checks can be made in the inerspace between the diaphragm and the stem O-ring seal.

The material, in the valve, in contact with the heavy water must either be stainless steel or a compatible material like rubber. Teflon has very poor radiation resistance and should only be used as a stem packing material in areas where the radiation fields are low or when the packing can be periodically checked and changed.

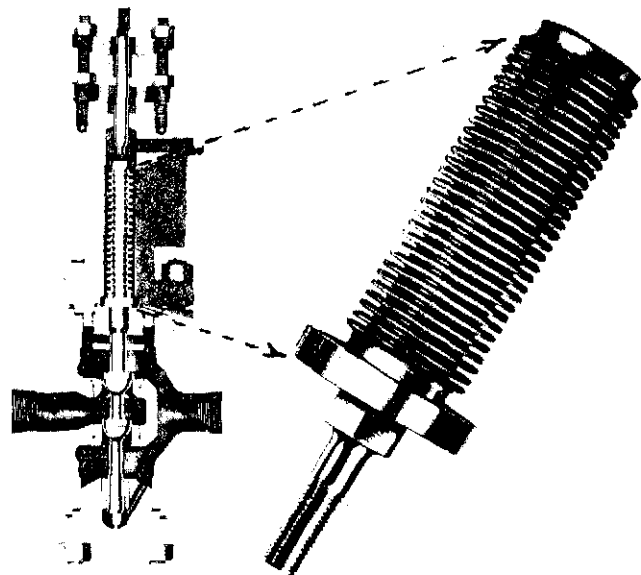


Fig. 8

(d) Piping

In order to limit heavy water losses pipe joints must be welded

wherever possible. Where two different materials meet at the joint or where the connection requires rapid or repeated breaking, flange connections are used. Weldneck flanges are preferred in larger pipe sizes, but slip-on flanges are used in locations of restricted clearance. The flange gasket material must not deteriorate due to contact with water or due to thermal cycling. The gasket material must also be radiation resistant. Natural rubber or Buna N rubber gaskets are generally suitable in the moderator system. Screwed or threaded connections have been known to loosen up because of vibration or thermal cycling. They should, therefore, be avoided if at all possible and should not be used unless they are sealed by back welding.

The piping and equipment must be arranged so as to reduce heavy water holdup as much as possible. The model of the Douglas Point moderator system layout, Fig. 9, shows how congested such a layout can become. It is clear from the figure that such congestion

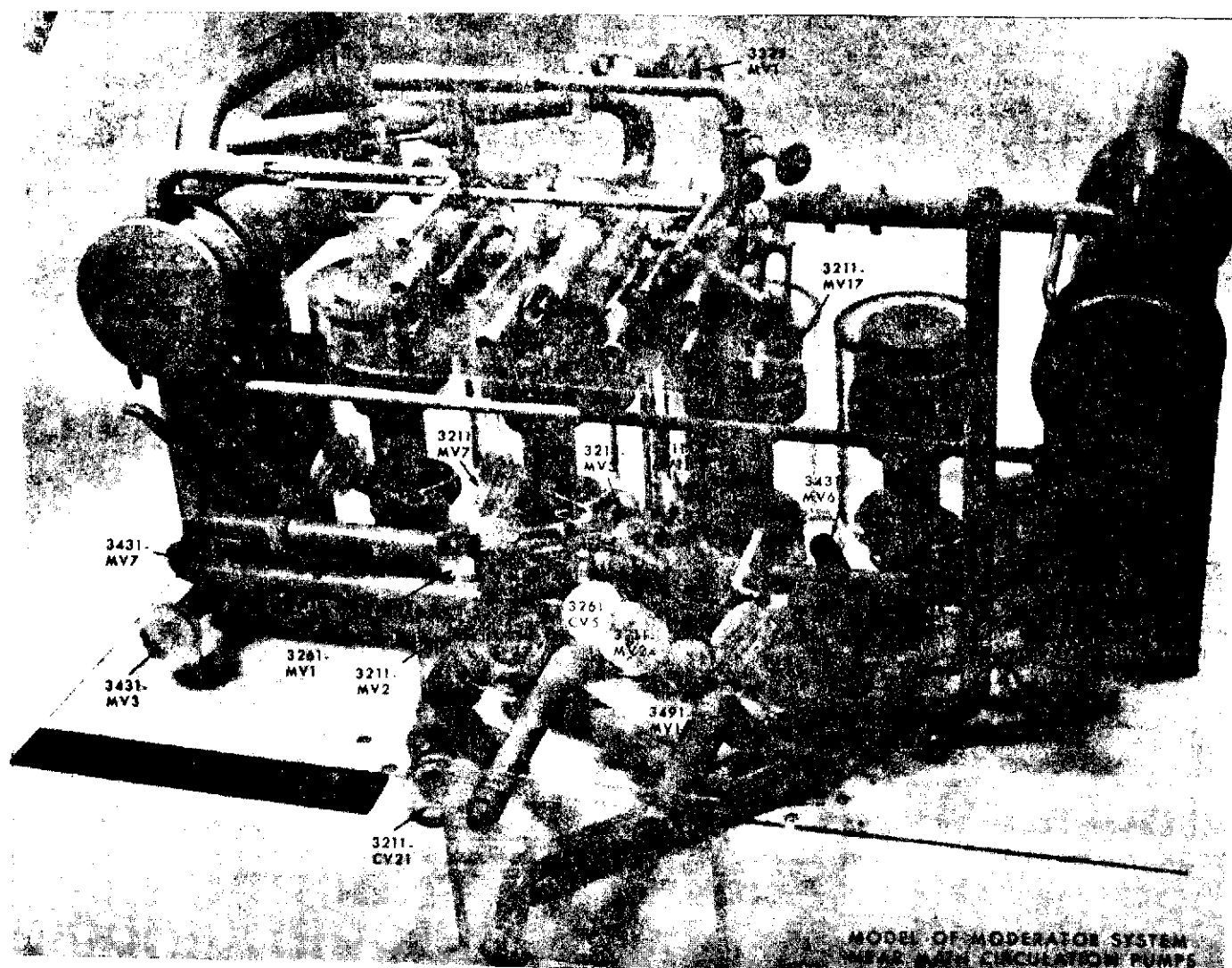


Fig. 9

could result in serious maintenance difficulties and would increase the possibility of equipment damage and accidental heavy water spillage. Such congestion at Douglas Point has already caused many problems resulting in high maintenance costs. It is estimated that, fairly early in the commissioning of Douglas Point, the increase in maintenance costs had already equalled the saving in the cost of heavy water. It may also be seen that there are likely to be many flange connections in the system. A leak detection system should therefore be installed. The general floor area below the equipment could be enclosed in a weir and moisture detectors placed inside the weir.

It is possible that the valves supplied in the system may not be sufficient to provide the isolation required for all maintenance work. Alternative isolation would, then, have to be provided. Ice plugs can be used for this purpose on small pipe or pipes in which the fluid velocity is low. For larger pipes or where the fluid velocity will not allow an ice plug to form, a gas bag inflated in the pipe can be used, provided the system is at low pressure. Such a gas bag might well be preferred to an ice plug because of the inherent hazards with ice plug formation and the effect of low pipe temperatures on welds. Isolation needs must therefore be anticipated and means provided of inserting the deflated gas bag into the pipes. Connections are also required for draining and venting equipment or various sections of piping.

If the calandria material is stainless steel, the pipes will also be of stainless steel. Aluminum pipe will generally be used with an aluminum calandria although stainless steel pipes can be used if flanged connections are used. Mild steel and aluminum would not be used in the same system since mild steel can only be used in a system where the pH is around 9 to 11 whereas aluminum corrodes rapidly under these conditions. Aluminum has good corrosion resistance at a pH of 6 or 7 but mild steel corrodes under such conditions. In any case it is desirable to keep the pH around 7 since this tends to reduce radiolytic decomposition of the heavy water. Therefore mild steel would not be a suitable material in the system.

Moderator Storage, Drainage and Level Control

There is no reason why the calandria cannot remain full of heavy water, as in Fig. 1, 2 and 3. The reactor would then have to be regulated and shutdown by neutron absorber rods which are inserted into or withdrawn out of the reactor. There are, however, a number of reasons for supplying a second tank into which the moderator can be drained:

- (a) It may be necessary to drain the reactor, in order to carry out maintenance or repairs.

- (b) A very large decrease in reactivity is obtained when the moderator is drained from the calandria. It is, therefore, very convenient to be able to shut down the reactor by partially or completely draining the moderator from the calandria.
- (c) A reactor trip or rapid shutdown is required if certain variables, such as reactor neutron power, exceed some predetermined values. Fast moderator drain provides a convenient method of quickly reducing the reactivity following a reactor trip. The tank into which the moderator is "dumped" is known as the dump tank. Moderator dump may be used as the only method of shutdown or as a backup to some other method, such as the insertion of absorber rods.
- (d) Small variations in moderator level may be used as a very versatile method of reactor regulation. Such a means of reactor regulation requires a stable, accurate level control with a very fast response.

If a dump tank is to be incorporated into the system, additional equipment will be required to permit fast draining into the dump tank, transfer of water back into the calandria and variation in calandria moderator level. One of two methods can be used. Fig. 10 shows how the moderator system, shown in Fig. 1, is changed to accommodate the first of the two possibilities. Water is constantly pumped from the dump tank, through the heat exchanger, to the calandria. The large valve B is completely closed. A is a smaller control valve and, if it is also closed the level continues to rise in the reactor until it is full. If A is partially opened, the calandria level rises until the amount of leakage through A is equal to the flow into the calandria from the pump. To raise the calandria level, A is closed further. The level then rises until the flows again balance. The line CDE allows for free gas exchange between the two tanks as the water flows from one to the other. On a reactor trip, the large valve B opens to allow fast draining or dumping of the moderator into the dump tank.

To simplify the figure no pump or heat exchanger duplication is shown and the valves in Fig. 2 and 3 have been left out. There may also be more than one valve A and there will undoubtedly be several of type B in large drain lines.

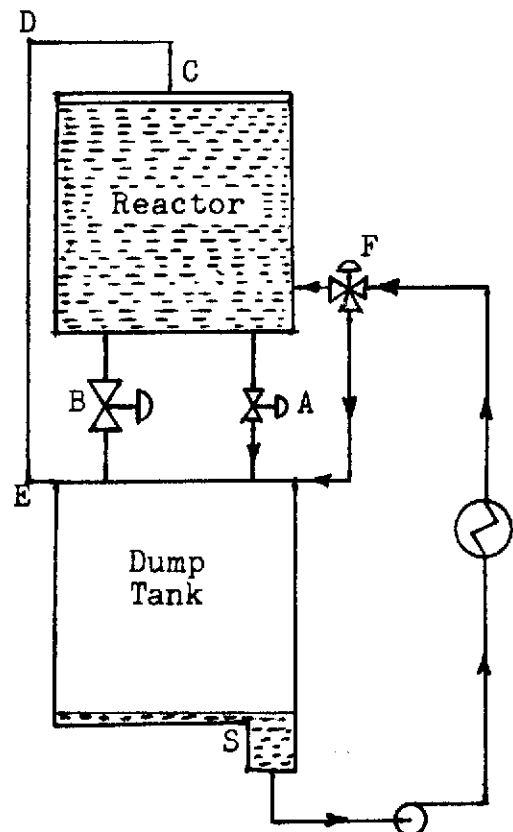


Fig. 10

In Fig. 11, there is, again, constant addition of water from the dump tank to the calandria. The water returns to the dump tank through the device W. This device, normally in the reactor vessel, is a weir arrangement over which the water spills. Such a weir arrangement is shown, diagrammatically, in Fig. 12. Because the water spills over the weir, a liquid-gas interface is formed at XY. The moderator is then kept in the calandria by establishing a Pressure differential between this liquid-gas interface and the top of the calandria. A pressure differential must, therefore, be established between the dump tank and the top of the calandria. The higher this pressure differential, the higher the moderator level in the calandria.

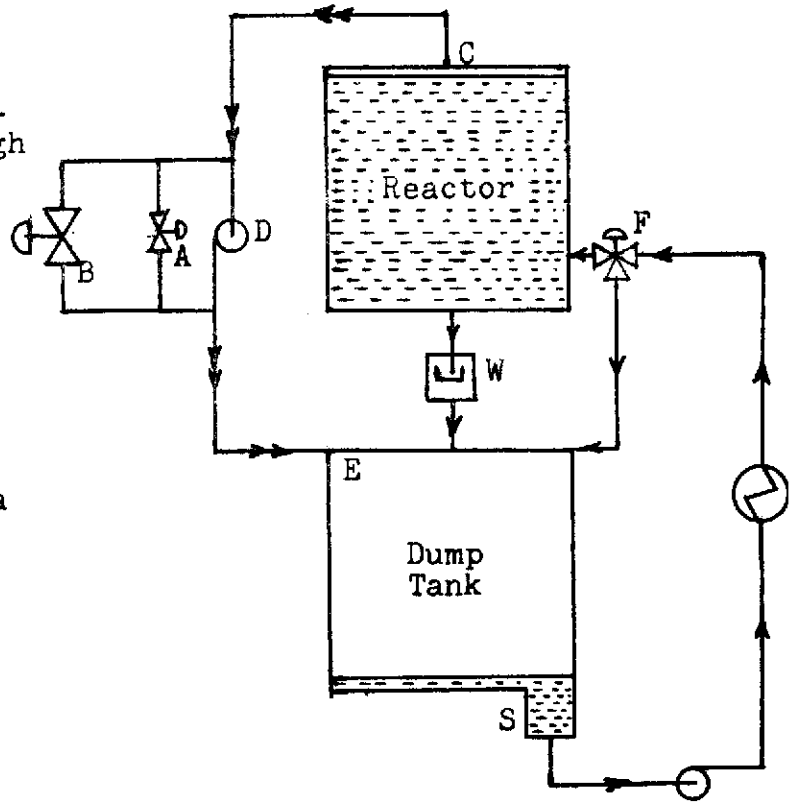


Fig. 11

The pressure differential, between the dump tank and calandria, is established by the cover gas system designated $\rightarrow\rightarrow$. Gas blowers or water-jet exhausters, D, maintain the pressure at C below that at E. If valve A and valve B were both closed, the pressure at C would become very low and the calandria would fill completely. However, a controlled gas leak rate can be established through the control valve A to give the pressure differential, between E and C, necessary to establish a specific moderator level in the calandria. Variation in the control valve leak rate can then be used to vary the cover gas pressure differential and, hence, the moderator level. A reactor trip will cause the large "dump" valve B to open. This equalizes the pressure at C and E allowing the moderator to empty rapidly into the dump tank.

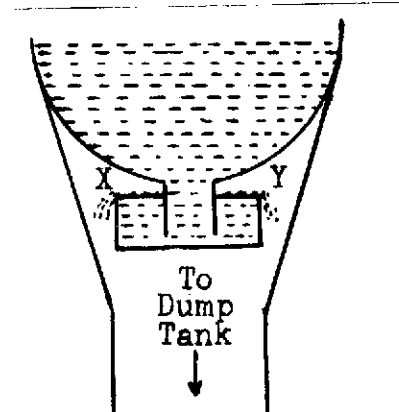


Fig. 12

The same considerations apply, to the valves in Fig. 10, as for the valves previously discussed. The following equipment requirements also apply:

- (a) The dump tank must be large enough to contain the moderator and mechanically strong enough to withstand the shock of a moderator dump.
- (b) The dump tank must be so shaped that it minimizes heavy water holdup while still providing adequate net pump suction head. An arrangement such as the sump S, (Fig. 10 and 11), could be used.
- (c) The dump tank and piping materials will generally be the same as that of the calandria.
- (d) Blowers, control valves and dump valves can be duplicated or triplicated to increase reliability.
- (e) The maximum moderator pump-up rate must be such that the rate of reactivity increase can not exceed some set value. The number and capacity of the blowers or water-jet exhauster, in Fig. 11, are based on this requirement. In Fig. 10, the pump capacity would be limited by this requirement and would result in more cooling capacity being required.
- (f) The fast drain and gas pressure equalization lines, in Fig. 10, or the weir arrangement and gas pressure equalization lines, in Fig. 11, must be large enough to empty the reactor fast enough on a trip. This tends to favour the arrangement in Fig. 11, since the water lines must be bigger than the gas lines i.e. dump valves B, in Fig. 10, would have to be substantially larger than dump valves B, in Fig. 11.
- (g) Flow diversion valves, F, may be incorporated in the moderator system. On a reactor trip, such a valve would divert the flow of water to the dump tank instead of the reactor. This would help to increase the dumping rate.
- (h) All dump valves must be quick acting to ensure a rapid dump. This will likely mean that they are butterfly valves of the "air to close-spring to open" types.
- (i) Interconnections between calandria and dump tank must have expansion joints in them to allow for changes in temperature in the two tanks.
- (j) A gas, called the cover gas, is required, particularly in the system in Fig. 11. The requirements of the cover gas system are considered separately later in the lesson.

Moderator Purification System

A moderator purification system may be provided for several reasons:

- (a) To remove corrosion products from the moderator. This corrosion product removal:

- (a) (i) Reduces the corrosion product radioactive, in the system due to neutron absorption.
- (ii) Reduces neutron capture in the reactor and so maintains the desirable neutron properties of the moderator.
- (iii) Reduces radiolytic decomposition of the water since impurities encourage radiolytic decomposition.
- (b) To control the pD of the water at a value which will reduce corrosion of calandria, dump tank, equipment and piping. The desirable pD in an aluminum system, for instance is about 6.
- (c) To remove liquid poisons, such as boric acid, which have been added to the moderator to counterbalance excess reactivity in the reactor. Such poisons are added to maintain a full calandria with new fuel or when the Xenon poison has decayed during a shutdown.

Purification, or demineralizer, systems may be full flow or by-pass systems. In the full flow system the total moderator pump output would pass through the purification system, which would be in series with the pump. However, the moderator flow is too high, (about 6,000 Igpm at Douglas Point), to permit a full flow system to be used. Consequently, a by-pass purification system is used. The purification system is connected across the moderator pumps, the discharge head of the pumps providing the pressure necessary for the flow. An orifice, in the line, restricts the maximum flow through the purification system to 40 Igpm or 50 Igpm. There may also be a flow control valve, H, provided. Fig. 13 and 14 show two possible arrangements.

In Fig. 13, the inlet to the purification system is taken from the outlet of the heat exchangers. This takes advantage of the cooling provided by the heat exchangers but, since the moderator temperature is always below 180°F, this is not an important advantage. As will be seen later some types of inter-connections with the heat transport system may make it necessary to adopt the arrangement in Fig. 14, with the system connected directly across the moderator pumps.

The low particulate materials concentration, or crud level, in the moderator system makes it unnecessary to have more than one filter, G, in the purification circuit and it may be considered unnecessary to have a filter at all, once the station is in normal operation. If a filter is used, it may be a disposable, cartridge type filter or a screen type filter which can be scraped and backwashed.

Soluble corrosion products are removed with ion exchange columns IX1 and IX2. There will be at least two of these in parallel so that one can be on line while the exhausted one is being changed.

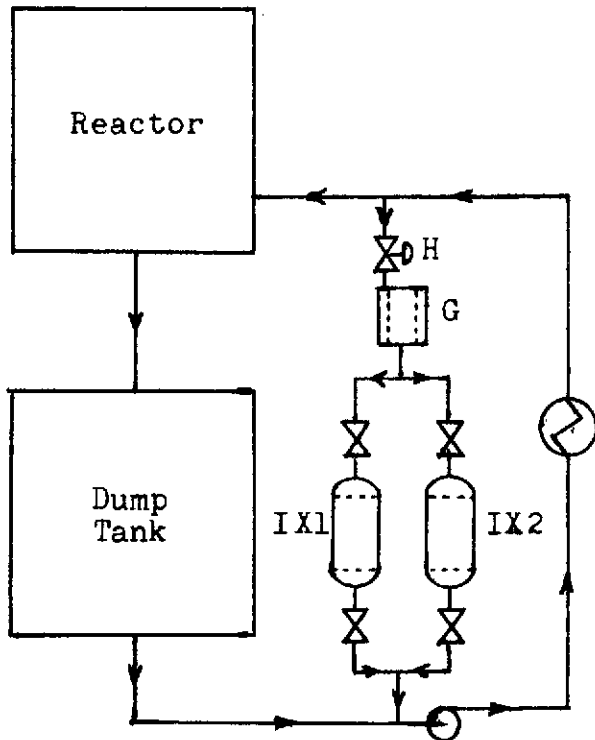


Fig. 13

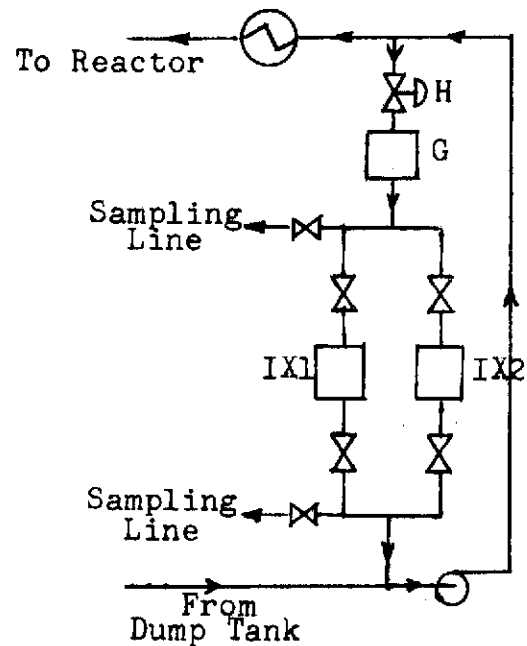


Fig. 14

Valves are then required for isolation. The ion exchange units themselves must be of stainless steel or must be lined with some compatible material such as PVC. The resin in normal use will be a mixed bed resin. If there is oil leakage into the moderator system or air inleakage into the cover gas, carbonates and nitrates will be formed. It may then be necessary to use a predominantly anion bed in parallel. A predominantly anion bed is also used to remove boron poison in the form of boric acid. The units may be entirely disposable, i.e. both container and resin being thrown away when the resin is exhausted. Alternatively provisions can be made to remove the resin only and to fill the unit with fresh resin. Heavy water conductivity measurements, at the inlet and outlet of the columns, indicate when the resin is exhausted. Facilities are also provided for taking samples at the inlet and outlet points, as shown in Fig. 14.

Before the resins are used they must be deuterated. Heavy water is passed through the resin beds until the H and OH ions, normally in the resin, are entirely replaced by D and OD ions. This prevents the hydrogen and OH ions from entering the moderator system and downgrading the moderator. When the resins are exhausted, the deuterium and OD ions must be recovered, by deuteriation, to avoid loss of D_2O .

Aluminum systems are normally operated at a pD of 5.5 to 7 whereas the pD in stainless steel systems should be 7 or a little higher. However, more efficient boron poison removal occurs with a pD of 5 to 6 and, under these conditions, evidence of corrosion in stainless system should be carefully checked. The chloride ion must be eliminated from stainless steel systems because severe stress corrosion occurs with oxygen in combination with a chloride ion concentration of only 0.1 ppm.

Since activated corrosion products accumulate on the filters and columns and since radioactive N-16 and O-19 normally circulate through the columns, the filter and columns will be contained in a shielded cavity or pit. Removable shielding blocks allow access to valves and enable filters, columns or resins to be changed. A moisture detector must be located in the pit to indicate heavy water leakage.

Connections to Auxiliary Systems

- (a) Spray Cooling - When the reactor is shut down, with the moderator drained from the calandria, the calandria tubes and reactor structure still receive some heat from the fuel. Heat is also being produced in the tubes and walls because of absorption of radiation emitted by decaying fission products. When the calandria is empty, or when all the fuel channels are not covered with moderator, auxiliary cooling is supplied from spray headers located at the top of the calandria, in the dump ports and elsewhere. The cooling water is supplied from the moderator system. Some advantage is gained by taking this water supply from the point J, at the heat exchanger outlet, as shown in Fig. 15. However, it could well be taken from the inlet to the heat exchanger, K, as shown in Fig. 16.
- (b) Booster and Absorber Rod and Reactor Support Cooling - Heat is produced in booster rods and absorber rods both during reactor operation and at shutdown. The required cooling water can again be taken from the points J or K. The same arrangement is suitable to provide heavy water for calandria supporting rods. Any return flow to the moderator system will be to the pump suction, as shown in Fig. 16.
- (c) Dousing Sprays - Dousing sprays are located above areas where pressure suppression is required in the event of line rupture. Heavy water dousing may be used initially in such areas, to avoid downgrading and light water dousing may be used only if the heavy water dousing is insufficient. Again the dousing supply may be taken from points J or K, but some advantage is gained if the supply water has been cooled in the heat exchanger.
- (d) Heavy Water Exchange Between the Moderator and Heat Transport Systems - Heavy water exchange between the moderator and heat transport systems may be required for one of two reasons. The moderator water may be used for emergency supply or injection

to the heat transport system in the event that the heat transport system becomes depressurized as a result of a rupture. This ensures that heat is removed from the fuel during emergency conditions. If this is the only requirement, then the necessary connection can be made at the points J or K, as shown in Fig. 15.

The moderator system may, alternatively or in addition, be required to receive the swell from and make up the shrinkage in the heat transport system as it expands or contracts with changes in temperature. Since the heat transport system is at a higher pH than the moderator system, the flow of water to the moderator system, during a swell, must be fed through the moderator purification system. The interconnection is then made at the point L in Fig. 16. A check valve prevents the swell passing directly into the main moderator system. The second check valve prevents drainage of the purification system due to the fact that the ion exchange column are at a high point in the system.

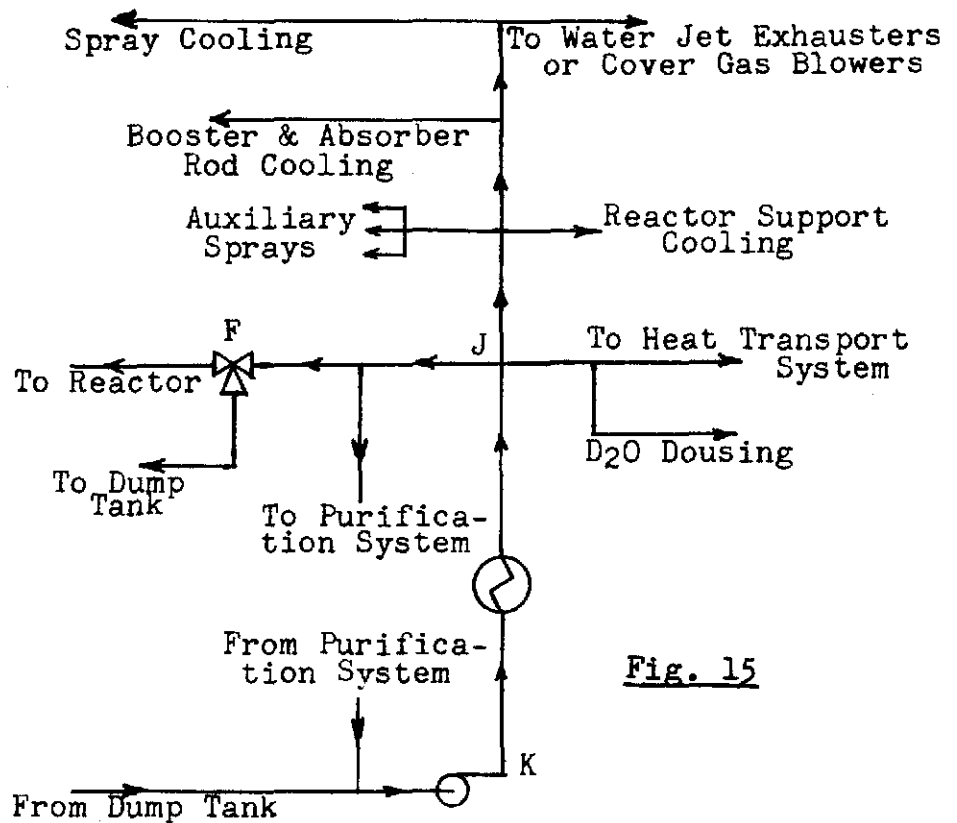


Fig. 15

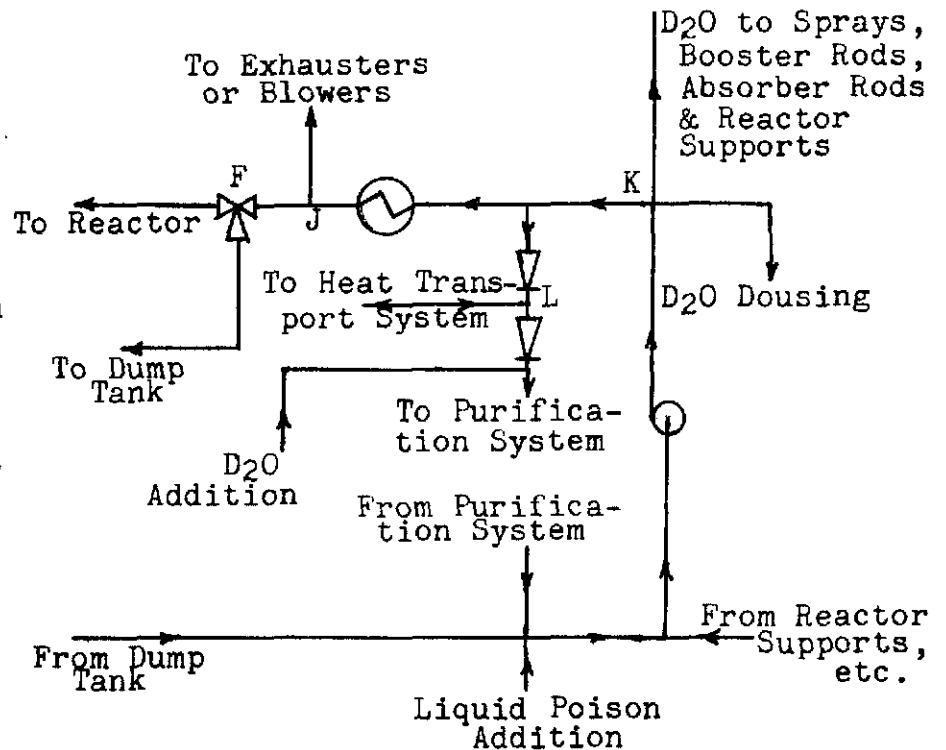


Fig. 16

The connection to the heat transport system is made at a point, such as at the outlet of the heat transport purification system, where the pressure is low.

- (e) Heavy Water for Water-Jet Exhausters or Cover Gas Blowers - Water-jet exhausters or cover gas blowers maintain the pressure differential between the dump tank and calandria. The exhausters require a continuous water supply and so do the blowers if they are of the water seal type. To avoid downgrading, this water is supplied directly from the moderator system. The water must be as cool as possible and so it is always supplied from the outlet of the heat exchangers at J.
- (f) Additions to the System - Provisions must be made for the addition of heavy water to the moderator system to make up for losses from the system by leakage or sampling. If the heavy water being added can be guaranteed to be free of impurities then the most convenient addition point is at the moderator pump suction. If there is any possibility of impurities being present, which would encourage radiolytic decomposition of the heavy water, heavy water should be added to the system through the ion exchange columns, as shown in Fig. 16. The second check valve, referred to above, now prevents the heavy water, being added, from entering the heat transport system and lowering the pH value.

Liquid poison addition to the system is made at the moderator pump suction so that it is dispersed through the system as rapidly as possible.

In all the above discussions, it is assumed that all the lines considered will have the appropriate valves fitted, even though these have not been shown. The connecting lines to the heat transport or dousing systems will have valves which open on a signal indicating an emergency condition. The D₂O addition line will have a manual isolating valve whereas the poison addition line is more likely to be fitted with a remotely operated isolating valve. All other lines will have provisions for isolation and may possibly have flow control valves. Note that in all cases, connections are made upstream, of any diversion valve, F, that may be in the system, since these auxiliary supplies are required during reactor shutdown.

The Cover Gas System

It has already been mentioned that water can be held in the calandria by establishing a pressure differential between the dump tank and calandria using water-jet exhausters or gas blowers. The level of water in the calandria can be varied by varying the cover gas leak rate through the control valve A (Fig. 11 and 17) and, thereby, varying the pressure differential between dump tank and calandria. When a reactor trip occurs, the dump valve B opens to quickly equalize the pressure between the dump tank and calandria. Further requirements of this cover gas system will now be discussed.

(a) Choice of Cover Gas

The cover gas is required primarily to provide a medium for establishing the pressure differential required to hold the water in the calandria. The essential properties of a cover gas may be stated as follows:

1. It should be chemically inert even in high radiation fields. This avoids the formation of compounds which would enter the moderator as impurities and increase the radiolytic decomposition of the water.
2. Its cost must not be excessive.
3. It should have a low neutron capture cross section. This is not so important from the point of view of neutroneconomy since the density is low. It is, however, important because of the resulting radioactivity induced. If neutron absorption does occur, the resulting nucleus should either not be radioactive or not be a gamma ray emitter.
4. Its chemical purity should be readily maintained.

There are many gases from which the choice could be made but all of them would be rejected on the basis of one or more of the above considerations. Air would be ideal because of its low cost and availability. However, it contains nitrogen and argon. These constituents capture neutrons to form radioactive carbon-14 and argon-41 respectively. Nitrogen, in a radiation field, combines with oxygen to form oxides which dissolve in the moderator to form nitric acid. This is most undesirable and is the main objection to using nitrogen as the cover gas. Hydrogen is unsuitable because of the explosion hazard associated with it.

All the gases, including the noble gases, can be eliminated in this way, except helium. Helium is chemically inert and does not acquire induced radioactivity. It is fairly expensive initially but once in the system its purity is easily maintained because it is inert. It is more expensive than nitrogen but the cost of ion exchange columns to remove nitric acid, when nitrogen is used, greatly offsets the difference in the cost of the two gases.

The main problem with helium as a cover gas is air inleakage in systems at pressures below atmospheric as it increases the nitrogen content. To avoid nitric acid formation and its consequences the system has to be purged and fresh helium added. It is imperative, therefore, that air inleakage be reduced to a minimum by using welded joints or flanged connections with reliable gaskets. It is an advantage, as in the Douglas Point system, to have the whole system at or above atmospheric pressure. Joints and connections must still, of course, be reliable to avoid loss of helium.

helium gas at the inlet and outlet of the recombination unit can be periodically sampled or continuously sampled in a chromatograph.

(c) Fast Pump Up

Provisions may be made for raising the moderator level more rapidly, immediately following a trip, to avoid a poison out. Such a facility would be in the form of a larger blower or additional exhausters, M, which would normally be isolated. The valve, S, would be automatically opened only when fast pump up was required and permitted.

(d) Helium Storage Tank

A helium storage tank or gas holder, P, is required to provide a helium feed or bleed to the system when necessary. Such a tank may be a gas holder riding on the system or it may be a storage tank connected to the system when a dump tank pressure signal opens the valve N.

(e) Pressure Relief

Valves, such as T and V, must be provided to prevent over-pressure of either the system or the storage tank. These valves would vent into the reactor vault or some other area where the heavy water vapour in the helium would be recoverable.

(f) Gas Addition

Provision must be made so that helium gas can be added from pressurized bottles to either the system or the storage tank.

The system might also become depleted in oxygen i.e. the deuterium:oxygen ratio in D₂O might not be maintained because of oxygen combining with other substances, e.g. corrosion. This will result in a deuterium build-up despite the recombination units. There is, therefore, an oxygen addition line, (not shown), upstream of the recombination units.

(g) Miscellaneous Connections

Helium may be used as a cover gas for other systems such as heavy water collection system. It may also be used to prevent air inleakage through the dump valve stems or the pump seals. Connections must be provided, from the storage tanks for these purposes.

ASSIGNMENT

1. Briefly summarize the basic requirement of the moderator system.
2. (a) Why is it necessary to cool the moderator?
(b) Why can the heat removed not be put to some practical use?
(c) Why are the pumps and, sometimes, the heat exchanger duplicated?
3. (a) What type of pumps are used in the main moderator cooling system and how are heavy water losses from these pumps minimized?
(b) What reasons are there for minimizing such losses?
4. Explain how the design and method of operation of a moderator heat exchanger may differ from a conventional heat exchanger and explain why these differences are necessary.
5. (a) What considerations govern the choice of valves in the moderator system?
(b) What types of valves are used and for what purposes?
6. (a) What two major considerations govern the piping connections and layout and in what principles do these considerations result?
(b) What other provisions may have to be considered?
(c) Explain how the pipe material is determined.
7. (a) What reasons exist for supplying a dump tank in the moderator system?
(b) Enumerate the basic requirements of the dump tank and dump pipes.
8. (a) Explain why a moderator purification system is required and why a by-pass system is used.
(b) What types of resin beds are used for what purpose and how is it known that the beds are exhausted?
9. (a) Why are spray cooling and booster and absorber rod cooling connections required?
(b) Give two reasons why heavy water exchange should be possible between the moderator and heat transport systems.
10. (a) What is the primary reason for having a cover gas system and how is it fulfilled?
(b) What are the other possible uses of the cover gas?
11. List the essential properties of the cover gas and explain why the only choice is helium.
12. Explain why a recombination circuit is necessary.

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