Chapter 12 - Part A
PROCESS EQUIPMENT

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ABSTRACT

The process equipment in the Primary Heat Transport System is described. The design requirements and performance of pipes, pumps, steam generators, pressurizer, Bleed/Degasser Condenser and valves used in the engineering of the CANDU system are discussed.

12.1 INTRODUCTION

The process equipment in a Nuclear station provides the means to extract the energy from the reactor's core and convert it into electrical energy.

The process equipment outside the reactor core includes the steam generators, heat exchangers, pumps, valves, pipes, pressurizer and a bleed or degasser condenser.

The process part of the title refers to the thermohydraulic phenomena that takes place in the equipment. The thermohydraulic changes take place in the heavy water fluid which transfers the energy from the core to the steam generators to produce steam that drives the turbine generator set (Figure 1).

We will examine how each piece of equipment fulfills its role in the process of generating steam for electricity. We will also examine the design requirements and how each piece of equipment is selected.

Figure 1 shows how the process equipment is placed in the general flow sheet of a nuclear station. The Primary Heat Transport System pumps move the heavy water through the reactor extracting the energy from the nuclear fuel. In the steam generators this energy is transferred to the natural water to form steam which drives the turbine and electric generator. From the steam generator the cooled heavy water re-enters the core to repeat the cycle.

The conditions of the heavy water at the Reactor Outlet Header vary from station to station. The heavy water at the Reactor Outlet Header at Pickering is subcooled, saturated - but not boiling at Bruce, boiling at Darlington and in the 600 MW reactors in Quebec and New Brunswick.

In order to control the pressure and heavy water inventory in the Primary Heat Transport System a feed and bleed system is added. In stations with boiling or saturated heavy water in the Reactor Outlet Header, the feed and bleed system is supplemented with a pressurizer.

When the reactor is shutdown, the nuclear decay energy is removed by the shutdown system. The shutdown system recirculates the heavy water of the primary heat transport system and cools it down in a heat exchanger.

In case of an emergency in which there is a loss of heavy water inventory, the Emergency Core Injection System is activated automatically and cools the core.

Since process equipment is connected with pipes we will first examine the role and function of the pipe in the CANDU system.

12.1 THE PIPE IN A NUCLEAR STATION

The pipe in a nuclear station is viewed with much more respect than in any other installation. Once a pipe is laid out and installed it is usually undesirable to fix or modify since it may be embedded in concrete in parts or may be radioactive. In a nuclear station the pipe performs the traditional function of a conduit for the heavy water, pressure boundary and an extension of the reactor containment up to the isolating valve.

Pipe diameters vary from 1/4" up to 40". The pressures vary from atmospheric to 12 MPa, while the temperatures vary from 0°C to 310°C. Pipes are integral part of all process systems. Each system is designed to specific requirements. The pipes - their diameter and wall thickness are designed to meet these requirements.

The pipes typically have a design life of 30 years exposed to the station environment, D_2O or H_2O flow rate, temperatures and pressure variation for the different modes of station operating conditions. In addition, the volume of the pipe network should be as small as possible to minimize the D_2O content. The volume restriction plus the temperature limits within which the systems operate results in quite high fluid velocities inside these pipes. In the primary heat transport system these velocities reach up to 17 m/s (55 ft/s).

The friction losses in these pipes are calculated in sections since the conditions of the fluid vary significantly from point to point in the same pipe. These losses have to be calculated for a series of operating conditions in order to ensure that the system is properly designed. These calculations also include the establishing of the inlet and outlet conditions for the process equipment. The contribution of the connecting process equipment to these end conditions are also factored in these calculations.

12.2 PUMPS

The heart of the Nuclear Station is the primary heat transport pump.

Failure of the Primary Heat Transport Pump to perform means shutting down the station. To shut down a nuclear station is costly since the electricity produced with fossil fuel is presently a factor of two more expensive.

The functional requirements of the primary pumps are:

(1) To move the Primary Heat Transport System heavy water from the Steam Generator through the Reactor Inlet Header, reactor, Reactor Outlet Header to the Steam Generator in the opposite side of the reactor.

(2) To have operating characteristics that will ensure stable operation for wide range of conditions in the Primary Heat Transport System.

(3) To operate without interruptions for prolonged periods of time according to the availability target and last for 30 years.

(4) The pumps are designed to withstand earthquakes of an intensity characteristic to the geographic location.

Except in Pickering, the nuclear stations have no reserve pumps. With a reserve pump the pipe network becomes complex and valves are required. Valves leak and this adds further complications plus man-rem expenditure. The post-Pickering Stations have no valves in the primary heat transport system.

Figure 2 illustrates the construction of a primary Heat Transport System Pump. The main parts of the pump are: the motor, coupling, glands, impeller and pump bowl. The motor when energized drives the pump. Some pumps have inertia wheels and in some the inertia mass is added to the motor. The inertia is needed to extend the rundown characteristics of the pump and prolong the circulation of the primary Heat Transport System D_2O when the power to the motor is lost. The motor and coupling are so designed that the replacement of a motor can be easily achieved. The glands are supplied with high pressure cold D_2O from the feed pumps. This water cools the glands. A small fraction of this water flows along the axis and enters the pump bowl thus providing a positive seal. The rest of the gland seal flow is returned to the D_2O storage tank.

The pumps are required to operate under normal and upset conditions. A typical pump curve is given in Figure 3. The pump provides quite a wide range of flow without large variation in the pump head. This provides a stable operation of the pump. The pump maintains sufficient flow rate for the expected range of the primary heat transport system operating conditions. The pumps have to operate at all levels of reactor power and during commissioning without fuel in the reactor. In some cases the reactor will have to be kept running at a lower power with less than four pumps available.

In order to maintain uninterrupted flow in the Primary Heat Transport System there is no automatic trip for the pump. The service life of the pump as mentioned above is 30 years with 30,000 hours minimum mission time for the pump seals. Outage for the pumpset is 12 hrs/yr. The target for seal replacement is 8 hrs during shutdown. The PHTS pump motor can be replaced on power. The replacement should last no more than 24 hrs.

12.4 STEAM GENERATOR

As the name implies this equipment generates steam to drive the turbine-generator set (Figure 4). The functional requirement of the steam generators are:

(1) To transfer heat from the primary heat transport system to the feed water.

(2) To serve as a receiver for secondary side reheater drains (this is relatively new feature).

(3) To generate steam at the required conditions for power production.

(4) To provide heat sink when needed.

In Figure 5 one can see the temperature distribution of the primary and secondary side in the steam generator. One important point to mention here is the distance between the two lines at the narrow point (termed the "pinch point"). The greater the distance the smaller the steam generator surface area to produce the amount of steam (as discussed in Chapter 1).

If one wants a smaller area for this steam generator obviously one should move these lines apart. By moving the primary line up this requires an increase in PHTS pressure. The increase in pressure will require heavier walls for all pipes including the pressure tubes. Thicker pressure tubes absorb more neutrons and the advantage of the CANDU System neutron economy will have to be sacrificed. The economic penalty on fuel burnup will be very high. The fuelling rate of the reactor will increase and more fuel will have to be used. On the other hand, dropping the secondary line down means reducing the steam pressure. The increase of the steam specific volume will require much larger turbine and may reduce the thermodynamic efficiency.

Optimizing all the parameters as mentioned above and some economic and construction considerations result in the selection of the Steam Generator.

Figure 4 presents a cross section of a steam generator. The primary side consists of two semispherical heads and a bundle of inverted U-tubes. The primary fluid enters the semisphere, flows upward to the U-tubes and exits at the second semisphere. The secondary side thermohydraulics is much more complicated. Feedwater enters the preheater, rises as more heat is transferred to it. At the steam drum the liquid separates from the steam and flows back down the downcomer while the steam exits at the top. The internal thermohydraulics of steam generator is not known very well.

The internal thermohydraulics of steam generator is very complex and can't be modelled very easy. Thus the design of steam generators has an element of "state-of-the-art" as well as the proprietary information of the suppliers.

The steam generator has to perform at different operating conditions normal and upset such as power maneuvering, reactor trip, turbine trip, Class IV power failure, loss of feedwater to one steam generator, loss of coolant accident, steam and feed lines failures.

The steam generator is constructed to withstand seismic event and the failures mentioned above.

The steam generator has a design life of 30 years. The heat transfer area plus the mechanical parts of the steam generator are designed to perform as required for these 30 years. The steam generator forced outage frequency shall not be higher than 0.03/yr per steam generator.

For proper maintenance and inspection each steam generator has a manway. The manway is large enough to allow access to all tube ends and for inspection of equipment or tools.

A leaking tube is plugged. The steam generator has spare surface area to function effectively with few tubes plugged.

Access is also provided to inspect the internals (secondary side) and inspect the top surface of the tubesheet.

12.5 PRESSURIZER AND BLEED CONDENSER/DEGASSER CONDENSER

The pressurizer and bleed condenser/degasser condenser are designed to maintain inventory and constant pressure in the primary heat transport system for range of operating modes (Figure 6). The functional requirements for the pressurizer are:

(a) To accommodate HTS swell from zero power hot to full power conditions.

(b) To provide a means of controlling heat transport system pressure over the range of zero power hot to full power.

(c) To control pressure increases in the PHTS by bleeding steam to the bleed condenser.

(d) To control pressure decreases by adding heat via the pressurizer heater pumps.

(e) To provide inventory to ensure rapid pressure recovery and minimize depressurization of the HTS following a sudden power reduction or trip. This ensures adequate NPSH for the PHTS.

(f) The pressurizer should withstand earthquake with an intensity characteristic to the geographic location.

The pressurizer is equipped with electrical immersion heaters for raising pressure when necessary. The heat can heat up with a rate of 3°C/min (5.4°F/min) maximum and 1°C/min (1.8°F/min) minimum depending on the water level. The controllers are set to keep the reactor outlet pressure within a control band during normal operating conditions.

The pressurizer vapor volume, connecting pipes and pressurizer steam bleed valves are sized to permit a power maneuver at the design rate without exceeding the setpoint of the PHTS pressure relief valves.

A proper chemistry of the water in the pressurizer is maintained to protect it from corrosion, D_2 generation and solids deposits. The pressurizer has a 30 year design life service with 0.03/yr forced outage frequency. The heaters can be replaced within 30 hrs.

12.6 VALVES

Valves are devices that control flow, isolates flow, prevents reverse flow, and relieves pressure to mention some major functions in which the valves are used.

As a general rule, the design of CANDU station attempts to minimize the number of valves. The incentive to minimize the number of valves is economic and in lowering the man-rem exposure from leaking valves.

Since valves are part of a process pipe network their design and selection is consistent with the requirements of the process.

These requirements include sizing the capacity of the valve, the degree of accuracy for control valves, rate of relief for relief valves, closure or opening rates for isolating valves, and reliability targets as well as operating pressure and temperature.

In Figure 7 an angle pattern globe valve is shown. This valve is used to control flow. The control is achieved by the pattern of the seat and the globe which provides variable flow area for different position of the valve. The glands prevents leaks along the stem. The glands are designed to withstand a specified pressure and temperature. Valves that are exposed to high pressure have two or more sets of glands with bleed-off points between them (Figure 8).

In Figure 9 the glands are replaced by bellows to prevent leaks. Other means to achieve the same effect is by using diaphragm as given in Figure 10.

Figure 11 shows a typical safety relief valve. The valve has a spring that keeps the valve shut. When the pressure in the system exceeds the setting of the spring the valve opens, release fluid thus lowering the pressure in the system.

In Figure 12 a wafer check valve is shown. This valve prevents reverse flow.

CHAPTER TWELVE - PART B

PROCESS EQUIPMENT

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SUMMARY

The design of the CANDU reactor primary heat transport system between the headers is considered. The inlet and outlet headers, feeders, end fittings, fuel channels and fuel bundles are briefly described. Design considerations for each component are given. Emphasis is given to the design criteria of constant header-to-header pressure drop, constant enthalpy rise, and constant single phase/two-phase pressure drop ratio to develop some basic concepts of the core thermohydraulic performance.

12.7 HEADERS

Figure 13 is a schematic of a typical CANDU heat transport system showing the two figure-of-eight circuits. Inlet and outlet headers are located adjacent to each other at each reactor face. Figure 14 shows this header arrangement. Operating temperature and pressure at the reactor inlet header for a CANDU 600 MW reactor are 266°C and 11.34 MPa, and at the outlet header 310°C and 9.99 MPa. The maximum single phase fluid velocity in the inlet header is 2.6 m/s, and the maximum two-phase velocity in the outlet header is 3.5 m/s. The steam quality in the outlet header is nominally 4%.

In the CANDU 600 reactor a total of 380 inlet and outlet feeders are connected to the four inlet headers and four outlet headers (i.e. 95 feeders/header). The nozzles on the header which connect to the feeders are cold drawn from the parent carbon steel header material (0.4 m in I.D., ASTM A106 Grade B).

12.8 FEEDERS

Figure 15 shows the geometric layout of a typical inlet/outlet combination for a high power channel. The feeder pipes are also constructed of A106 Grade B material, and five pipe diameters from 0.038 m to 0.085 m inside diameter are used in feeder sizing. The design temperature and pressure for the feeders are 316°C and 12.9 MPa(g).

Maximum single phase velocities in the inlet feeders are 15.2 m/s, and maximum two-phase velocities in the outlet feeders are 16.8 m/s. Twelve inlet feeders (six per loop) have orifice flow meters installed for feeder flow (channel flow) measurements used for safety related low flow trips. Other inlet feeders may have flow restriction orifices installed to trim channel flows and to adjust the single-phase pressure drop.

12.9 END FITTINGS AND FUEL CHANNELS

The two circuits of the heat transport system are arranged on each side of the vertical centre line of the reactor core with 190 fuel channels in each circuit. The flow through the core is bidirectional (i.e. opposite directions in adjacent channels). The fuel channel assembly is shown in Figure 16. The end fittings are ANSI type 403 stainless steel, with type 410 stainless steel liners, to provide shielding extensions to the pressure tubes, connections to the feeders, and access for re-fuelling. The pressure tubes are zirconium-niobium alloy (6.3 m long x 105 mm nominal bore x 4.16 mm minimum wall thickness) to house fuel and pressurized D_2O.

Thermohydraulic parameters for a design basis channel are listed in Table 1. Figure 17 shows a fuel channel section. It should be noted that the pressure tube is the PHTS boundary containing within it the fuel and D_2O coolant. An annulus gas separates the pressure tube from the calandria tube and D_2O moderator. The annulus gas acts as a thermal insulator between the PHTS and moderator and is useful in sampling for any D_2O leakage.

12.10 FUEL

Figure 18 is a sketch of a 37-element fuel bundle, showing seven component parts. The fuel elements (rods, pins) contain high-density natural UO_2 pellets in a thin zircaloy-4 cylindrical sheath. A thin graphite layer (CANLUB) on the inside surface of the sheath reduces the pellet/sheath interaction. End caps are resistance welded to the fuel sheath, and the elements are held in a close-packed bundle by welded end plates. Inter element spacers are brazed to the elements to control fuel element vibration and fretting. Bearing pads support the fuel bundle within the pressure tube.

The fuel bundle is designed for maximum content of fissile material and minimum content of neutron absorbing material (i.e. high neutron economy). The fuel is designed to operate as shown in Figure 19 within the power and burnup conditions for normal station operation (curve A) and is also assessed for operation within the reference overpower envelope (curve B in Figure 19).

TABLE 1

NOMINAL CONDITIONS FOR THE DESIGN BASES CHANNEL

Power	6.5	MW
Flow	25.4	kg/s
Mass Flux	7439.0	$kg/s\text{-}m^2$
Inlet Temperature	266.5	°C
Reactor Outlet Header Pressure*	9.99	MPa (absolute)
Header-to-header Pressure Differential	1.31	MPa (differential)
Quality of the Feeder Exit at the Outlet Header	2.6	percent
Thermal Power (Total heat transferred by Steam Generators)	2064	MW(th)
Steam Flow Rate	1033	kg/s
Core Total Flow Rate	7.7	Mg/s
Core Inlet Subcooling of Coolant	53	°C
Core Exit Temperature of Coolant	310.9	°C

* The outlet pressure is held constant in the design because the reactor outlet conditions are controlled by a pressurizer linked to the reactor outlet headers.

12.11 CORE THERMOHYDRAULIC DESIGN CONCEPTS

12.11.1 General Design Basis

Nominal maximum channel flows are targeted at 23.9 kg/s due to fuel bundle vibration and fretting concerns. However, AECL has tested fuel at higher channel flows with no problems.

At, or near full power the coolant boils as it passes through the reactor core (600's, Bruce, Darlington). Boiling allows an increase in steam pressure with increased plant efficiency, without a corresponding increase in primary system pressure, temperature, or steam generator area.

For a fixed channel power, the channel exit quality is set by the coolant inlet temperature, coolant flow and outlet header pressure. These parameters affect the pumping power, pressure tube thickness (burnup) and critical power ratio (CPR).

12.11.2 Power Generation Design Basis

The heat transport system design matches the flow in each fuel channel to the power in that channel to produce the same outlet feeder exit conditions. That is for a given header-to-header pressure drop, and given inlet temperature and pressure, we design for a constant enthalpy rise across the core. Hence the maximum power channel is also the maximum flow channel. Since the fuel and end fitting portions of each channel are identical and since the header-to-header pressure drop across each channel is the same, this necessitates that the low flow (low power) channels have much larger inlet feeder resistances than the maximum power channel. Thus from a single channel flow instability point of view, the maximum power channel is the limiting channel.

Lower inlet resistance yields a steeper channel flow/power characteristic as shown in Figure 20 which also implies a lower value of critical power ratio defined as

$$CPR = \frac{\text{Channel Power at Which Dryout Occurs}}{\text{Nominal Channel Power.}}$$

Thus for both dryout and channel flow instability considerations, the maximum power channel becomes the limiting or critical channel.

Because of the large number of parallel channels between the inlet and outlet headers, variations in flow resistance in one or more channels do not significantly change the header-to-header pressure drop. Thus, simulating the limiting channel with a constant header-to-header pressure drop as a boundary condition, is a valid simulation of a multi-parallel channel situation.

12.11.3 Feeder Sizing Criteria

The design criterion of a constant enthalpy rise across each channel at 100% FP (Full Power) has already been mentioned.

A second criterion is that feeders should be sized such that the single phase/two-phase pressure drop ratio ($\Delta P_{1\phi}/\Delta P_{2\phi}$) is constant for all channels at 100% FP.

If both the above criteria are met, ideally the onset of boiling will occur at the same axial location in each fuel channel at 100% FP. This may be demonstrated as follows.

The integrated power input H to the primary coolant as it traverses a fuel channel an axial distance Z measured from the F/C inlet is

$$H(Z) = \frac{Q}{2}\left(1 - \cos\frac{\pi Z}{L}\right) \qquad (1)$$

where Q = channel power
L = fuel channel length

The corresponding coolant enthalpy rise is

$$H(Z) = W\,(h(Z) - h(i)) \qquad (2)$$

where W = channel mass flowrate
h(Z) = coolant enthalpy at position Z
h(i) = coolant enthalpy at inlet to fuel channel

Hence
$$h(Z) = h(i) + \frac{Q}{2W}\left(1 - \cos\frac{\pi Z}{L}\right) \qquad (3)$$

Since feeder sizing is performed to ensure the enthalpy rise is constant for every channel at 100% FP, then the ratio Q/W is constant, or the flow/power characteristic curves for each channel are parallel to each other. Hence the maximum power channel conditions can be applied in eqn. (3) so that the enthalpy distribution in every channel is identical. Noting that the inlet enthalpy is the same for every channel (i.e. $h(i) = h_i$)

$$h(Z) = h_i + \frac{Q_{max}}{2W_{max}}\left(1 - \cos\frac{\pi Z}{L}\right) \qquad (4)$$

The second criterion is that $\Delta P_{1\phi}/\Delta P_{2\phi}$ be constant. Every channel experiences the same header-to-header pressure drop ΔP_{H-H}, such that for each channel

$$\Delta P_{H-H} = \Delta P_{1\phi} + \Delta P_{2\phi} \qquad (5)$$

The single phase region ($\Delta P_{1\phi}$) exists from the inlet header (subcooled conditions) to some point in the fuel channel where boiling begins. For simplification we will ignore subcooled boiling and consider only bulk boiling to occur where saturated conditions are reached in the fuel channel. Eqn. (5) may be re-written as

$$\frac{\Delta P_{H-H}}{\Delta P_{2\phi}} = \frac{\Delta P_{1\phi}}{\Delta P_{2\phi}} + 1 = \text{Constant} + 1 \qquad (6)$$

Since ΔP_{H-H} is constant for all channels, therefore $\Delta P_{2\phi}$ is also constant for all channels

Since $\Delta P_{2\phi} = P(Z) - P_o$

where $P(Z)$ = channel pressure at location of OOB (Onset Of Boiling)
$= P_{sat}$
P_o = outlet header pressure held constant by pressurizer

As shown in Figure 21 it becomes obvious that for the same enthalpy distribution in each channel, and for the same single phase/two-phase pressure drop ratio, saturated boiling must occur in each channel at the same axial location (CURVE A).

What is not so obvious, is that the full power reactor conditions are selected such that saturated conditions can only be attained within the fuel channel. That is, boiling cannot start in the inlet feeder or outlet feeder (CURVE B or C).

Another important point, is that the use of a constant single phase/two-phase pressure drop ratio for every channel minimizes any flow redistribution among channels as reactor power is varied. That is, the flow in any channel will be maintained at the same percent of total core flow regardless of reactor power.

12.11.4 Departure From Simple Theory

It has been shown that it is possible in theory to represent the entire core thermohydraulics by one channel. However, because of the other design criteria and design processes such as limiting feeder velocities, available feeder and restriction orifice sizes, and differences in the channel power maps, the ideals of constant $\Delta P_{1\phi}/\Delta P_{2\phi}$ and constant enthalpy rise cannot be satisfied across the entire core. Therefore, regionalization of the core must be done to perform an accurate analysis. That is, more than one channel must be used to model the entire core. 25 channels have been found to accurately model half the core (or one circuit of 190 channels for a 600MW reactor).

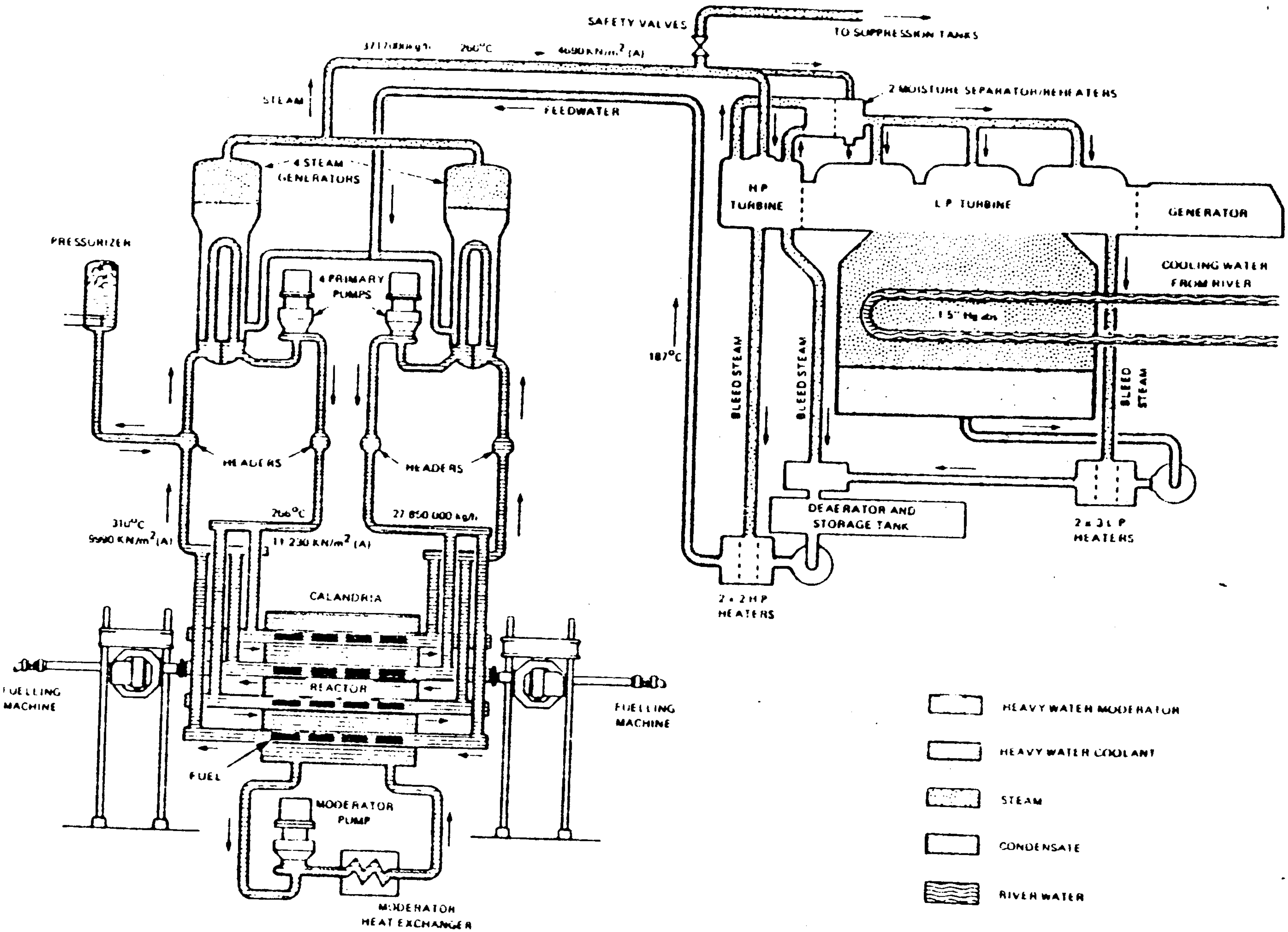


FIGURE 1 - CANDU NUCLEAR POWER SYSTEM

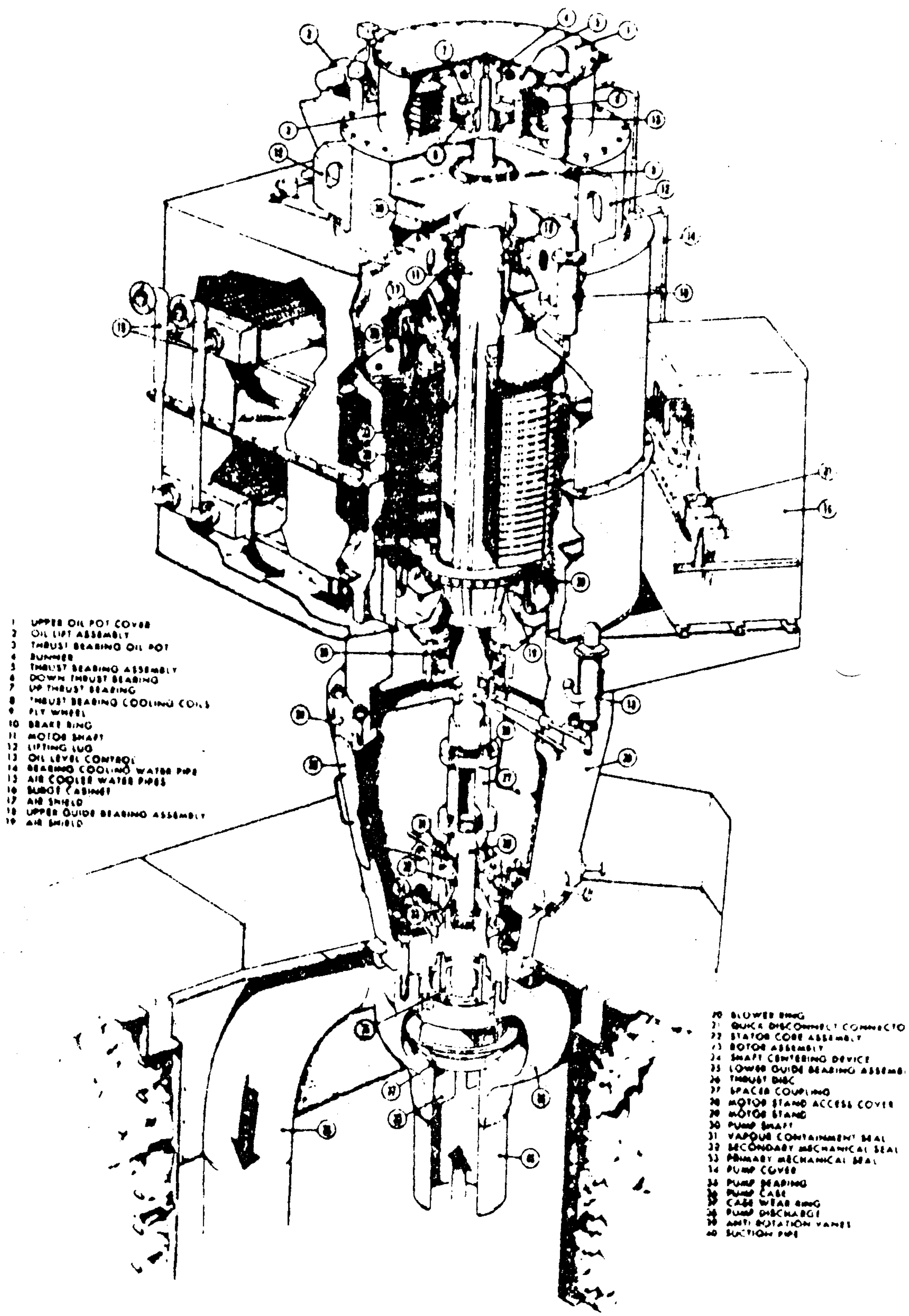


FIGURE 2 - HEAT TRANSPORT PUMP

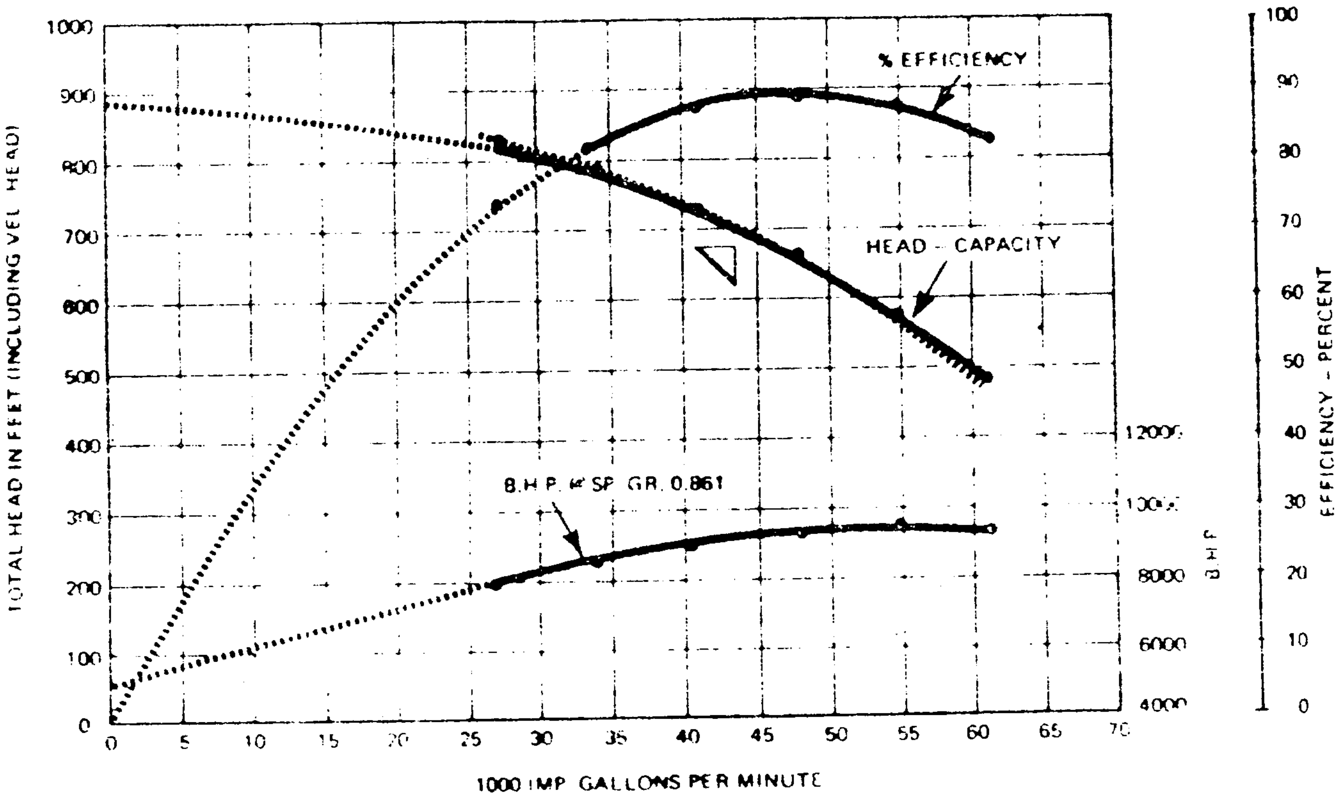


FIGURE 3 - PRIMARY PUMP CHARACTERISTIC CURVE

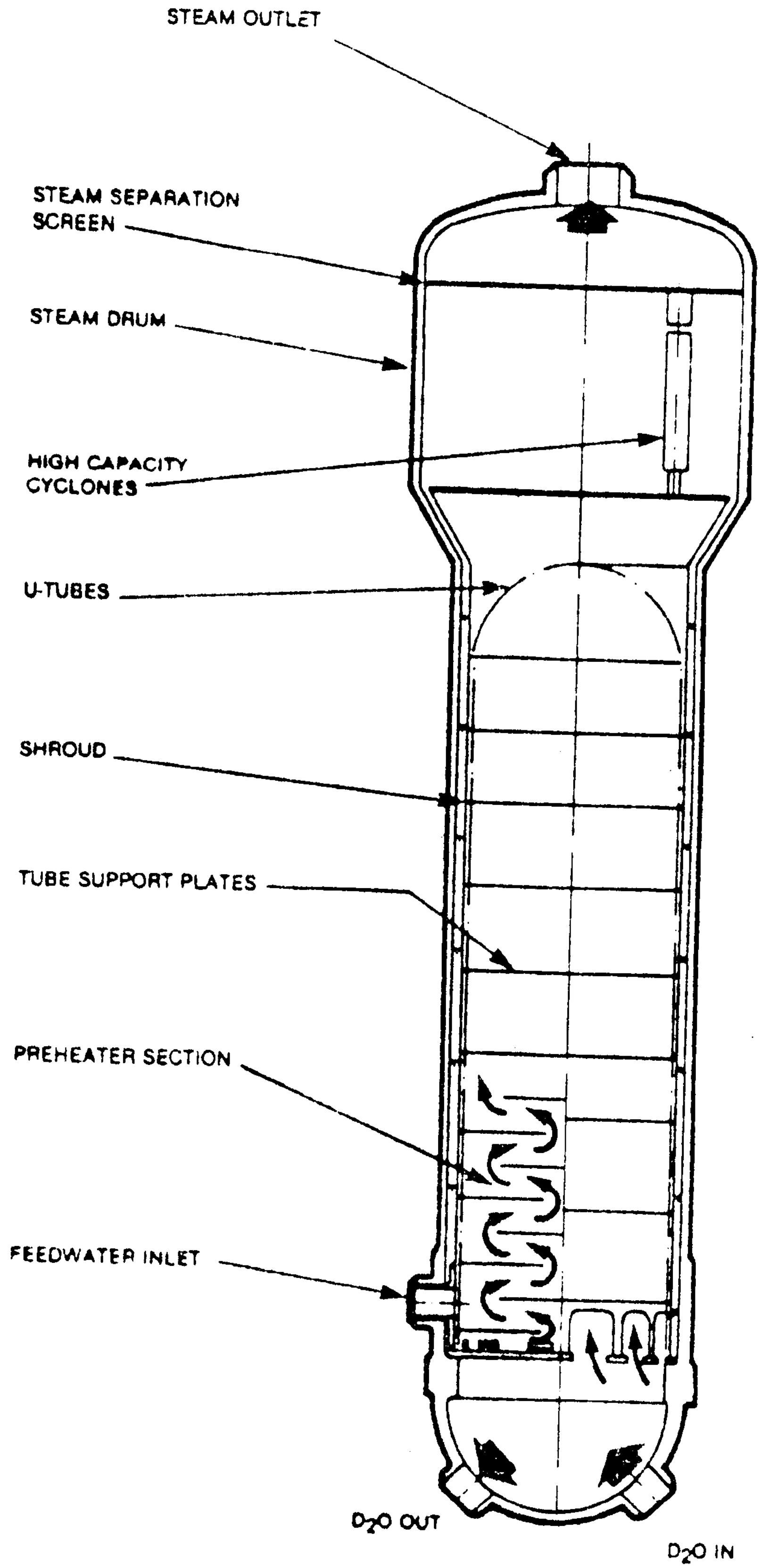


FIGURE 4 - TYPICAL STEAM GENERATOR

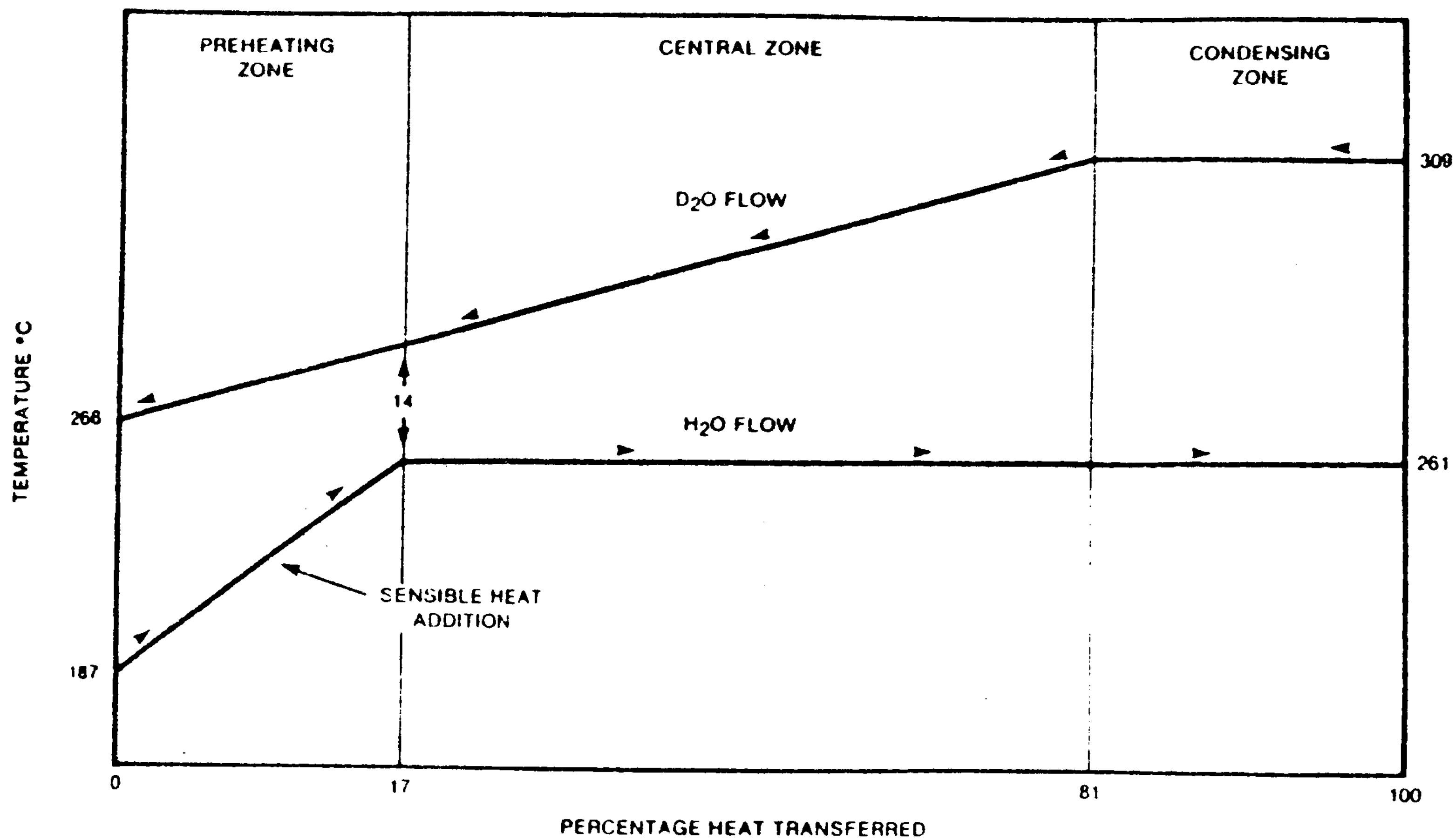


Figure 5 - Temperature vs. Percent Heat Transferred

ANGLE PATTERN GLOBE VALVE

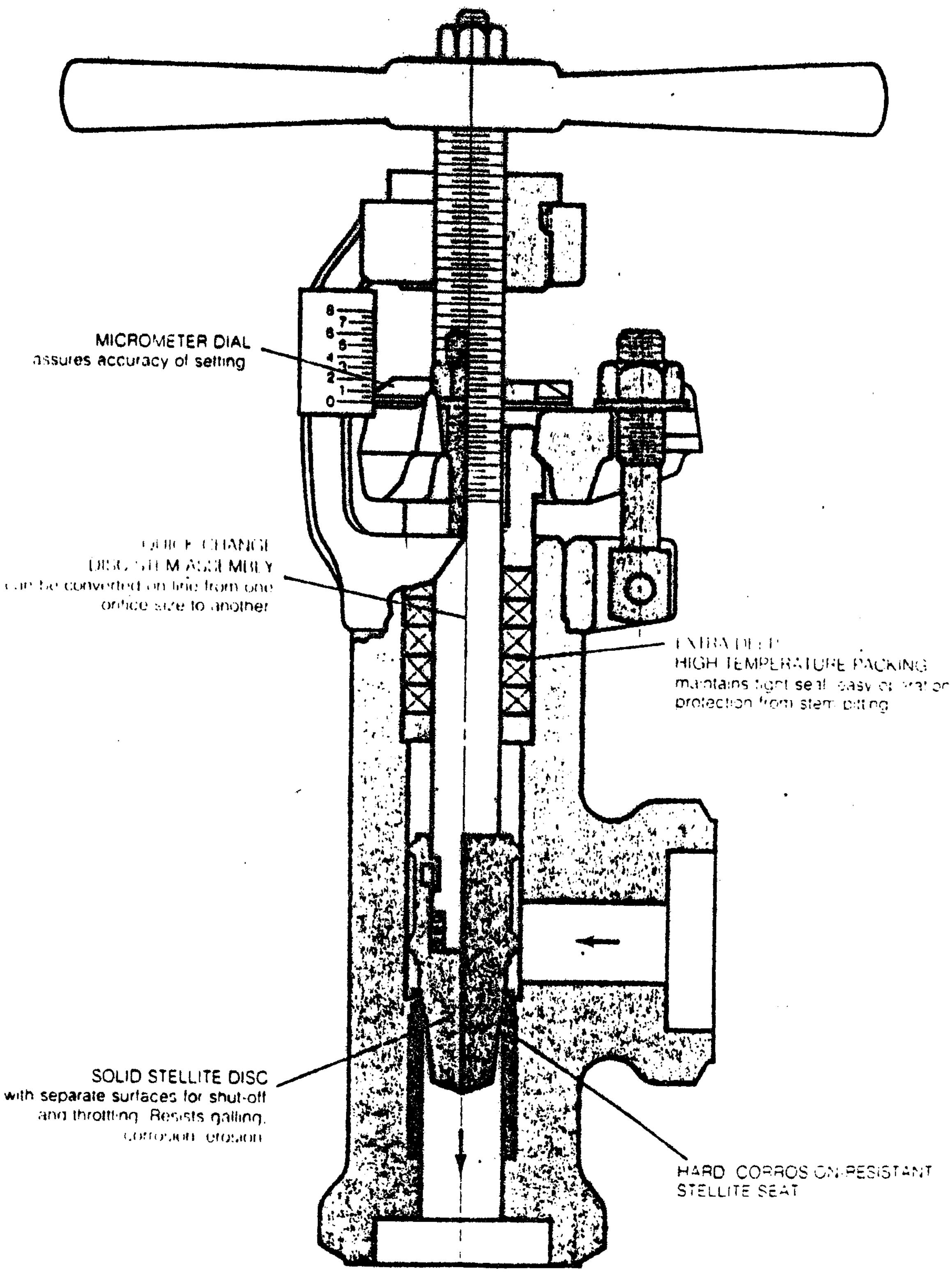


FIGURE 7 - Angle Pattern Globe Valve

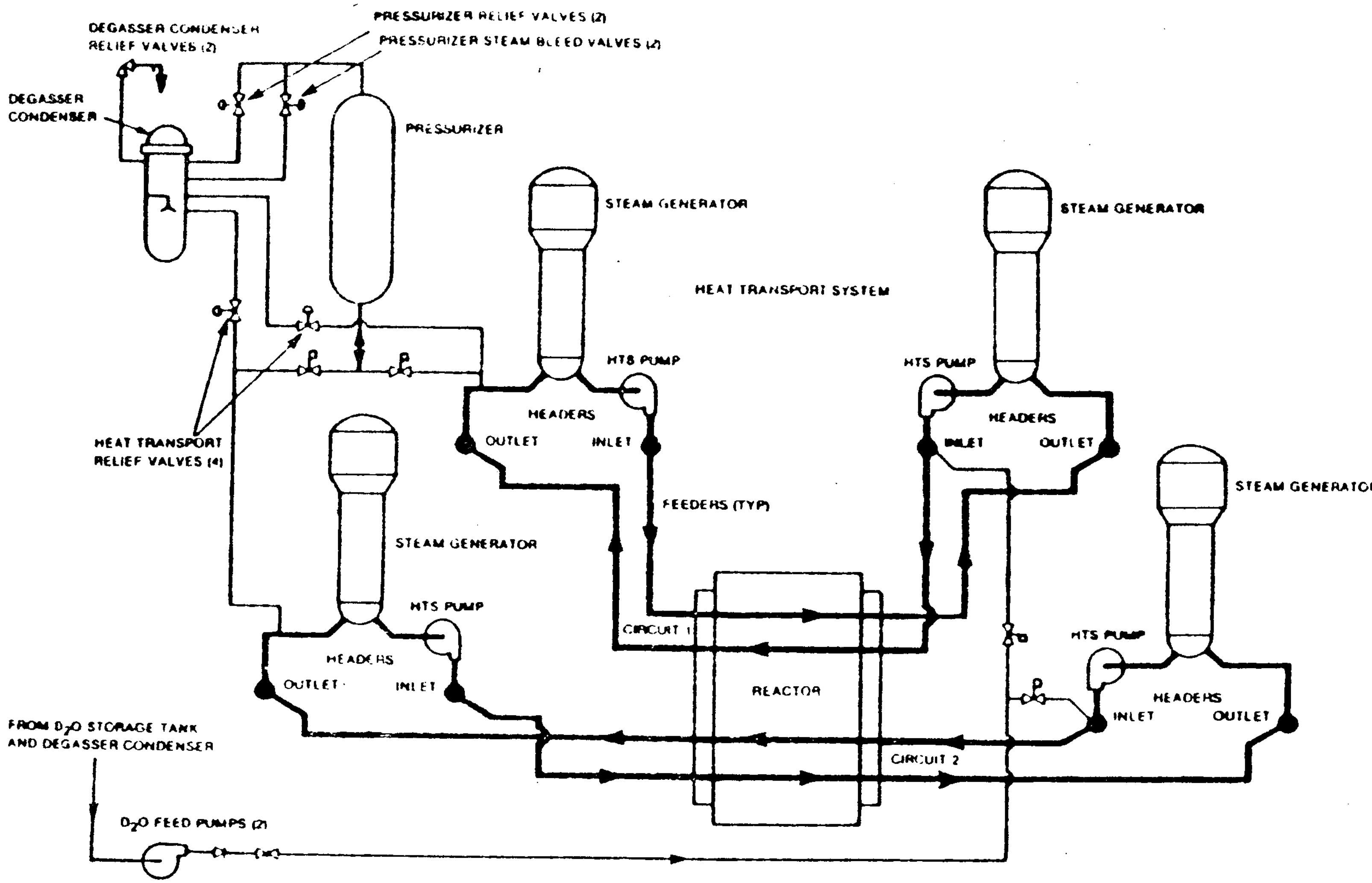


FIGURE 6 - HEAT TRANSPORT PRESSURE AND INVENTORY CONTROL SYSTEM

The parallel slide gate design was introduced by Hopkinsons in the 1880 s, since when, it has been continuously developed for use at the highest pressures and temperatures.

Many of the world's leading power utilities specify the design for the most demanding applications where the requirements are safety, reliability and ease of operation.

Main advantages

- Fluid pressure effects the seal–not from mechanical wedging action.
- Lower operating effort achieves fluid tightness.
- Complete flow isolation in either direction.
- Minimum pressure drop.
- Freedom from leakage independent of temperature changes.
- Freedom from leakage independent of pressure changes.
- Self aligning fully supported discs.
- Travel limits external to pressure envelope.
- Inherent self cleaning action.
- Seats fully protected in open position (on Venturi type).

Re-lapping of seating surfaces can be achieved without removing valve from pipeline.

Special features

- Provision for seal welding body/cover joint.
- Live loaded gland.
- Double stuffing box with lantern ring and leak-off connection.
- Provision for gland packing blow-out.
- Back seat.

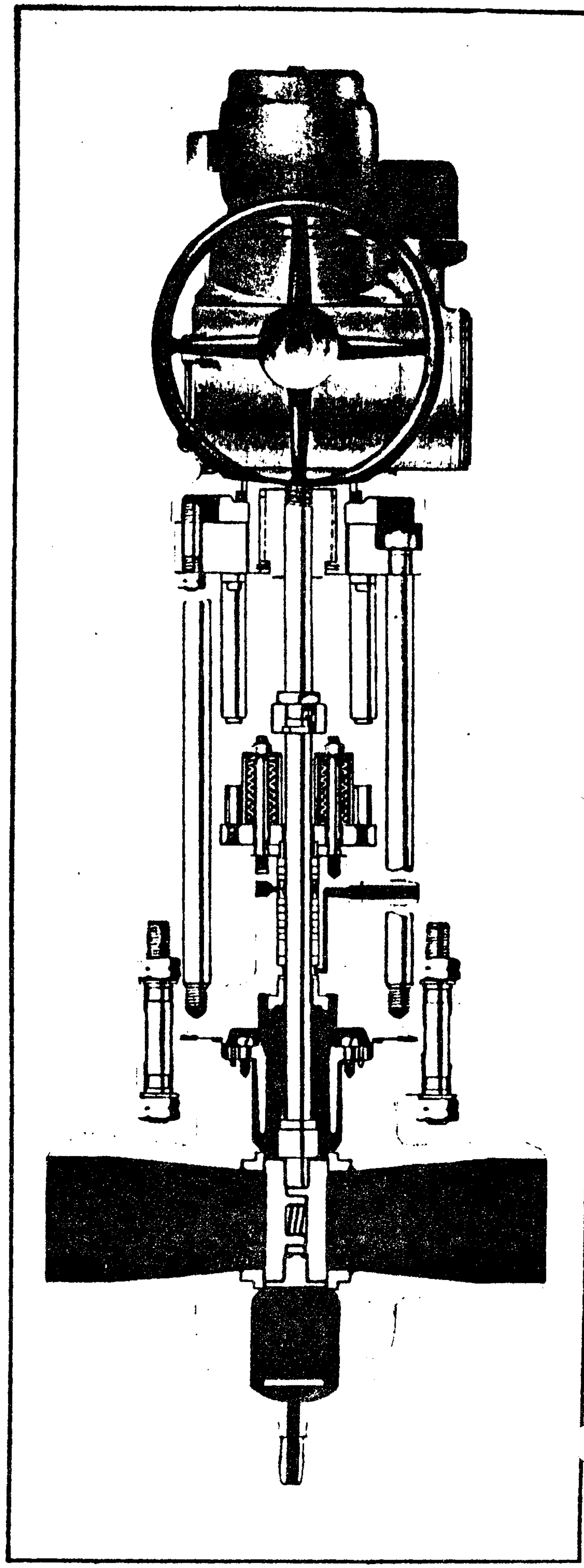


FIGURE 8 - Motorized Gate Valve

BELLOWS SEALED VALVES

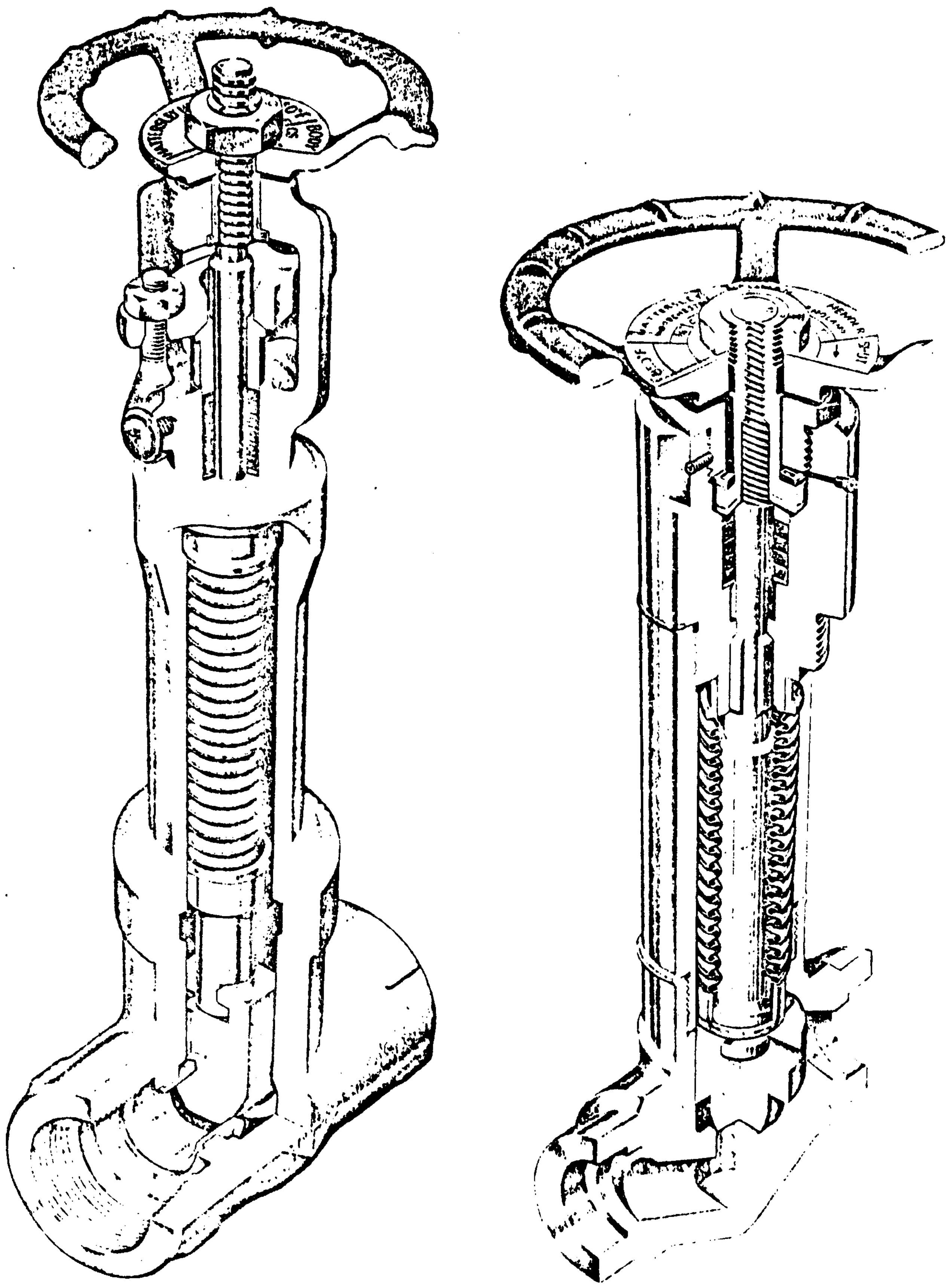


FIGURE 9 - Bellows Sealed Valves

achievement.

METAL DIAPHRAGM VALVE

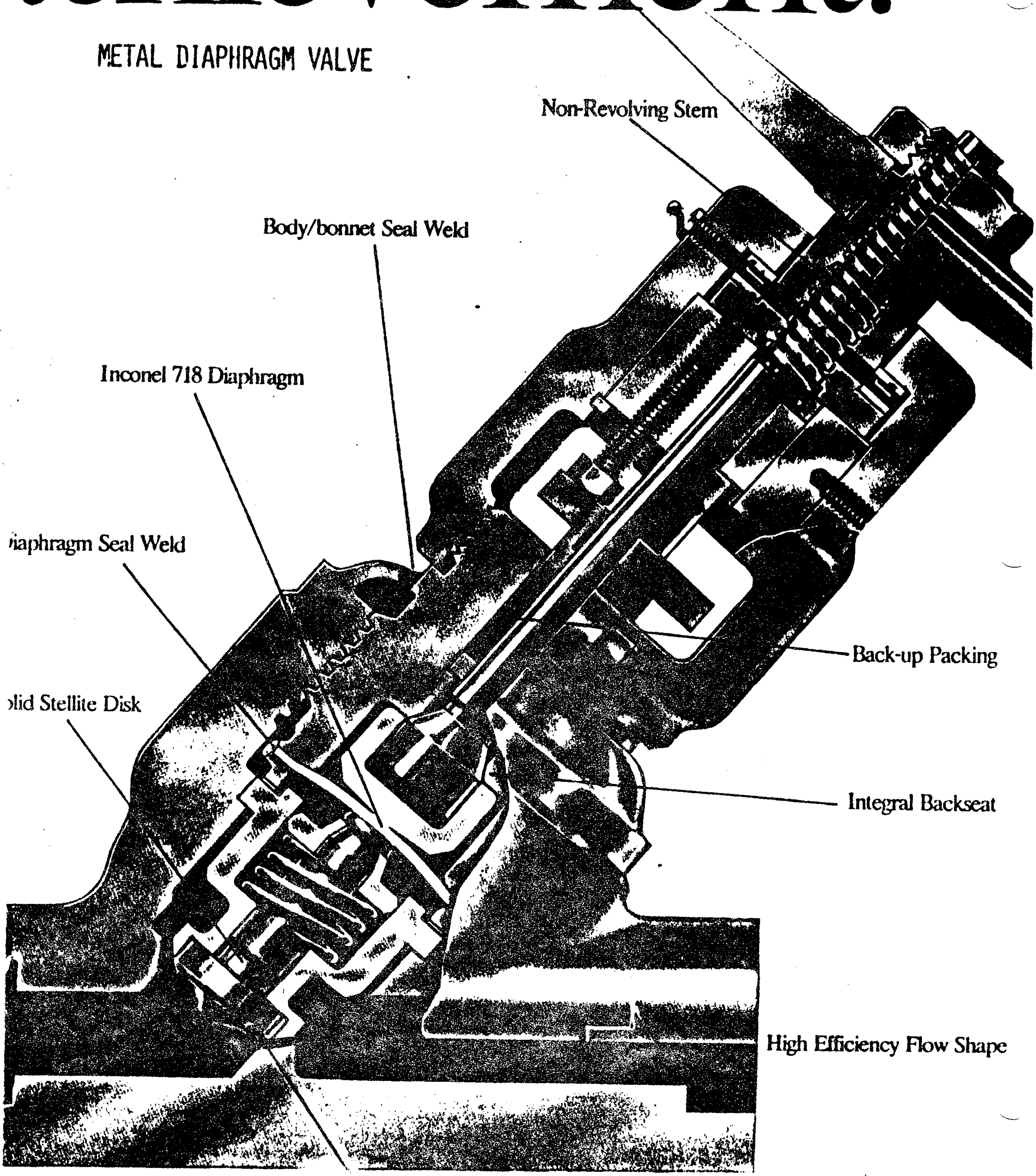
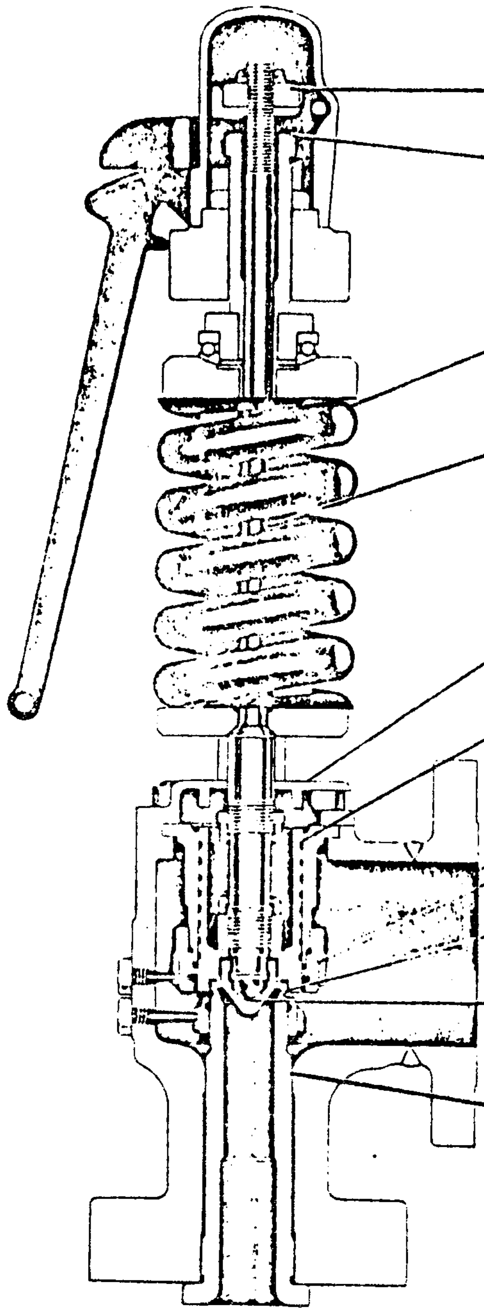


FIGURE 10 - Metal Diaphragm Valve

SAFETY VALVE - OPEN BONNET



SPRING COMPRESSION — retained during disassembly by running release nut down to top of compression screw.

LIFTING GEAR — adjustable, compound type.

PRECISION WOUND SPRING — specially designed to eliminate eccentric loading and to provide full relieving capacity at minimum accumulation.

SPINDLE OF STAINLESS STEEL — with Hard Faced spherical bearing having large contact area for low unit loading. Heavy cross-sectional area for strength and rigidity.

SAFETY DEFLECTOR PLATE — deflects discharged steam toward valve outlet.

GROOVED DISC HOLDER — prevents disc rotation. Permits motion with minimum friction.

HIGH CAPACITY DISCHARGE — body and outlet areas.

BLOWDOWN CONTROL — ease in adjustment and minimum blowdown. Completely adjustable with valve under pressure.

THERMODISC® SEAT* — eliminates distortion due to thermal stresses. Temperature differential quickly equalized and permanent tightness assured.

LOW SPINDLE BEARING POINT — spring load transmitted directly to valve disc at seat level for proper load distribution at the seating surface. Prevents disc from sliding across seat on opening and closing.

HIGH NOZZLE GUIDING — locating the guiding of the nozzle in the base at this point permits better alignment between the seat and disc, assuring a greater degree of tightness.

High capacity, flat seated reaction type safety valves, CONSOLIDATED MAXIFLOW safety valve series 3700, is designed specifically to meet the stringent requirements of the A.S.M.E. Nuclear Code, Section III. This valve is used on boiling water reactors, as well as on secondary systems of pressurized water reactors.

Tested Seat Tightness

Safety valve is popped on steam. A standard test is conducted on steam, with condensate leakage maximum of 2 cc/hr. after valve has "popped" and the pressure reduced to 94% of set pressure.

FIGURE 11 - Safety Valve

Side Rod Construction

Located outside the body, side rods provide an "even" thermal compensation; expansion or contraction of the valve body has no effect on spring compression or valve setting.

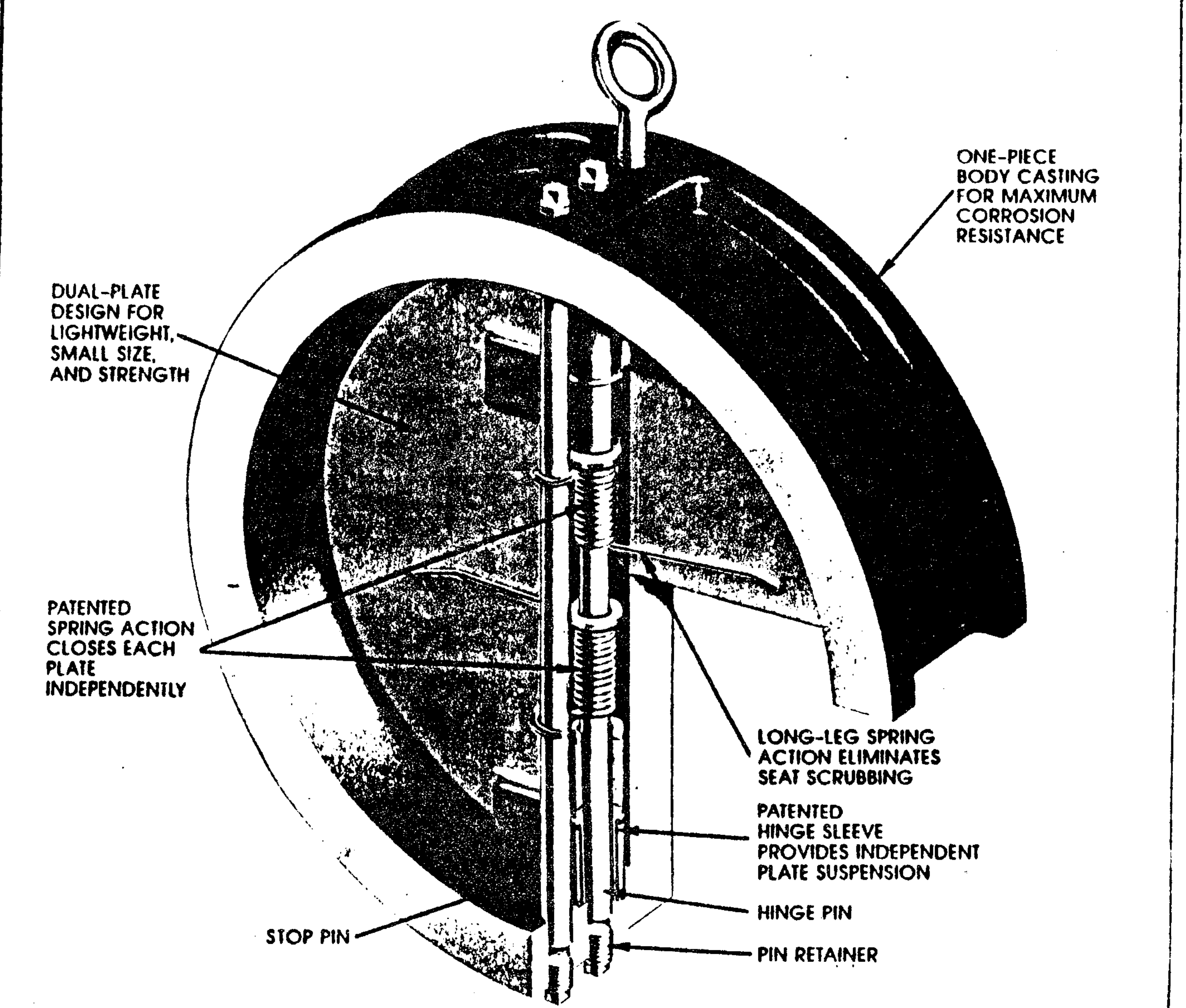
Thermodisc® Seat*

The disc seat in the CONSOLIDATED safety valve is the Thermodisc design. The experimental work conducted by a research institute some years ago for CONSOLIDATED valves, demonstrated conclusively that extreme tightness on steam service required some means of compensating for temperature variations around the periphery of the seat bushing. This was accomplished by the Thermodisc* seat construction, a patented feature of CONSOLIDATED valves.

*U.S. PATENT No. 2,643,671

DESIGN FEATURES

Mission DUO-CHEK II The High Performance Check Valve



Duo-Chek II check valves are available to meet your process conditions.

- A complete range of sizes from 2 through 72 inches.
- A wide variety of cast or forged materials for bodies, plates and trim for all types of service and temperature conditions.
- Full line of Duo-Chek II valves, designed and rated in accordance with any ANSI 125# thru 2500# and API 2000# through 10,000# standards.
- For hydrostatic pressures from vacuum through 15,000 psi.
- For operational temperatures from -450°F through 1000°F.
- The Duo-Chek II meets API 594 wafer check valve standard (except face to face on ANSI 125 cast iron 2-1/2-inch through 12-inch dimensions).

FIGURE 12 - Spring Action Check Valve

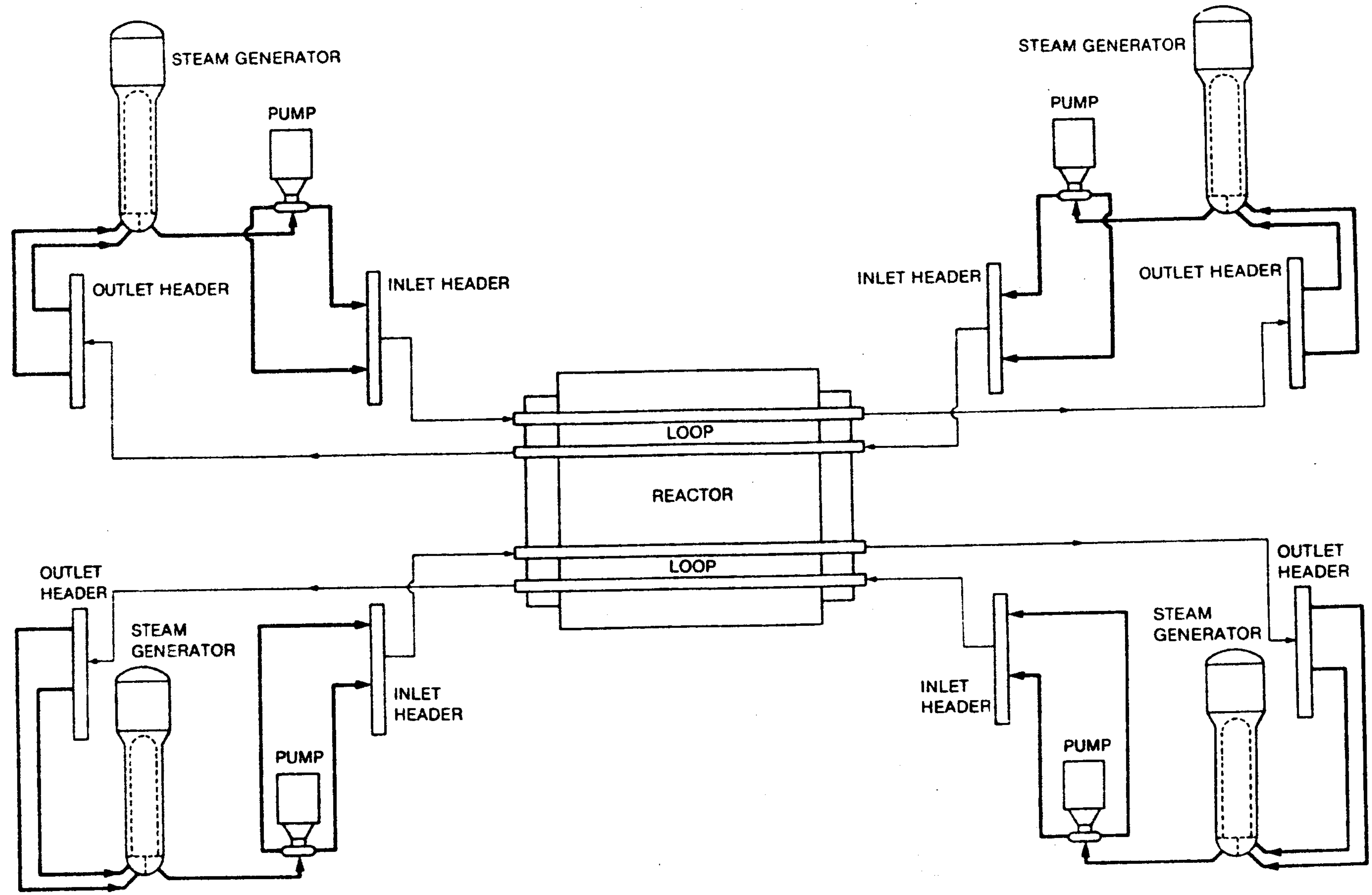


FIGURE 13 A HEAT TRANSPORT SYSTEM

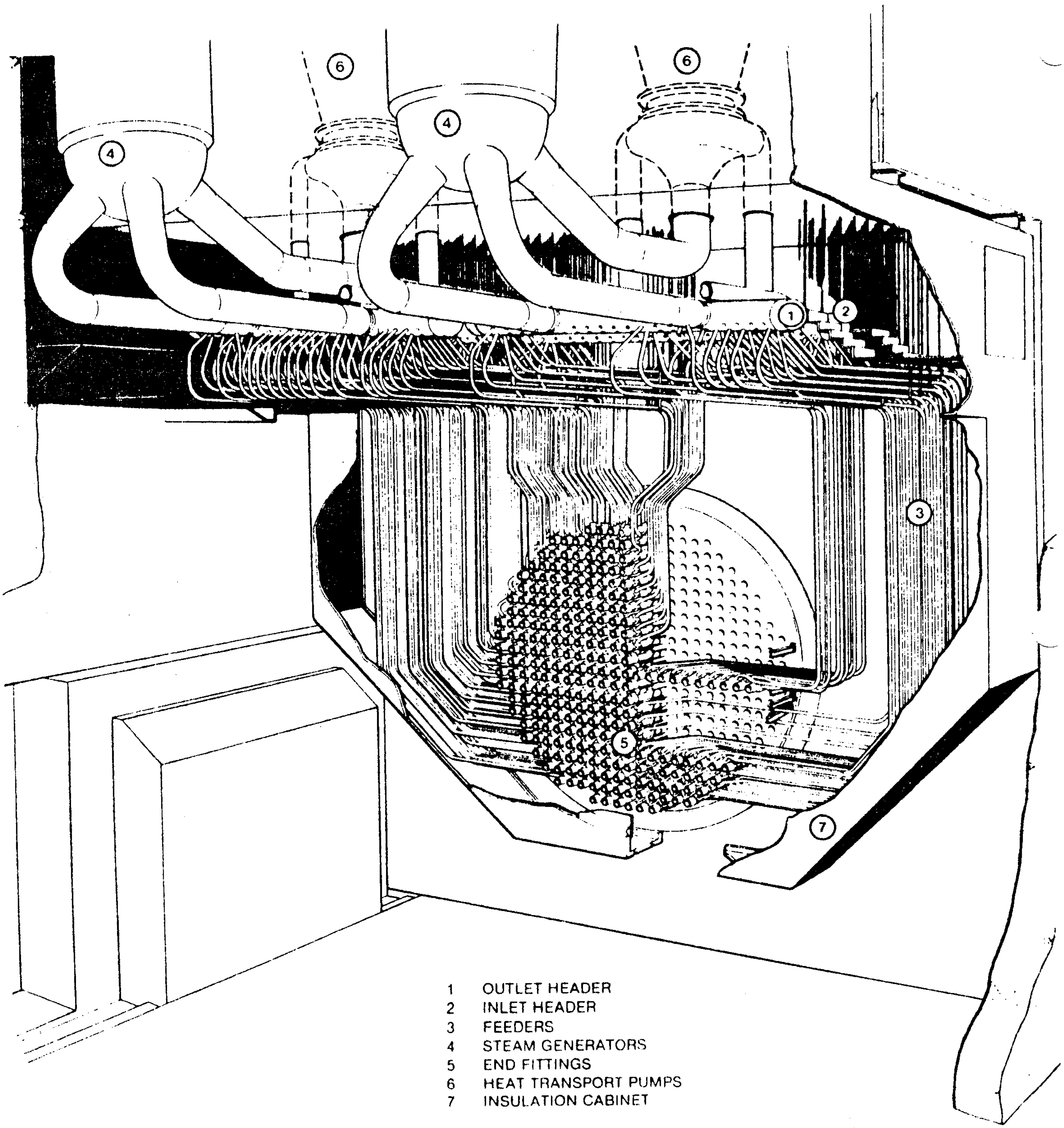


FIGURE 14 FEEDER AND HEADER ARRANGEMENT

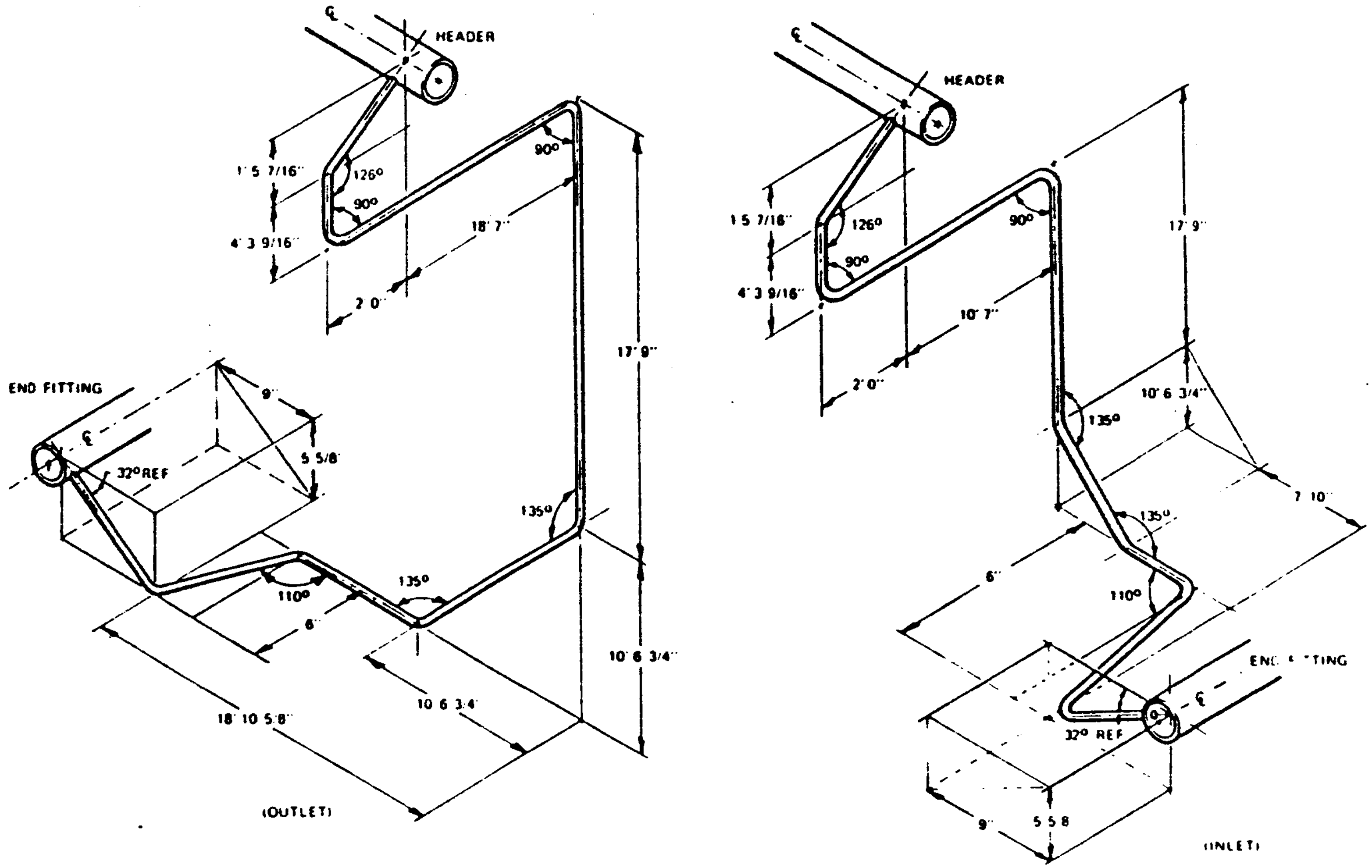


FIGURE 15 HEAT TRANSPORT SYSTEM — TYPICAL FEEDER CONFIGURATION.

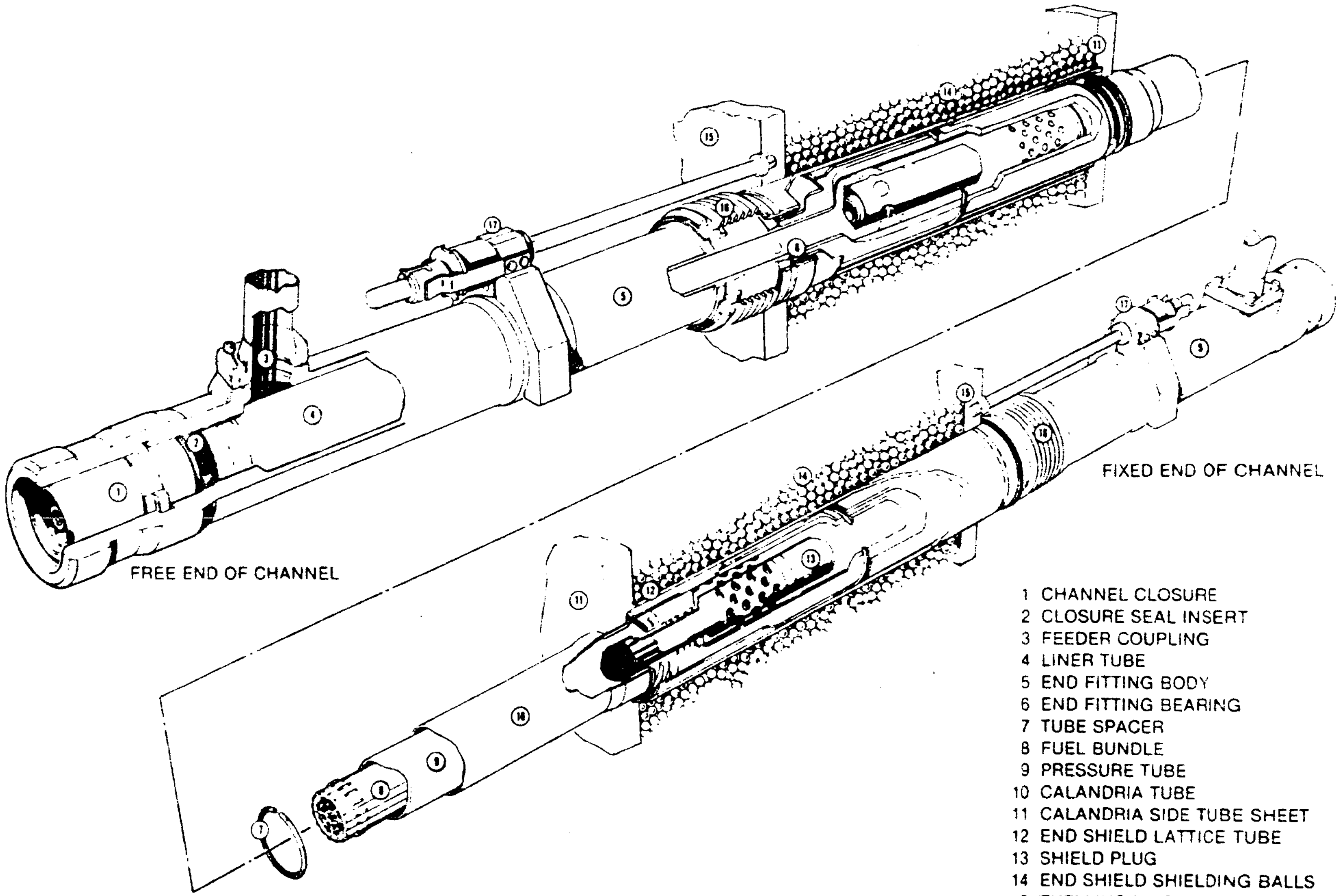


FIGURE 16 FUEL CHANNEL ASSEMBLY

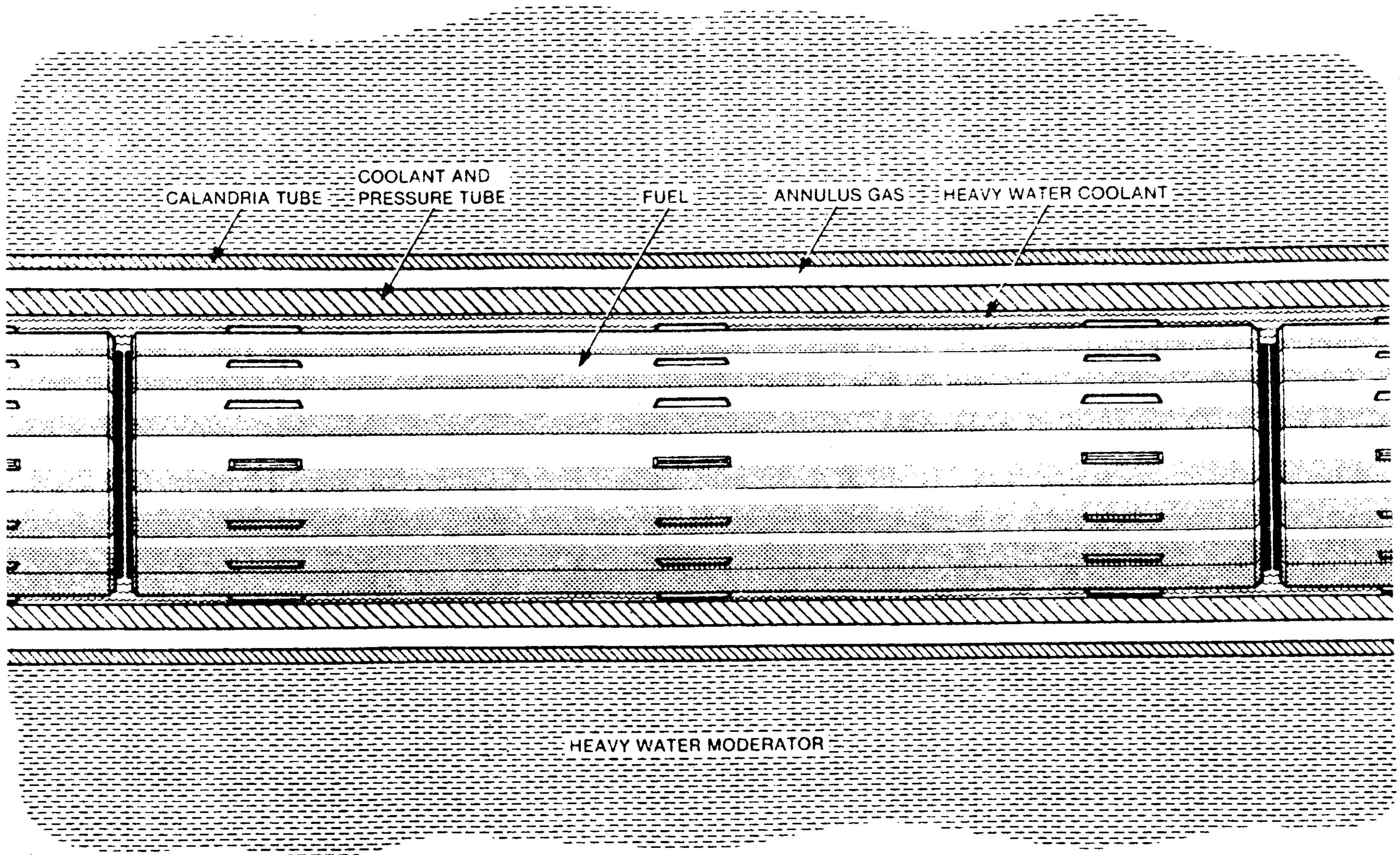


FIGURE 17 FUEL CHANNEL ARRANGEMENT

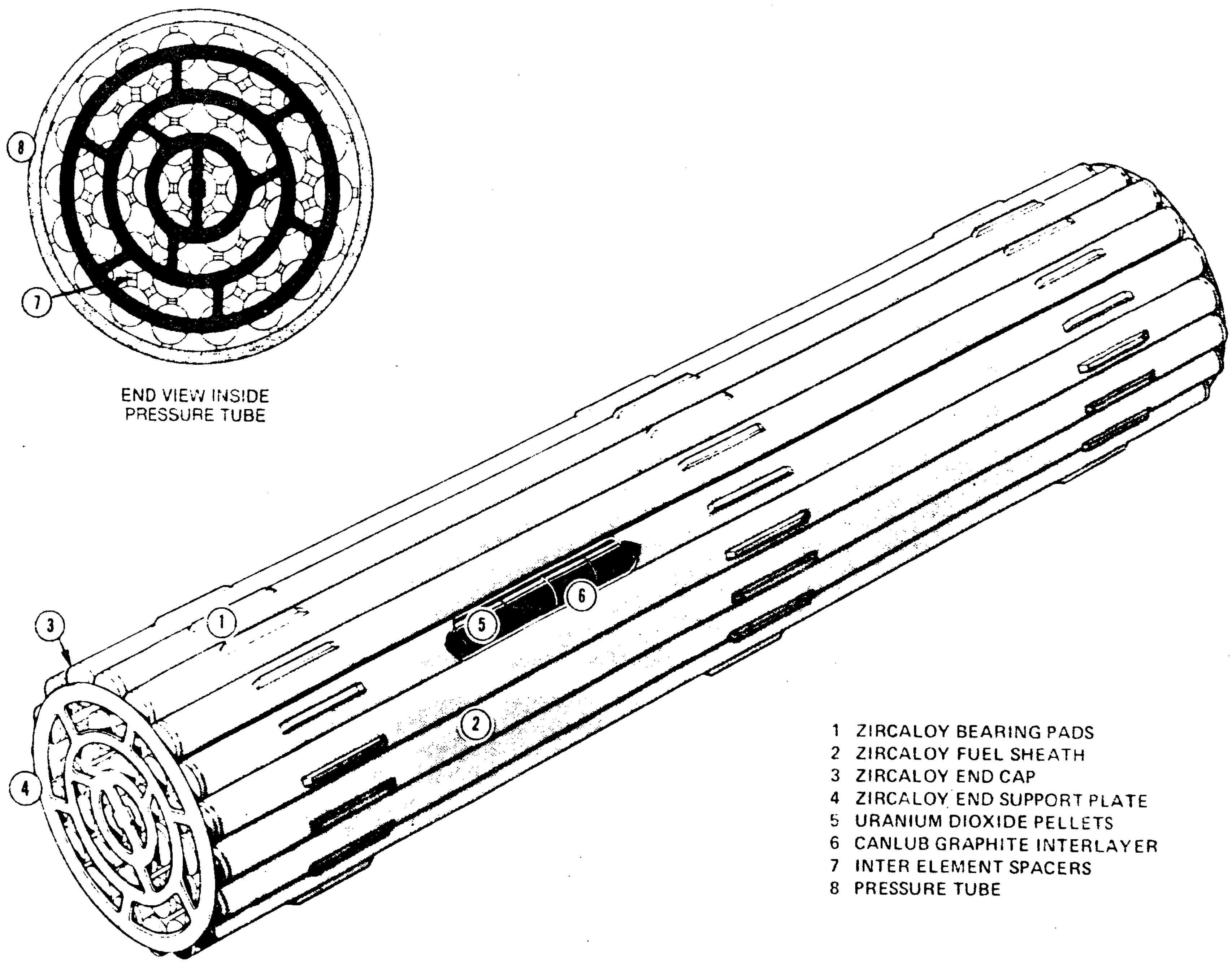


FIGURE 18 37-ELEMENT FUEL BUNDLE

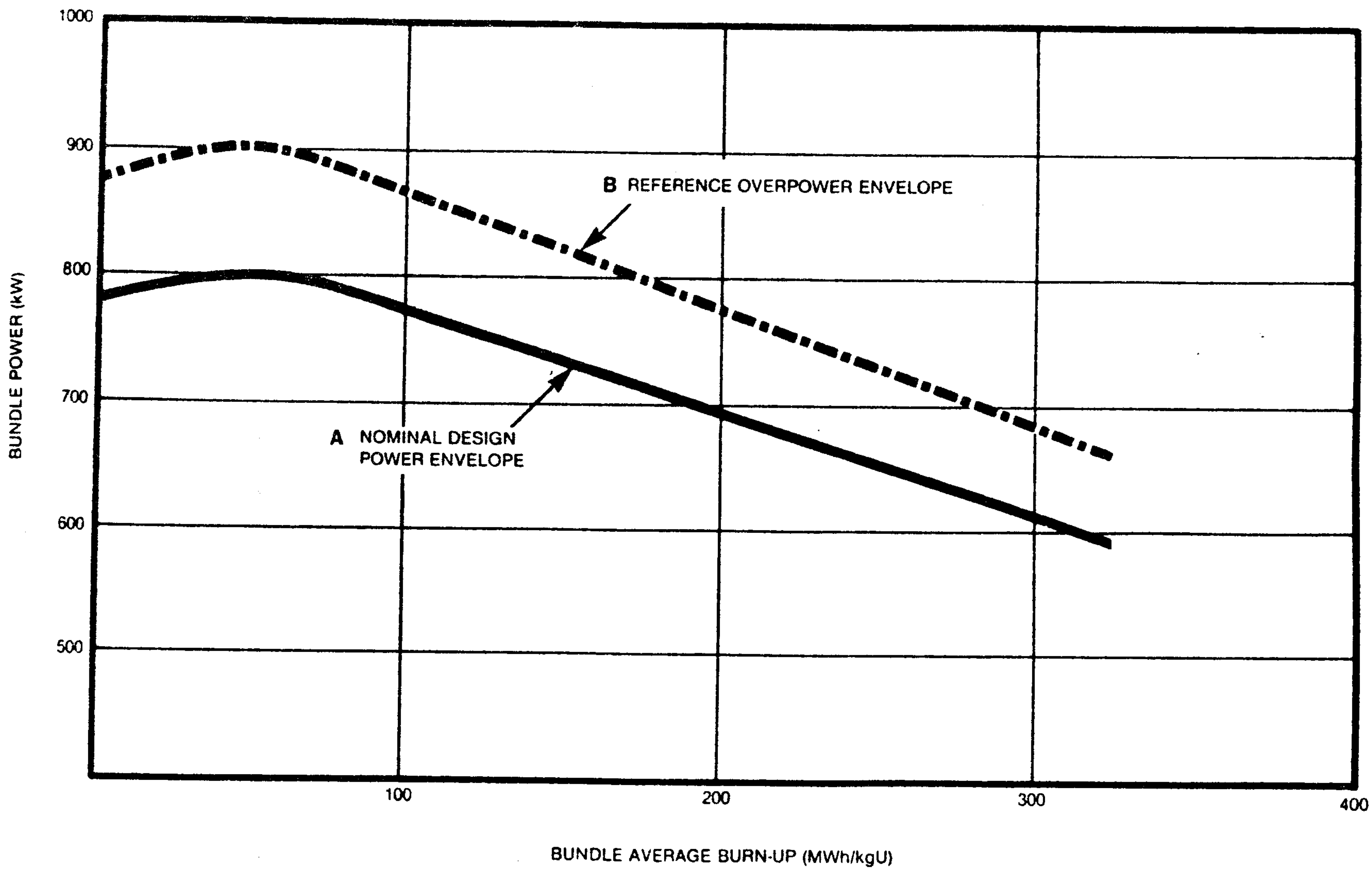

1000
900
800
700
600
500
BUNDLE POWER (kW)
100
200
300
400
BUNDLE AVERAGE BURN-UP (MWh/kgU)
B REFERENCE OVERPOWER ENVELOPE
A NOMINAL DESIGN
POWER ENVELOPE

FIGURE 19

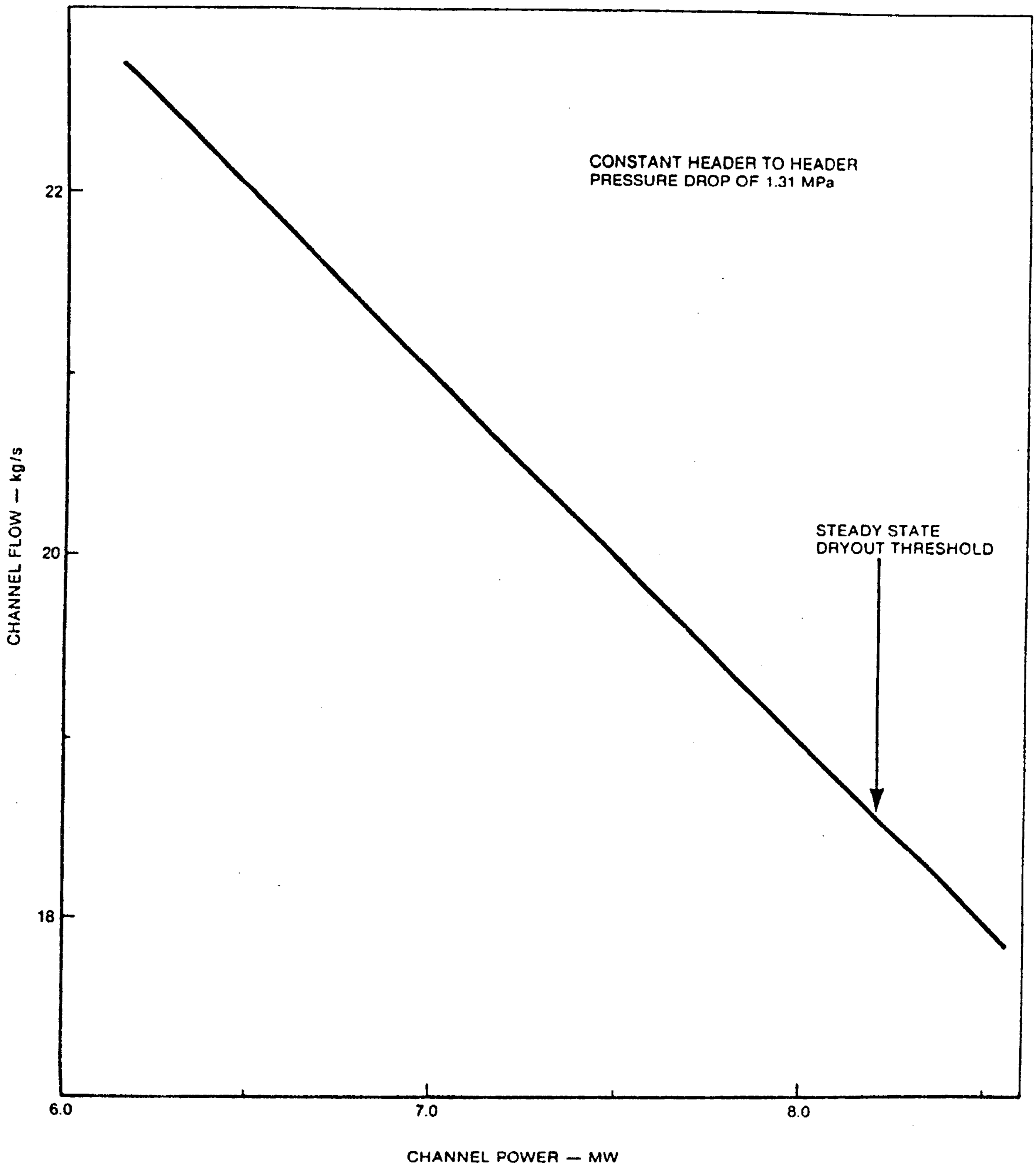


FIGURE 20 **FLOW/POWER CHARACTERISTIC FOR CHANNEL**

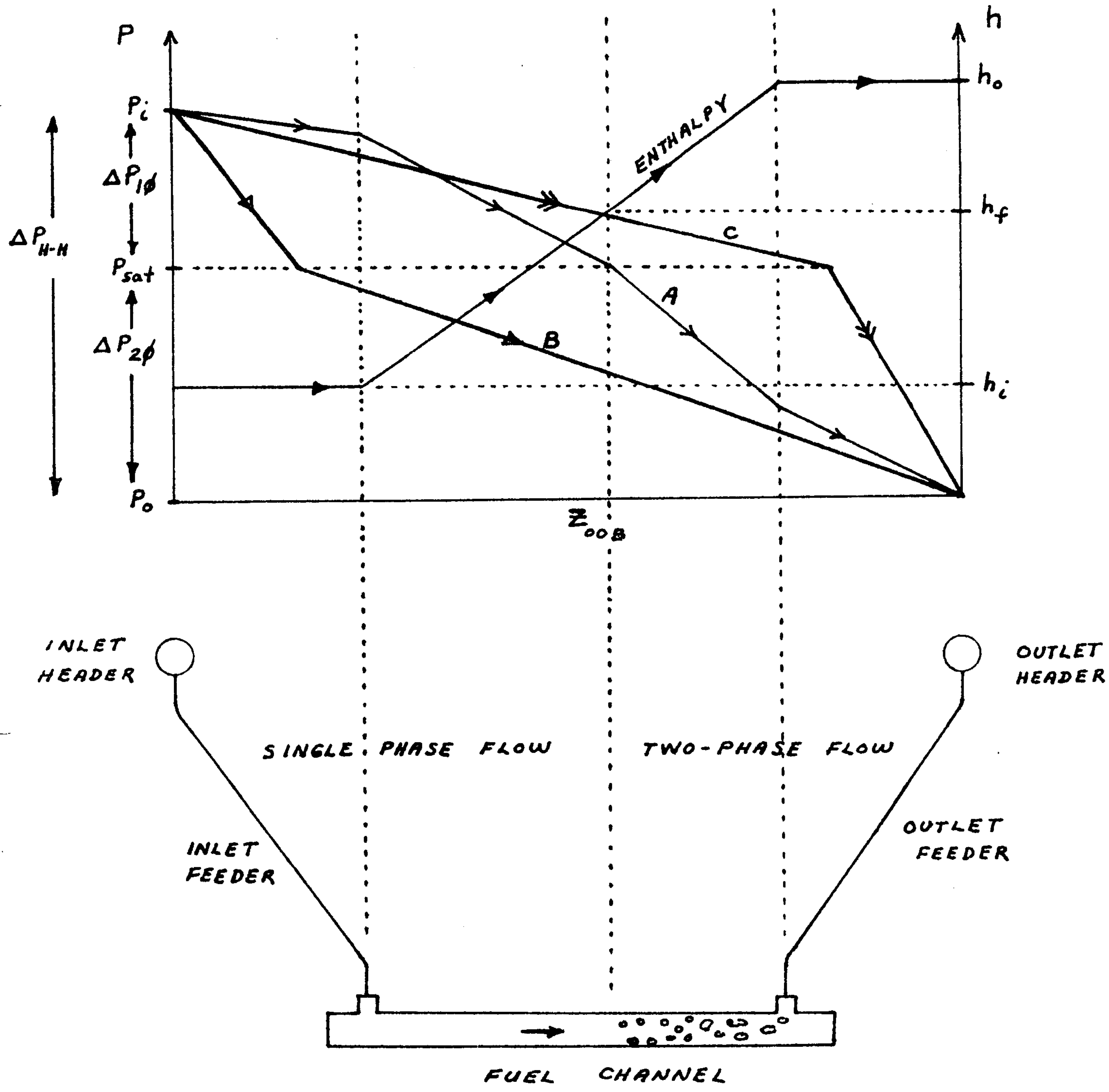

P
h
P_i
h_o
$\Delta P_{1\phi}$
ENTHALPY
ΔP_{H-H}
h_f
C
P_{sat}
A
$\Delta P_{2\phi}$
B
h_i
P_o
Z_{OOB}
INLET HEADER
OUTLET HEADER
SINGLE PHASE FLOW
TWO-PHASE FLOW
INLET FEEDER
OUTLET FEEDER
FUEL CHANNEL

FIGURE 21