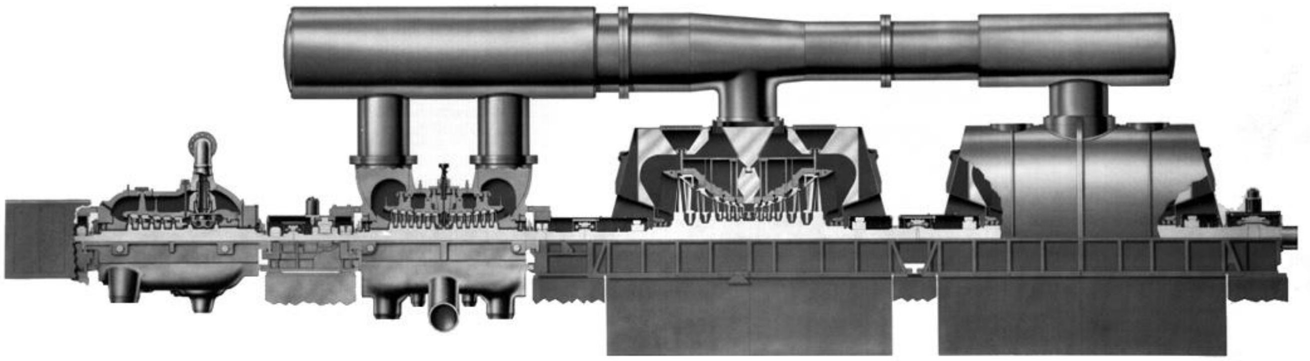
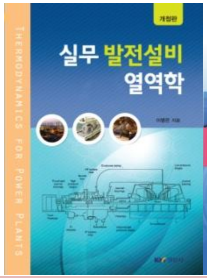
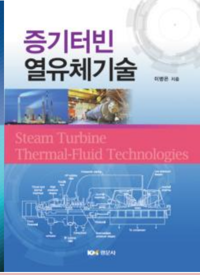
1. Introduction to Steam Turbines







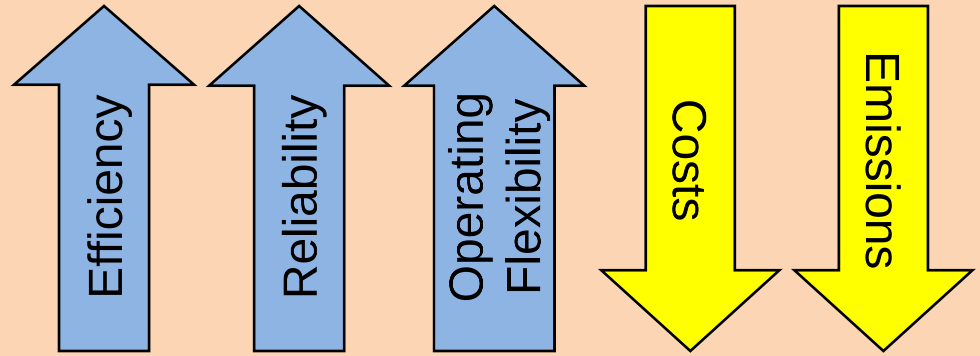
Contents

Power Generation Requirement

Variety of Fuels

Coal
Gas
Oil
Water
Nuclear
Wind
Solar
Geothermal
Biomass

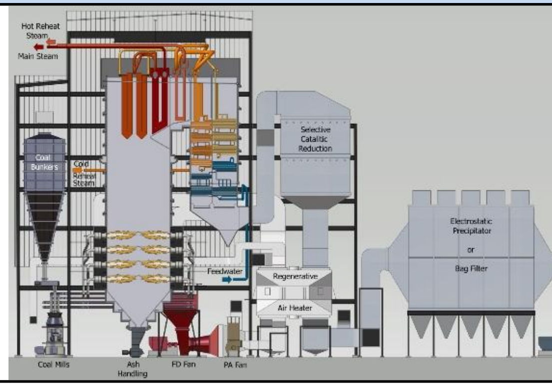
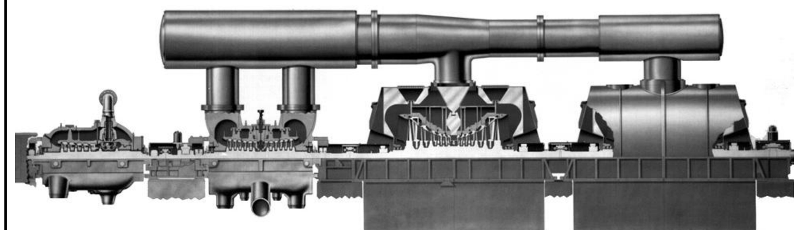
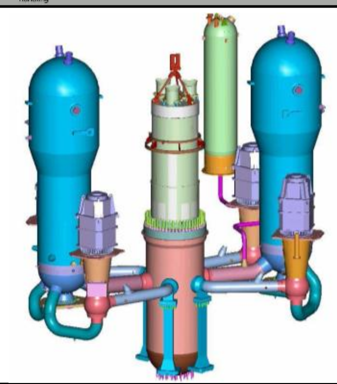
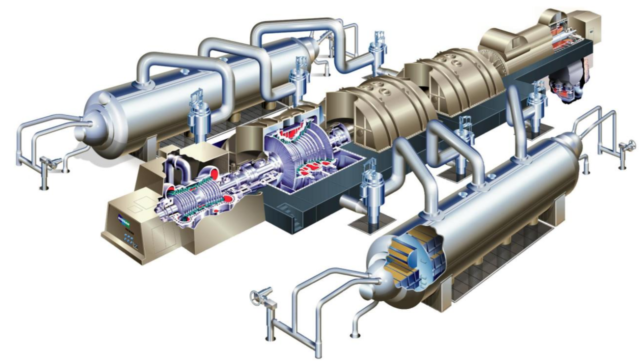
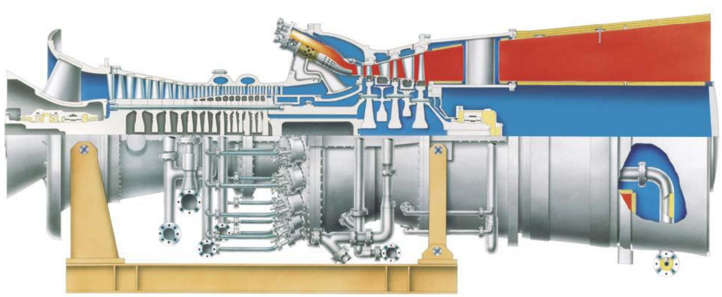
Competitive Machine



Variety of Studies

열역학
유체역학
구조역학
연소공학
회전체동력학
재료공학
진동
전기공학

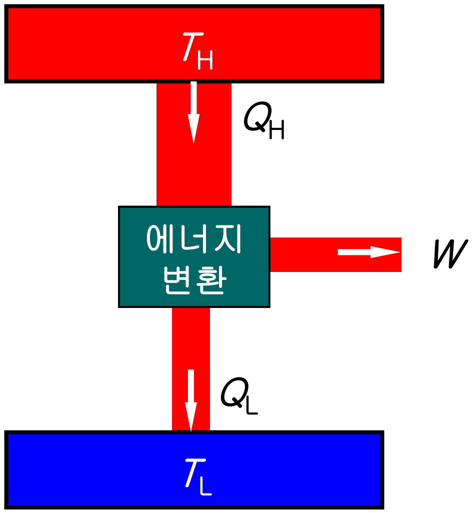
발전설비 대분류

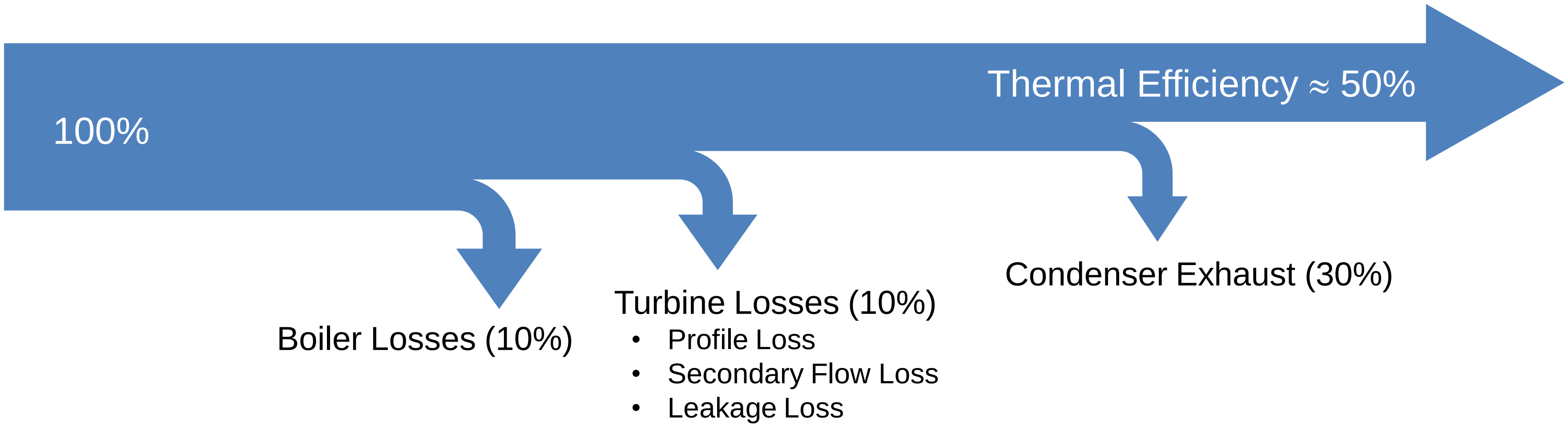
형태	1차 계통	2차 계통
화력발전		
원자력발전		
복합발전		

Major Factors

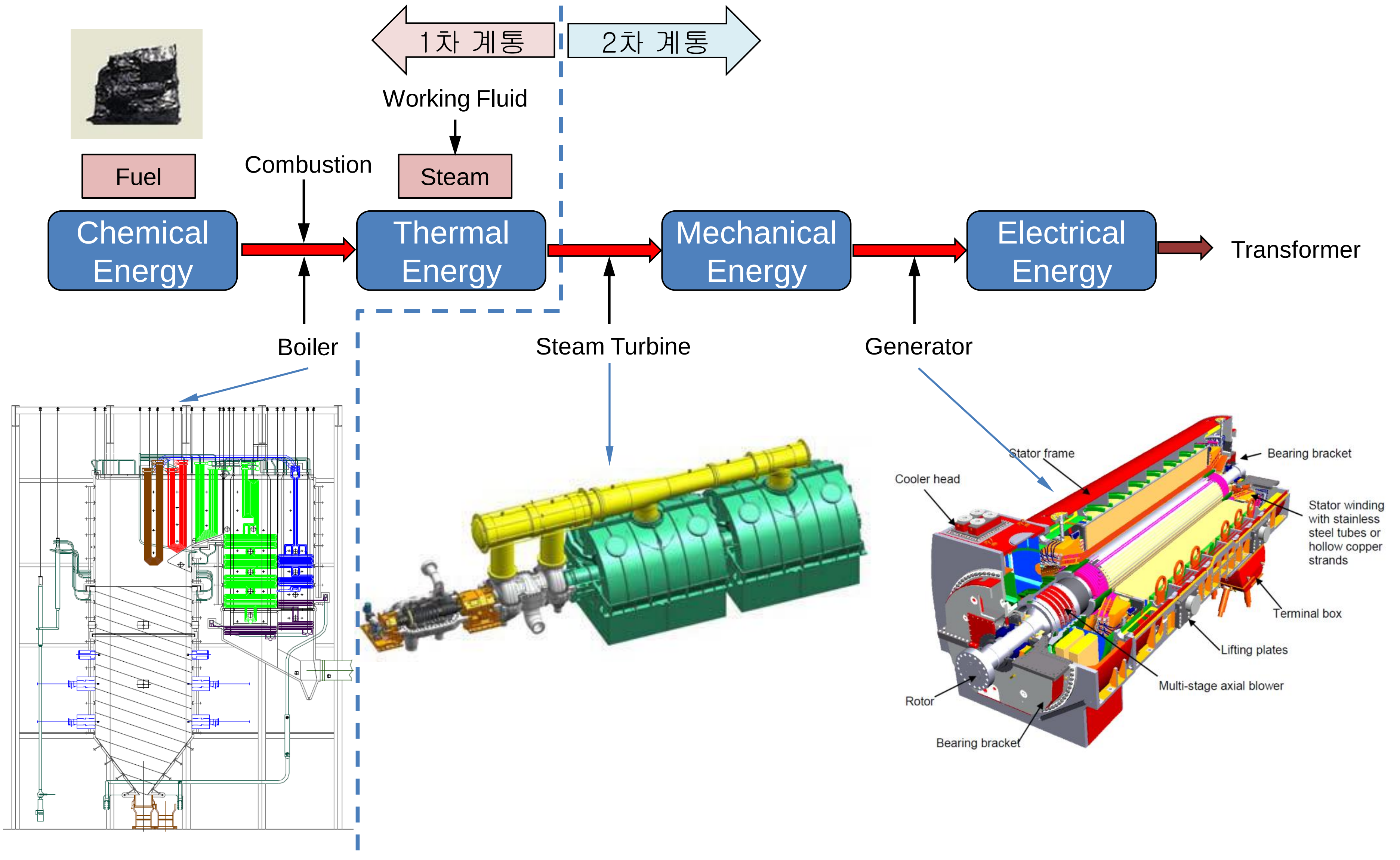
❖ Factors should be considered for power plants

- Thermal efficiency
- Environmental problems
- Reliability
- Durability
- Compactness





Energy Conversion

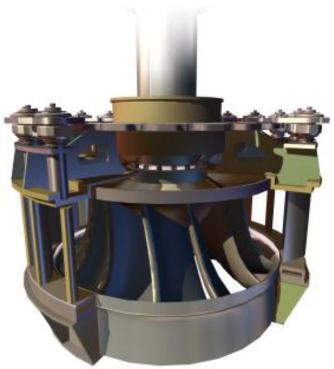


Turbine

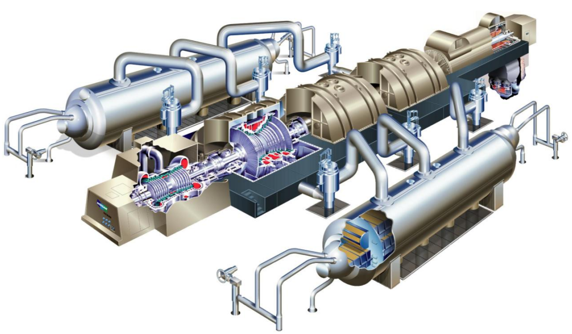
작동유체 종류에 따른 터빈 분류

작동유체(working fluid): 계 내부를 채우고 있거나 계를 통과하여 흘러가는 유체. 에너지를 저장하기도 한다.

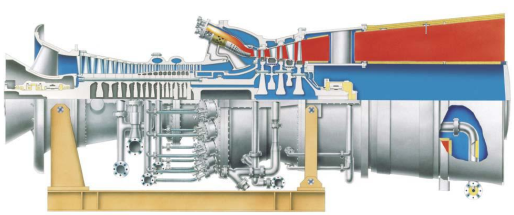
- Working Fluids
  - Water
  - Steam
  - Combustion Gas
  - Air



Hydraulic Turbine



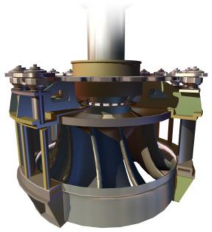
Steam Turbine



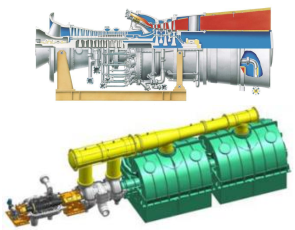
Gas Turbine

Wind Turbine

The Forms of Input Energy

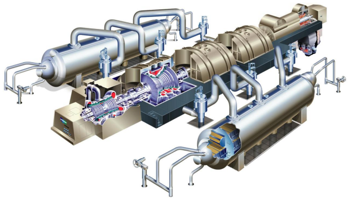


Hydroelectric power plant : The *potential energy* of an elevated body of water.



Fossil fuel fired power plant: The *chemical energy* that is released from the hydrocarbons contained in fossil fuels such as coal, natural gas, and boimass fuels. The chemical energy is converted into thermal (heat) energy when the fossil fuel is burned.

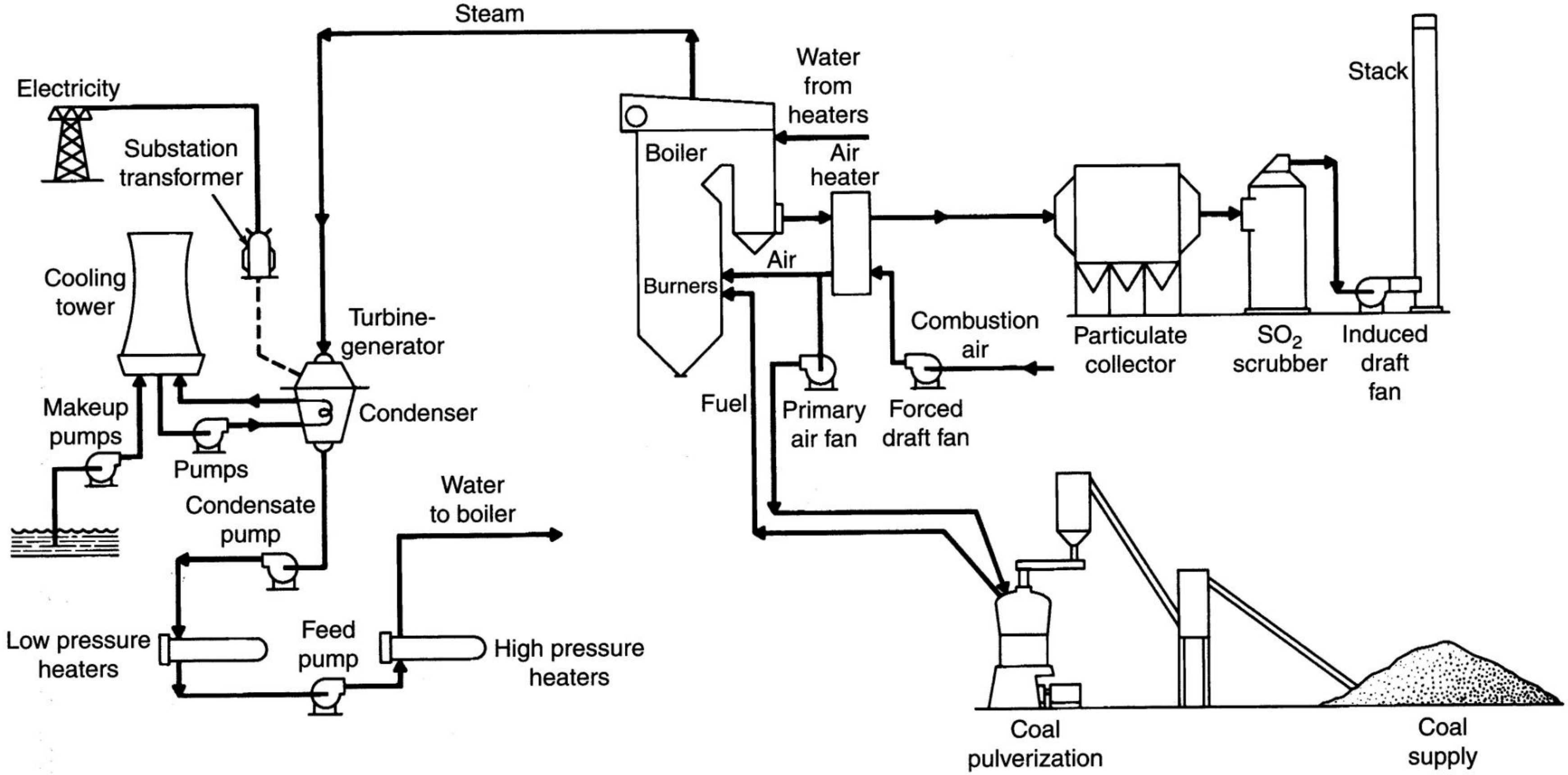
Solar power plant: The *solar energy* from the sun.



Nuclear power plant: The *fission or fusion energy* that separates or attracts atomic particles.

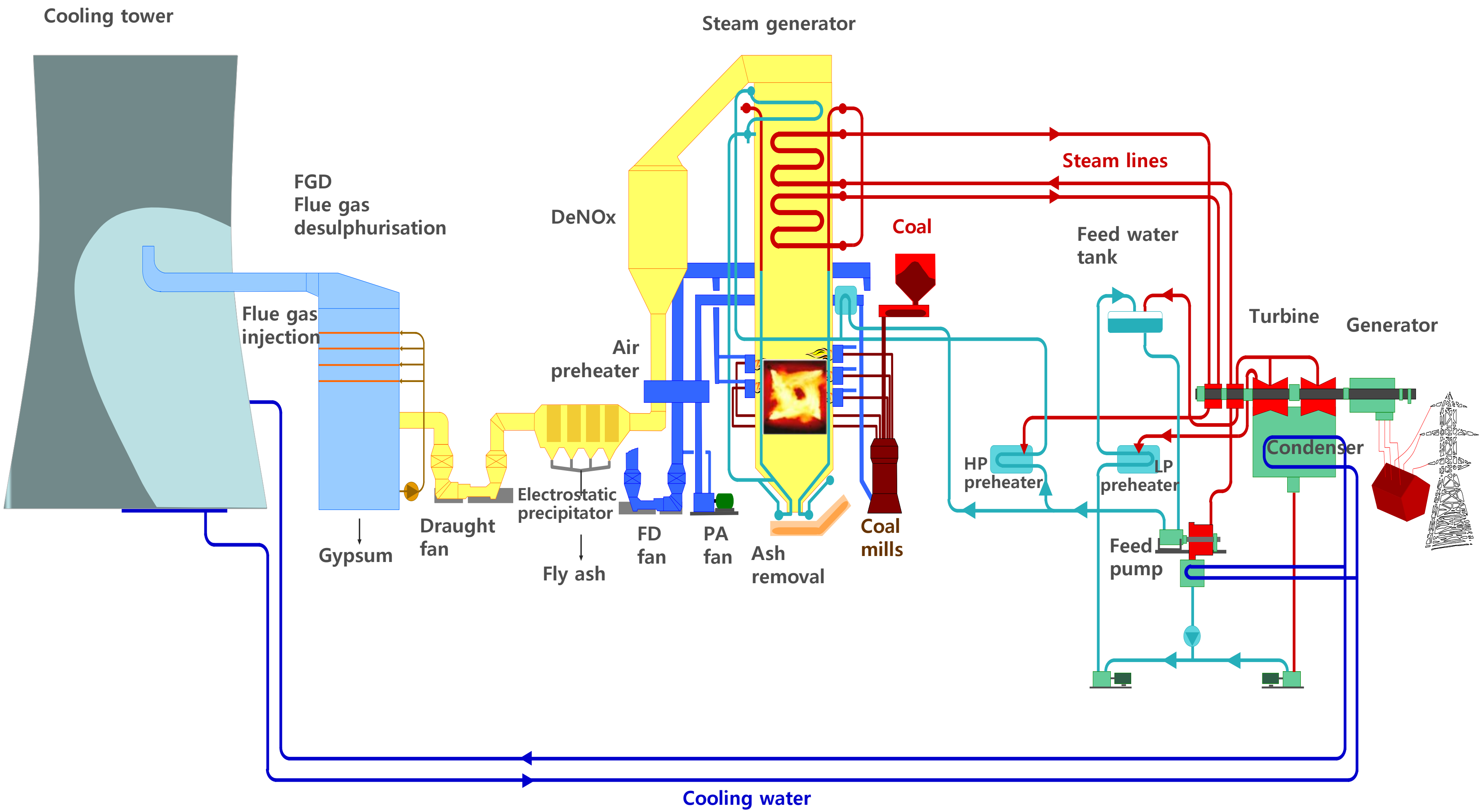
Wind farm: The *wind energy* generated from natural environment.

Schematic Diagram of Fossil Power Plant

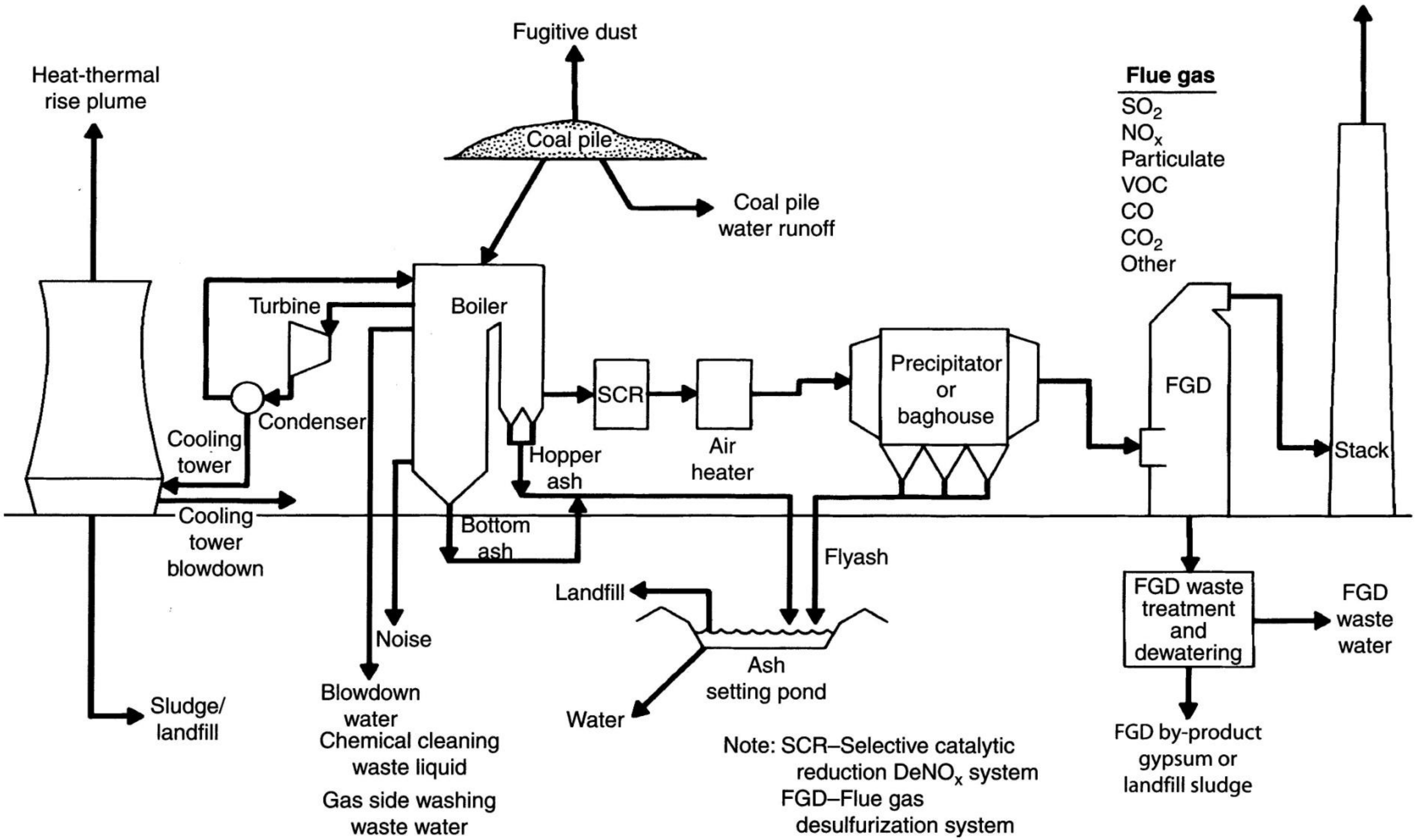


The major systems of a coal-fired power plant
1) Coal receipt and preparation   2) Coal combustion and steam generation
3) Environmental protection   4) Turbine and generator
5) Condenser and feedwater system   6) Heat rejection, including the cooling tower

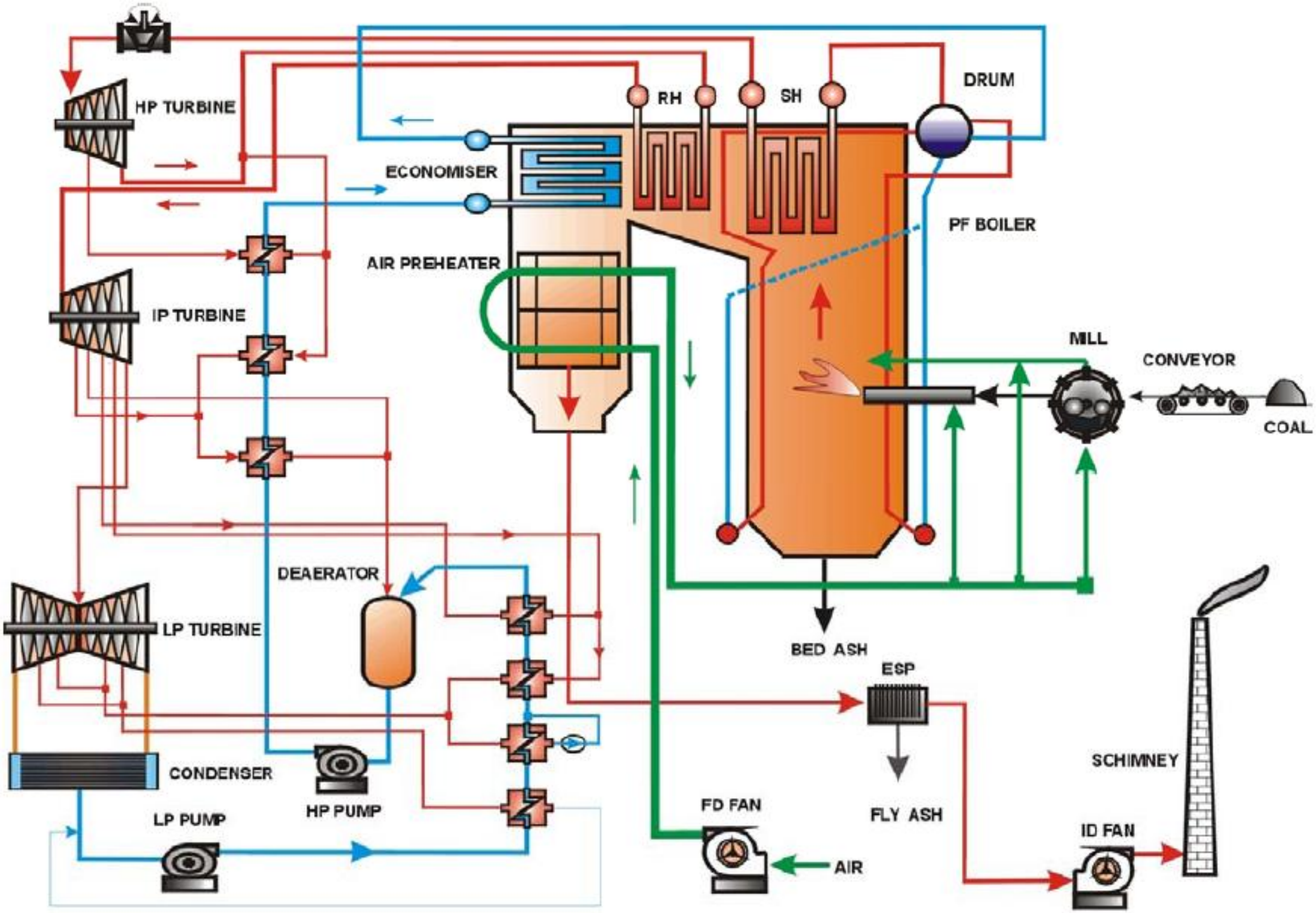
Schematic Diagram of Fossil Power Plant



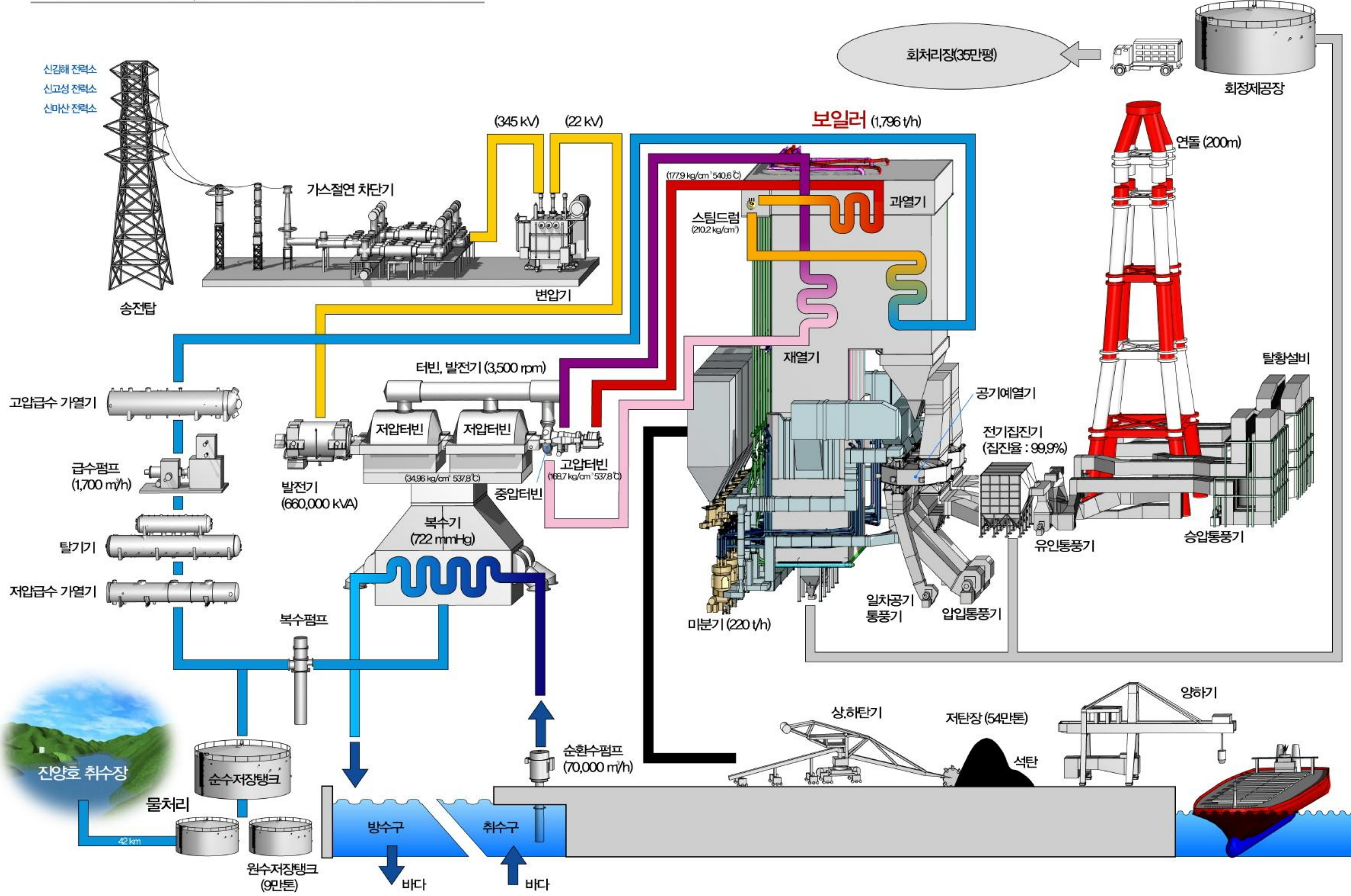
Emission from a Coal–fired Power Plant



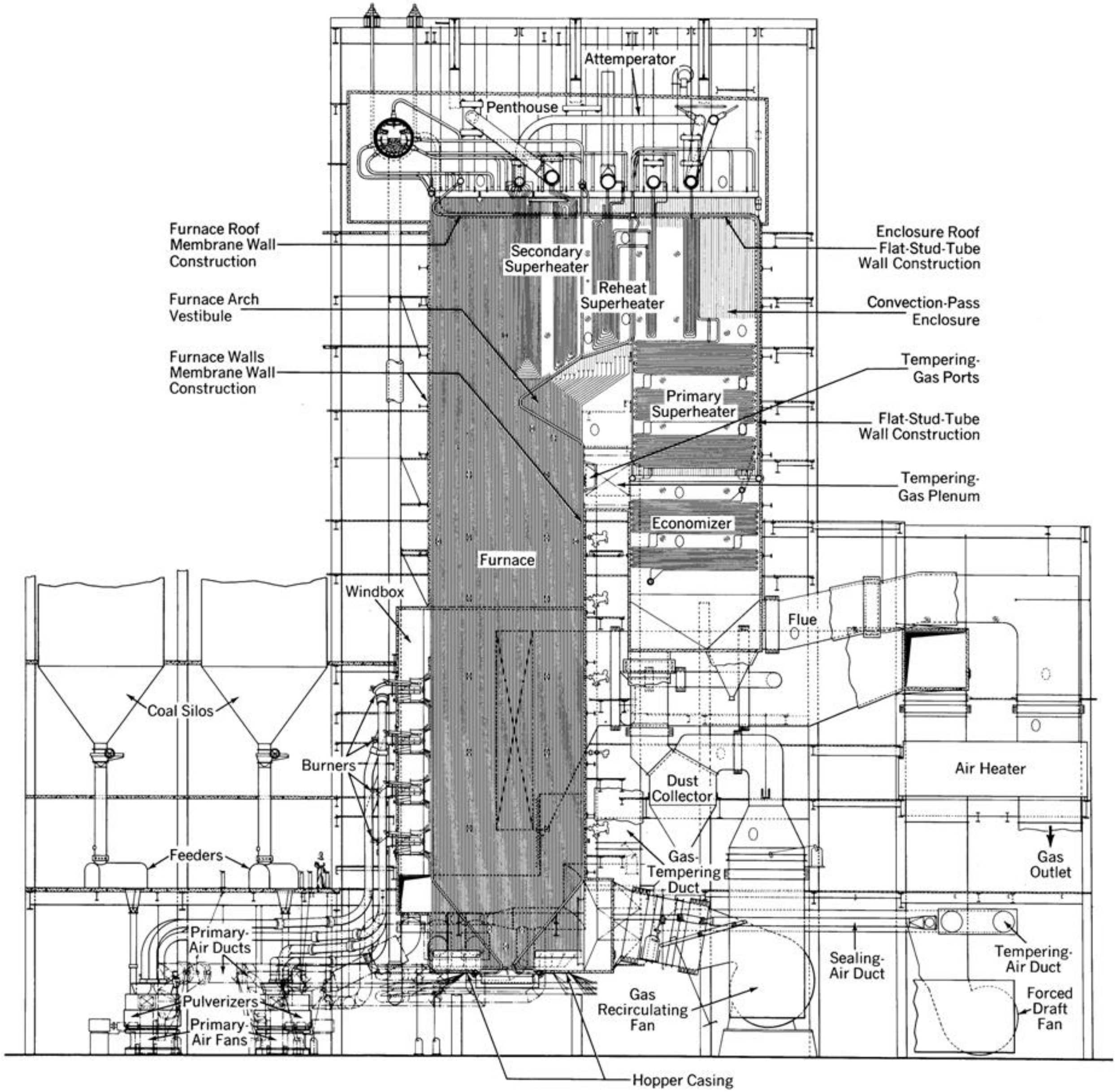
Schematic Diagram of Fossil Power Plant



삼천포화력 1,2호기 전체계통 흐름도

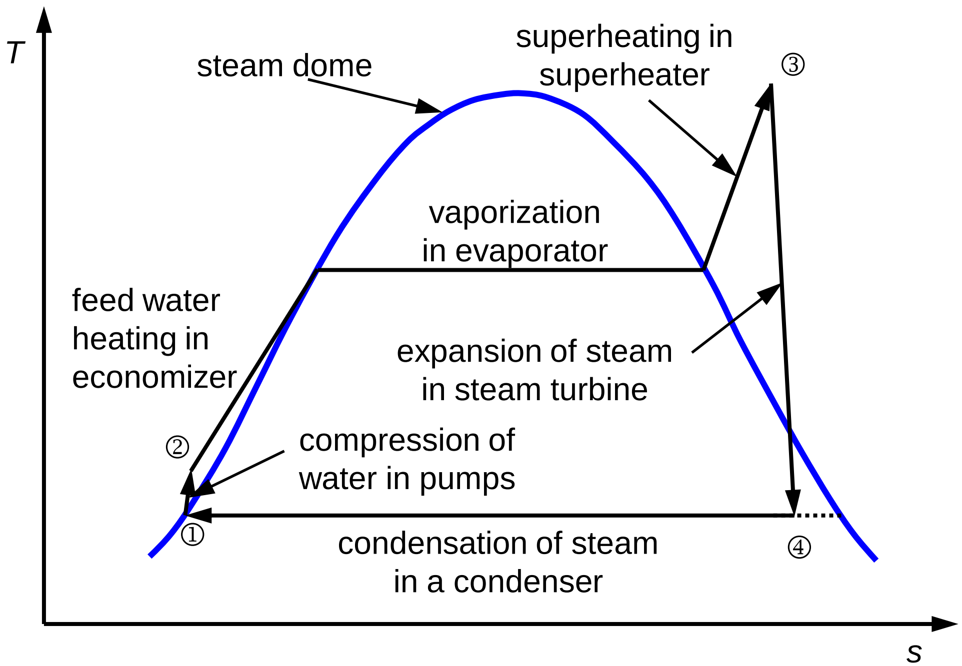


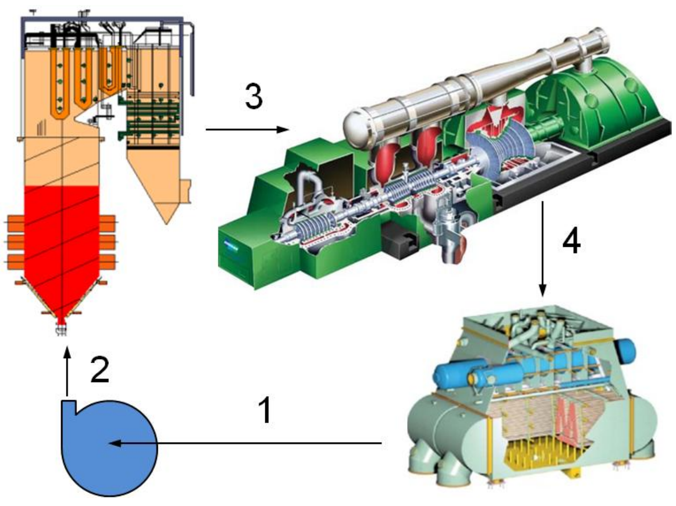
A Typical Cial-Fired Boiler



Rankine Cycle

T-s 선도

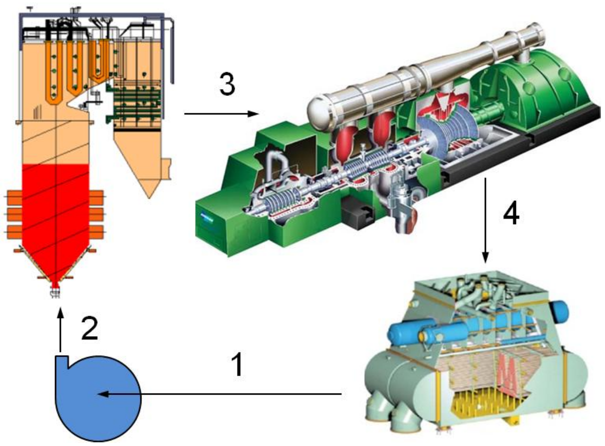




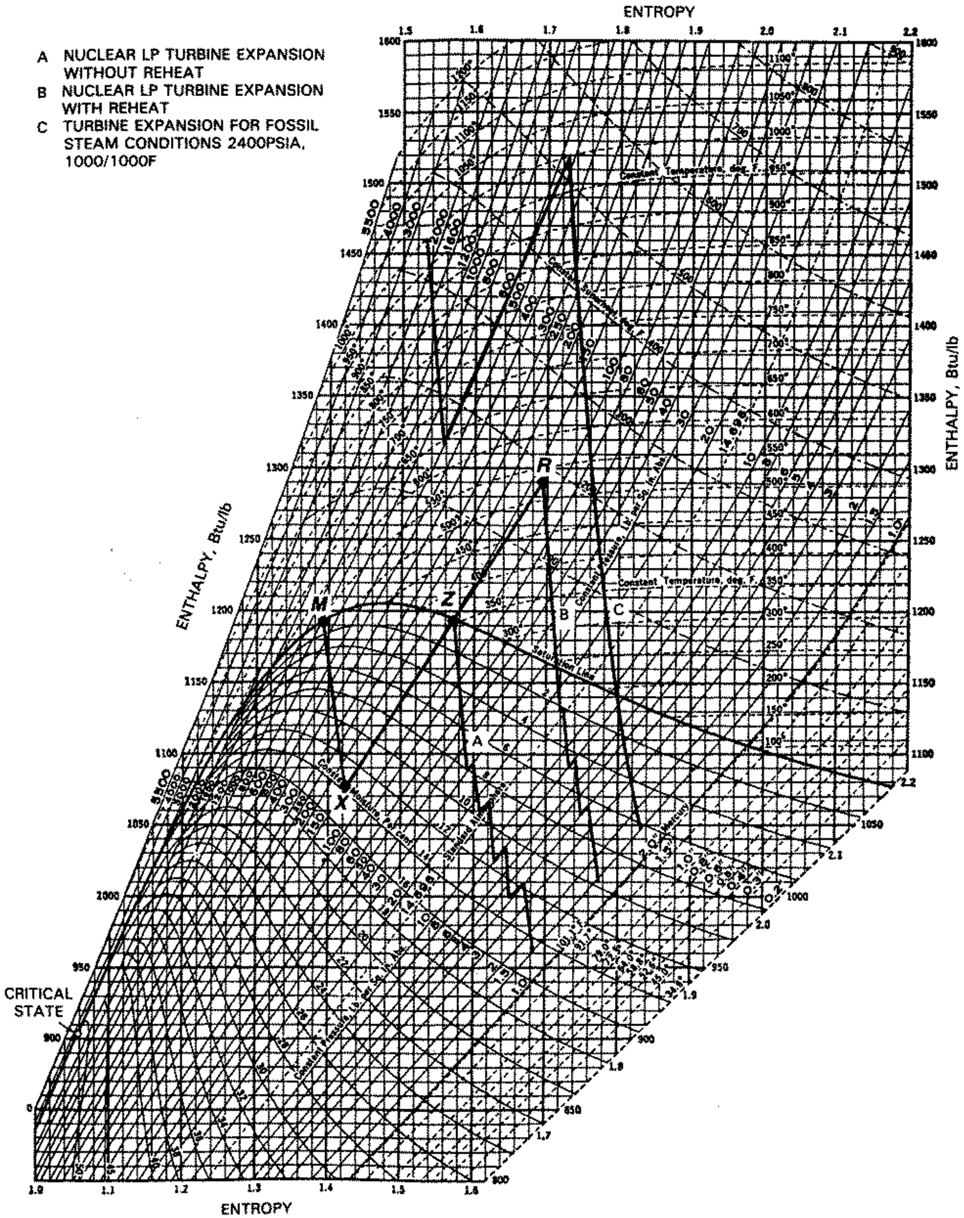
- ❖ The economizer is a heat exchanger used to increase feedwater temperature.
- ❖ The evaporator, which is usually surrounds the boiler furnace, is to produce saturated steam and supply it to the superheater.
- ❖ In the superheater the steam is further heated and has its temperature raised to the level above the saturation temperature.

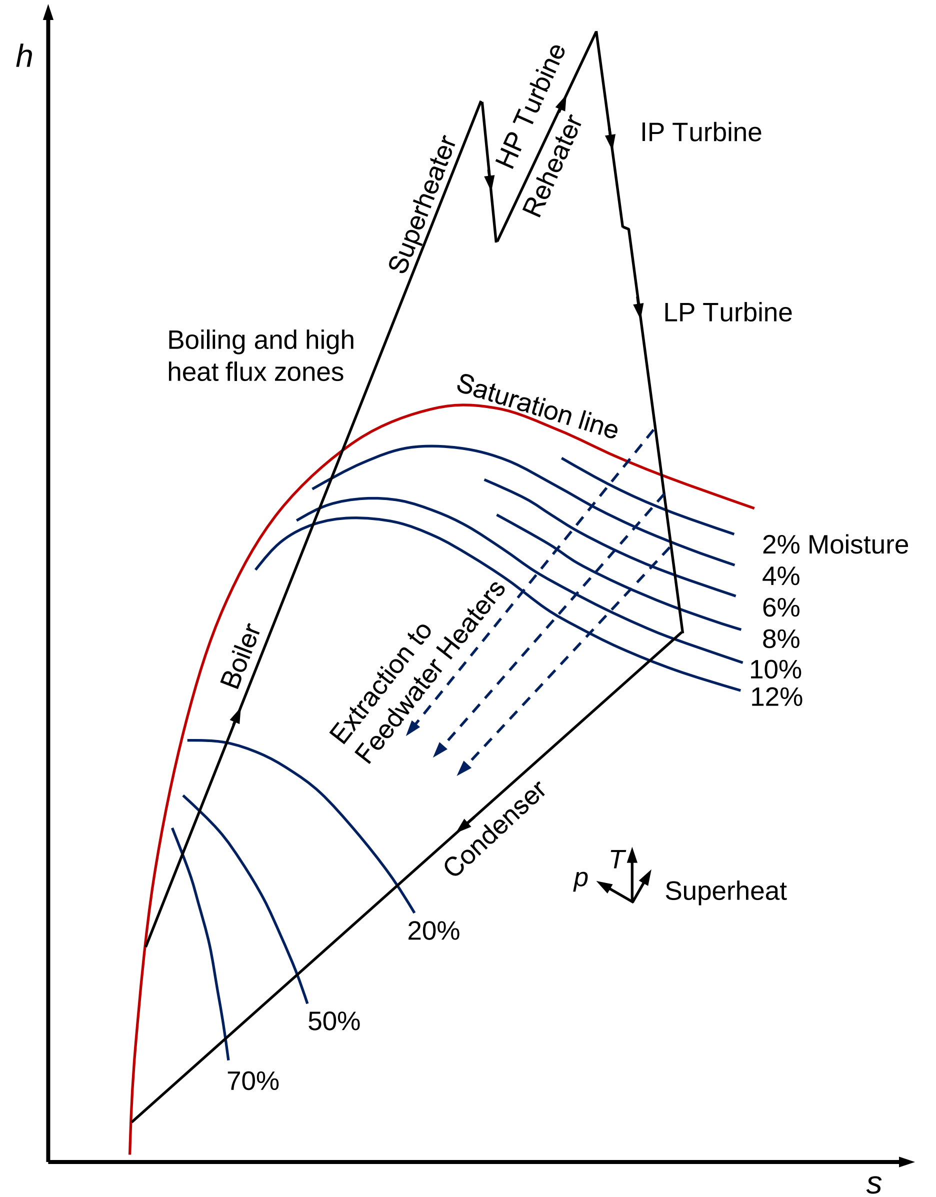
Steam Turbine

- The prime mover in a steam power plant is a steam turbine that converts part of the thermal energy of steam with high pressure and temperature to shaft power.
- The thermodynamic cycle for the steam turbine is the Rankine cycle.
- The cycle is the basis for conventional power generating stations and consists of a heat source (boiler) that converts water to high pressure steam.
- In the steam cycle, water is first pumped to high pressure.
- It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapor), and then superheated (heated to a temperature above that of boiling).
- A multistage turbine expands the pressurized steam to lower pressure and the steam is then exhausted either to a condenser at vacuum conditions or into an intermediate temperature steam distribution system that delivers the steam to the industrial or commercial application.
- The condensate from the condenser or from the steam utilization system returns to the feedwater pump for continuation of the cycle.

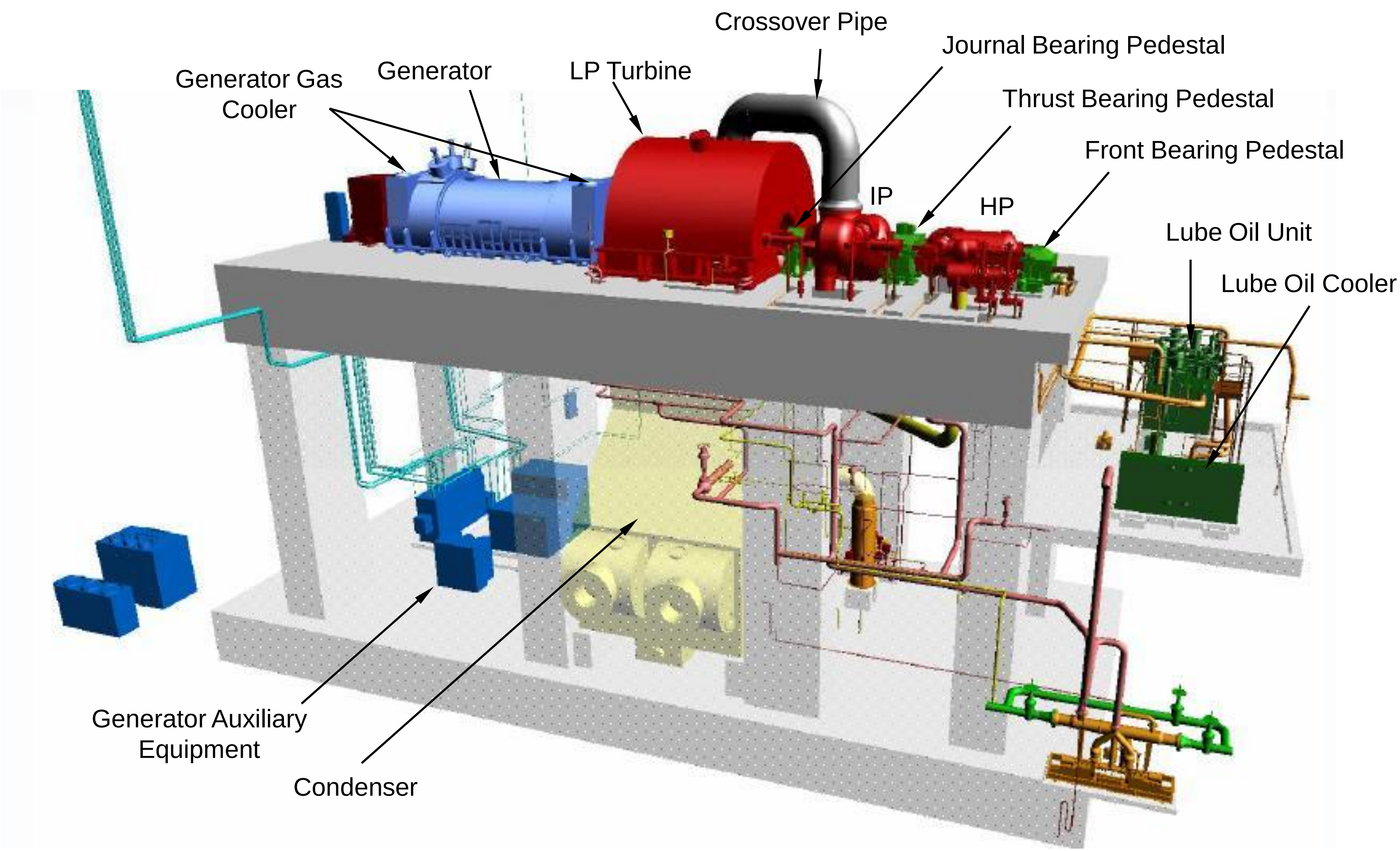


Expansion Lines in h-s Diagram

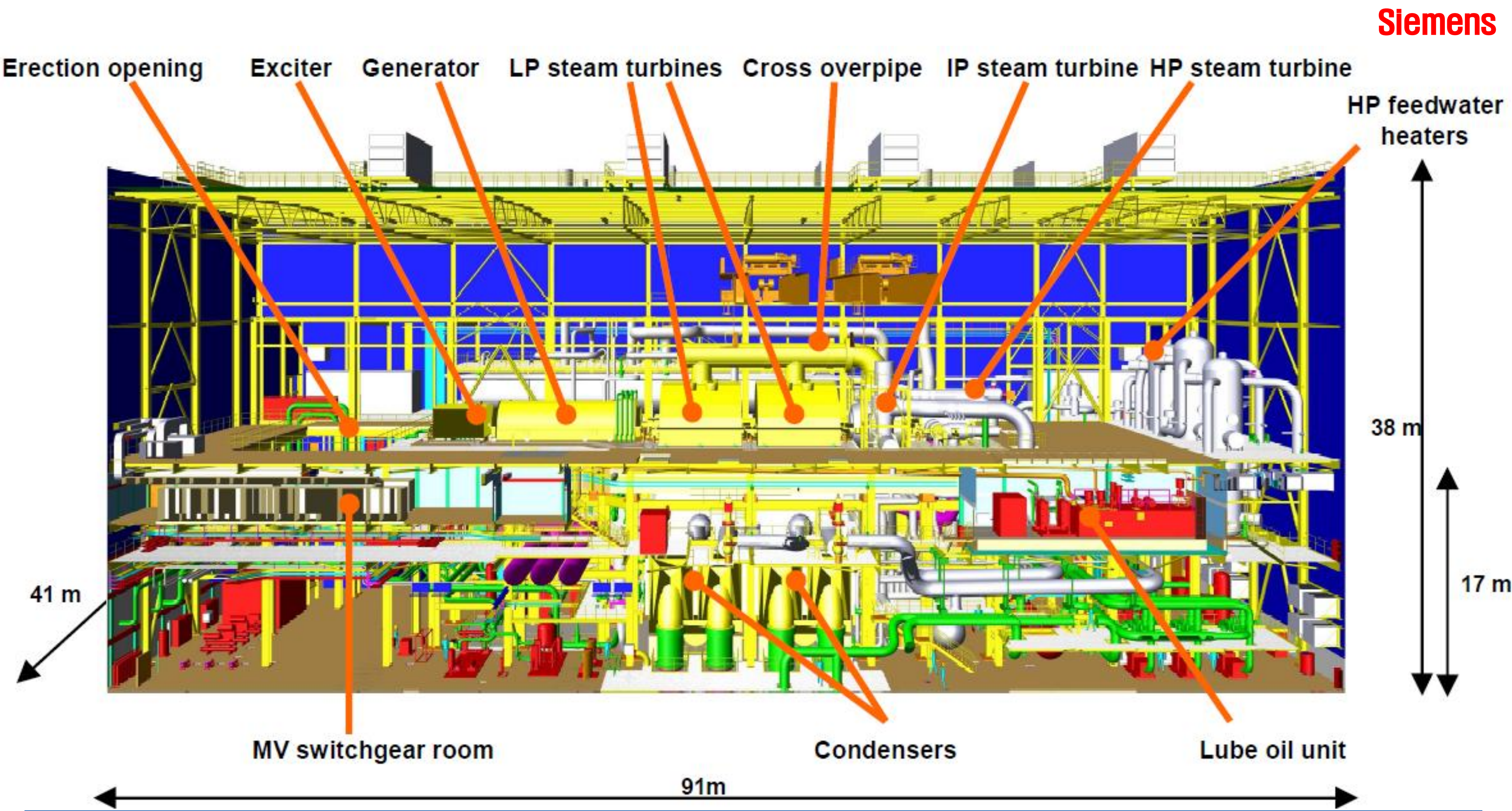




Layout of a Steam Turbine



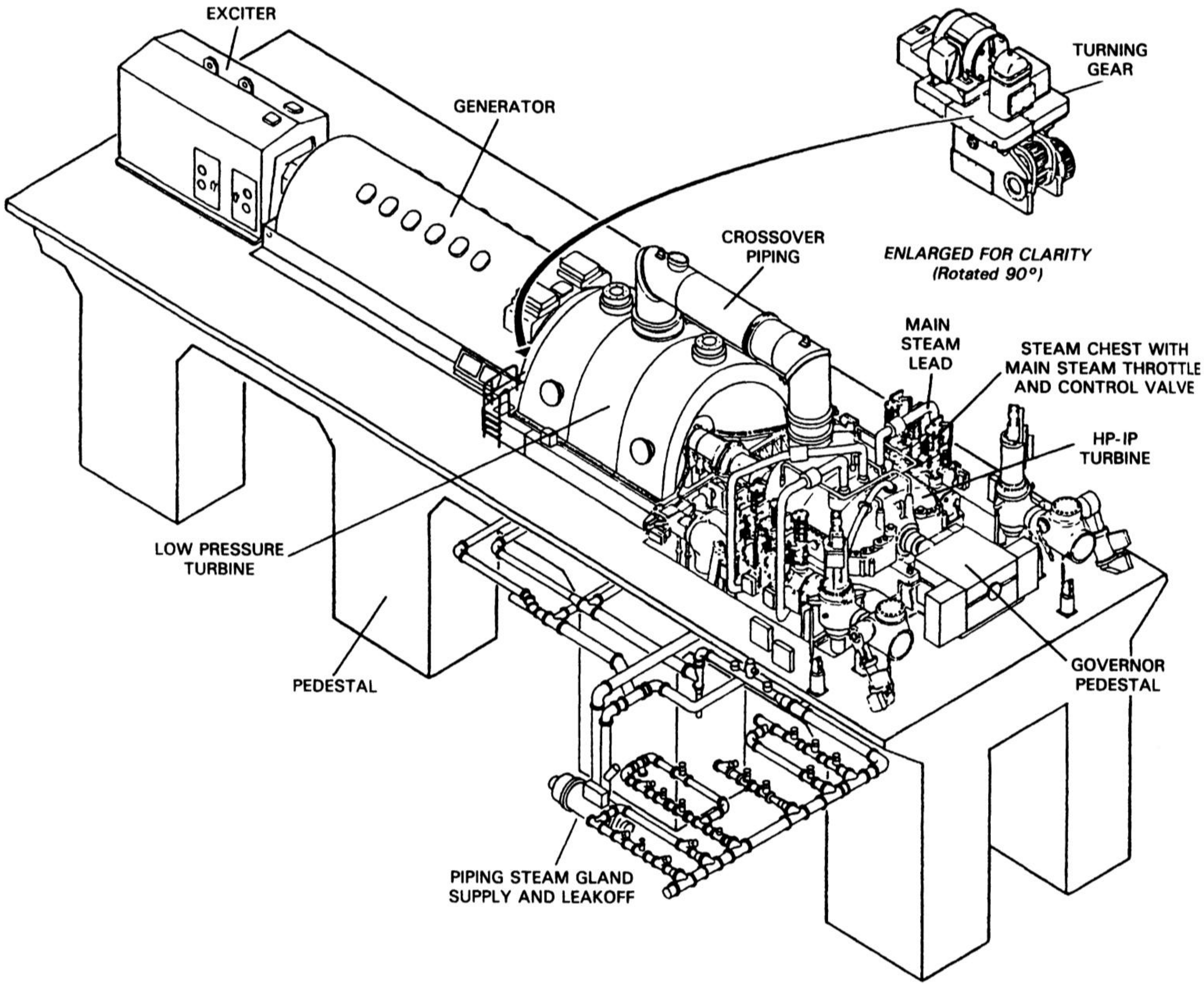
Layout of a Steam Turbine



SST5-6000 (Siemens), 280 bar 600°C/610°C, net plant efficiency above 45% (LHV)

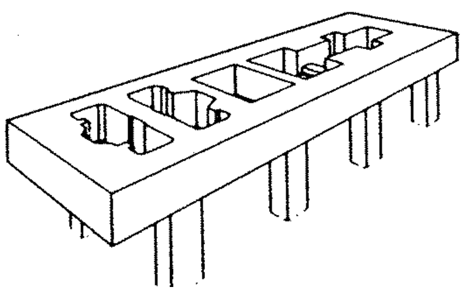
The function of the steam turbine is to convert the thermal energy contained in the steam into mechanical energy for turning the generator.

Layout of a Steam Turbine

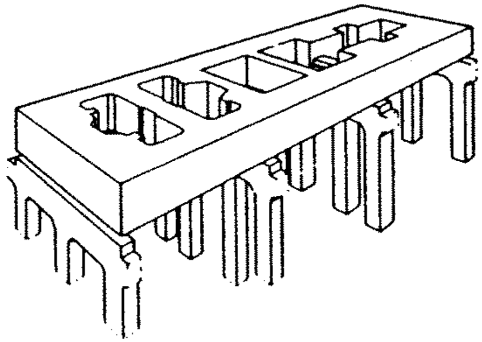


Foundation

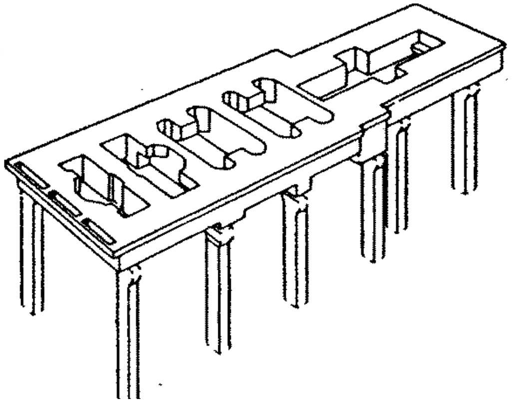
Foundation is decoupled from the overall structure



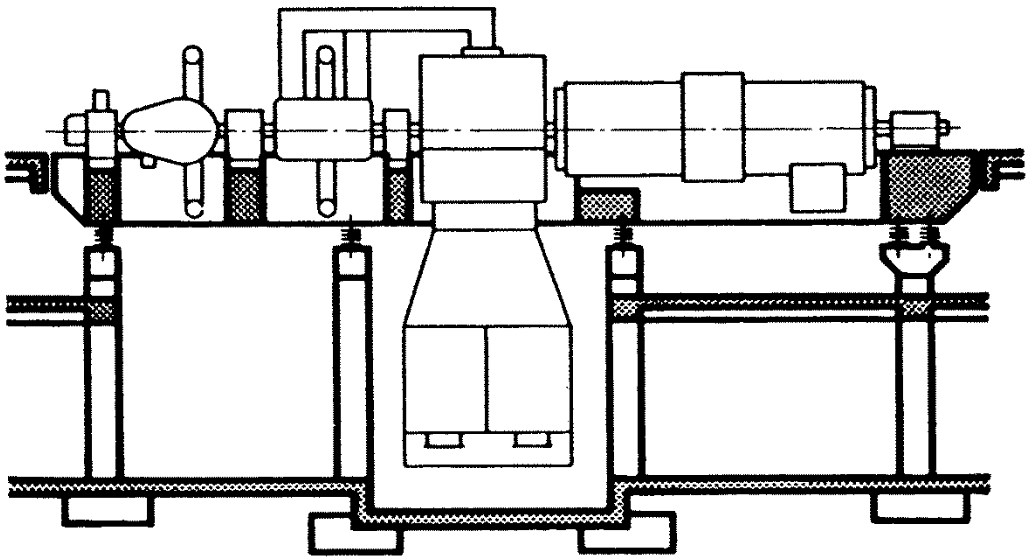
Monolitic concrete foundation

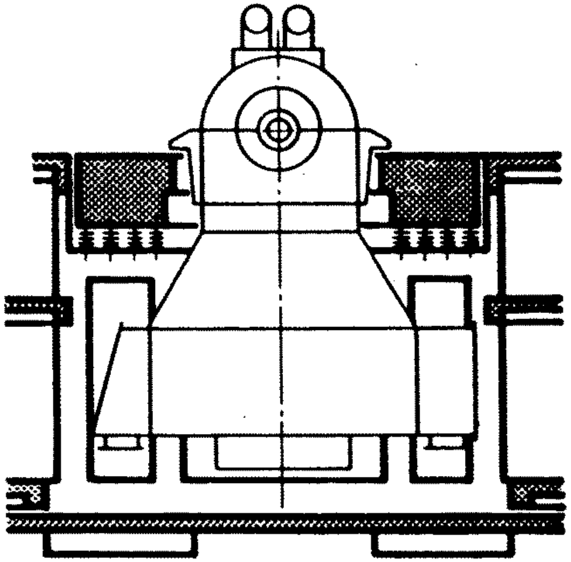


Spring foundation on transoms



Spring foundation on single supports

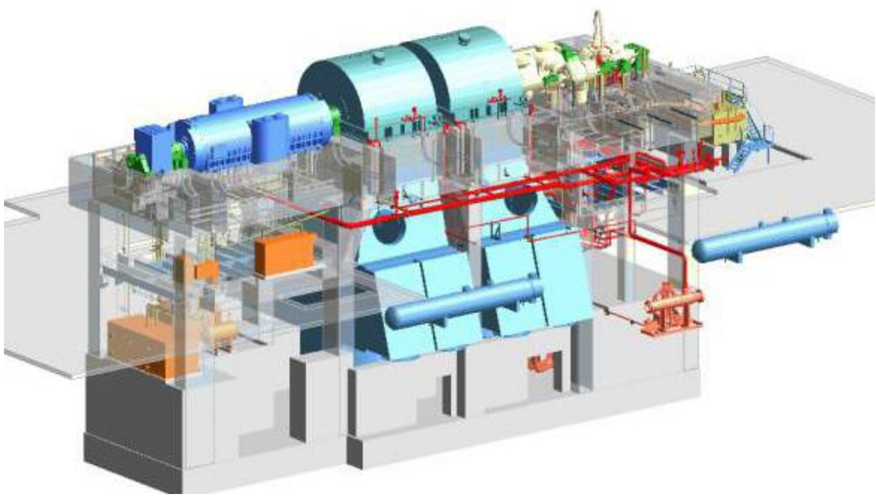


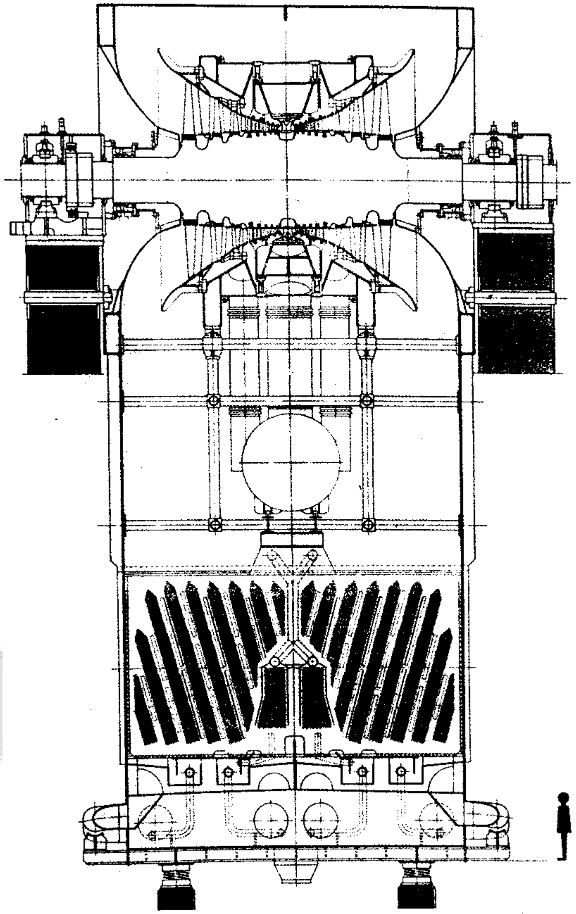


Spring supported foundation

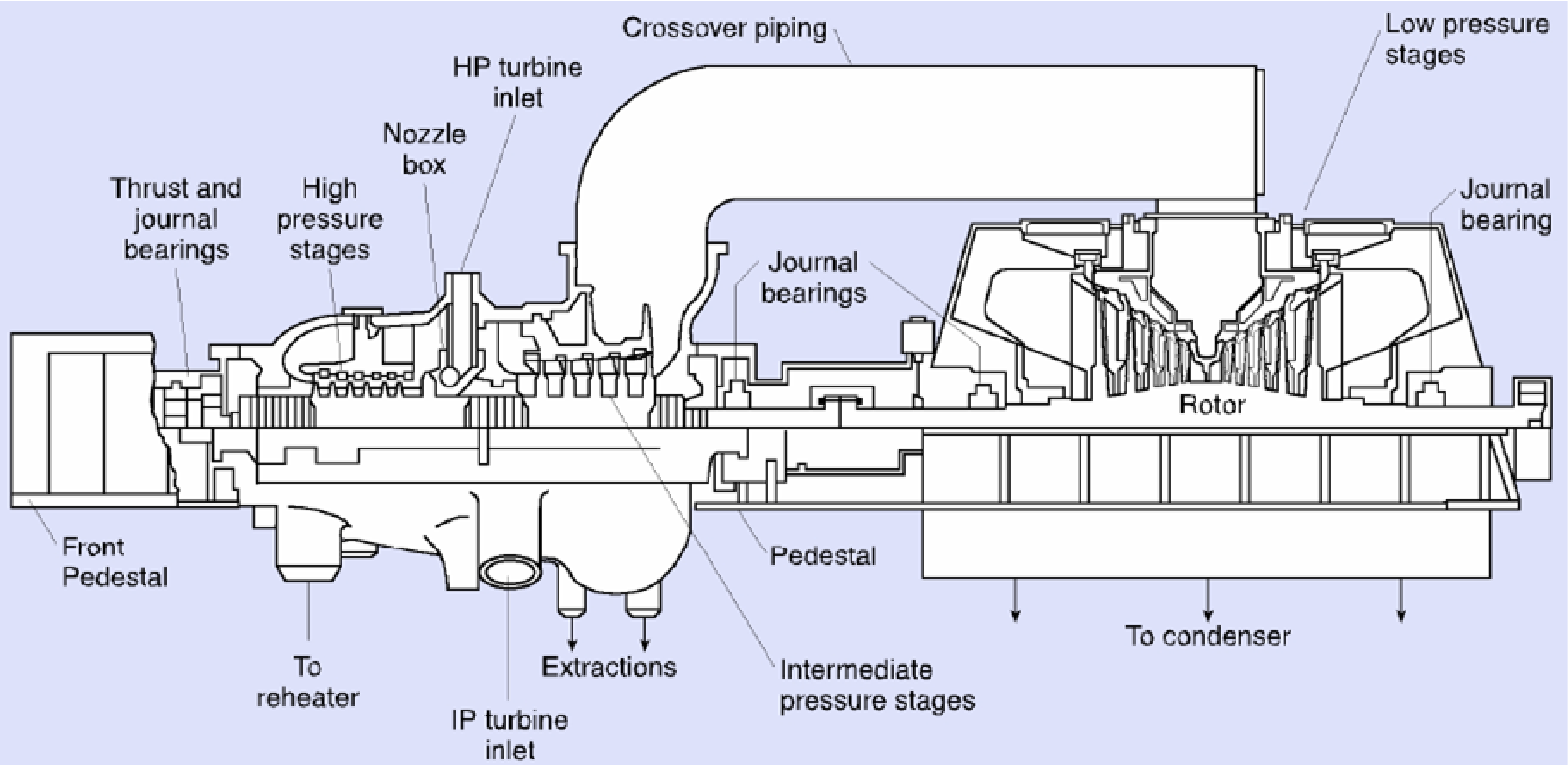
Layout of a Steam Turbine

- Steam turbines are one of the most versatile and oldest prime mover technologies still in general production.
- Power generation using steam turbines has been in use for about 100 years due to higher efficiencies and lower costs.
- A steam turbine uses a separate heat source and does not directly convert fuel to electric energy.
- This separation of functions enables steam turbines to operate enormous variety of fuels, nuclear energy, natural gas, oil, coals, wood, wood waste, and agricultural byproducts.
- The energy is transferred from the steam generator to the turbine through high pressure steam that in turn powers the turbine and generator.

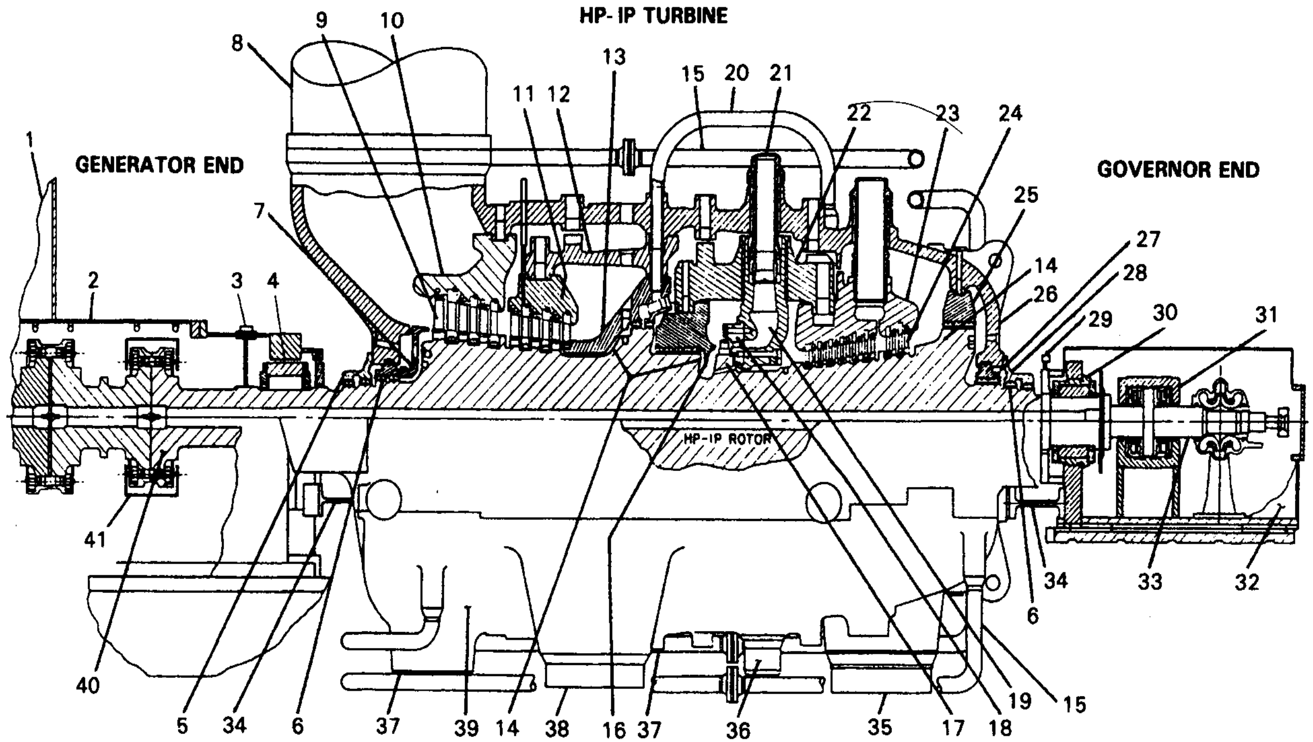




Steam Turbine Components

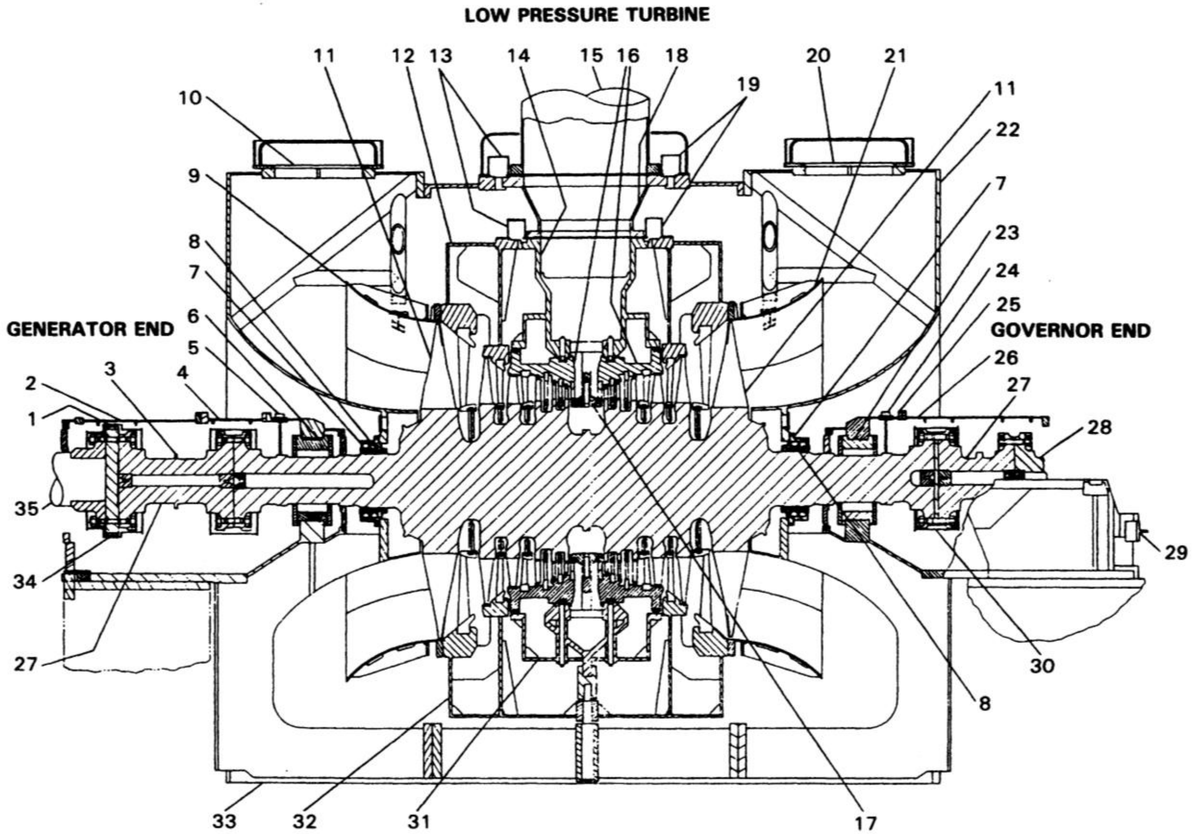


HP/IP Turbine Components



1 LP TURBINE
2 BEARING HOUSING AND COUPLING GUARD COVER
3 VIBRATION PICKUP
4 NO. 2 BEARING
5 HP- IP OUTER GLAND
6 GLAND SEAL
7 HP- IP INNER GLAND
8 HP- IP EXHAUST (Crossover Pipe)
9 IP BLADING
10 NO. 2 IP BLADE RING
11 NO. 1 IP BLADE RING
12 INNER CYLINDER
13 IP DUMMY RING
14 BALANCE POSITION
15 EQUILIBRIUM PIPE
16 HP DUMMY RING
17 CONTROL STAGE
18 NOZZLE BLOCK
19 INLET NOZZLE CHAMBER
20 COOLING STEAM PIPE
21 MAIN STEAM INLET
22 HP INNER CYLINDER
23 HP BLADE RING
24 HP BLADING
25 LP DUMMY RING
26 HP- IP OUTER CYLINDER COVER
27 HP- IP INNER GLAND GVN
28 HP- IP OUTER GLAND GVN
29 VIBRATION PICKUP
30 NO. 1 BEARING
31 THRUST BEARING
32 GOVERNOR PEDESTAL
33 ROTOR EXTENSION SHAFT
34 CENTERING BEAM
35 HP EXHAUST (Cold Reheat Outlet)
36 MAIN STEAM INLET
37 EXTRACTION
38 REHEAT STEAM INLET
39 HP- IP OUTER CYLINDER BASE
40 COUPLING
41 COUPLING GUARD

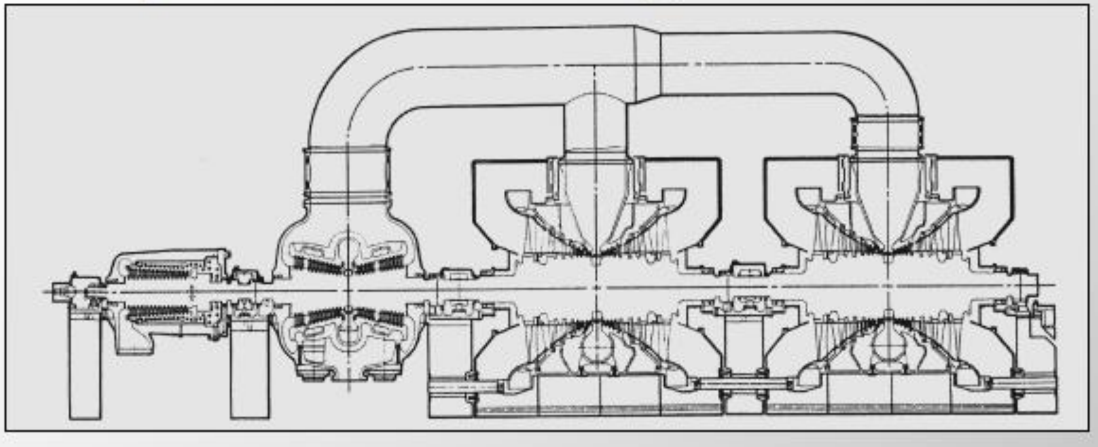
LP Turbine Components



1 SPEED SENSING PICKUP
2 COUPLING COVER
3 DIFFERENTIAL EXPANSION PICKUP LOCATION
4 BEARING COVER
5 VIBRATION PICKUP
6 NO. 4 BEARING
7 GLAND
8 GLAND SEAL
9 EXHAUST FLOW GUIDE
10 BREAKABLE DIAPHRAGM
11 BLADING
12 INNER CYLINDER COVER NO. 2
13 TOP SEALING DIAPHRAGMS
14 INNER CYLINDER COVER NO. 1
15 TURBINE STEAM INLET
16 BLADE RINGS
17 INLET FLOW GUIDE
18 CROSSOVER PIPE ADAPTER
19 TOP SEALING DIAPHRAGMS
20 BREAKABLE DIAPHRAGM
21 EXHAUST FLOW GUIDE
22 OUTER CYLINDER COVER
23 NO. 3 BEARING
24 VIBRATION PICKUP
25 BEARING AND COUPLING COVER INNER
26 BEARING AND COUPLING COVER OUTER
27 COUPLING
28 HP- IP ROTOR
29 CENTERING BEAM
30 COUPLING GUARD
31 INNER CYLINDER BASE NO. 1
32 INNER CYLINDER BASE NO. 2
33 OUTER CYLINDER BASE
34 TURNING GEAR COUPLING SPACER
35 GENERATOR ROTOR

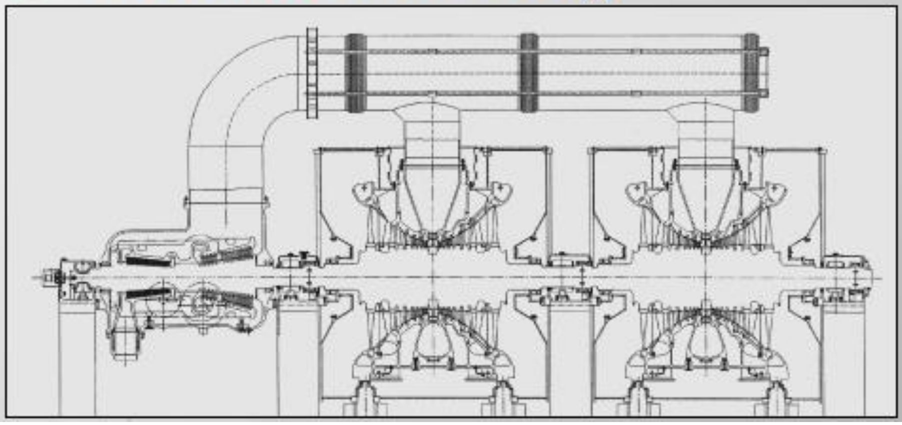
Typical Steam Turbine Arrangements

- **Separate HP and IP casings**



- Reduced potential for thermal stress
- Lower impact on differential expansions
- Preferred on large units
- Can accommodate more stages
- Used for split flow design

- **Combined HP/IP casing**

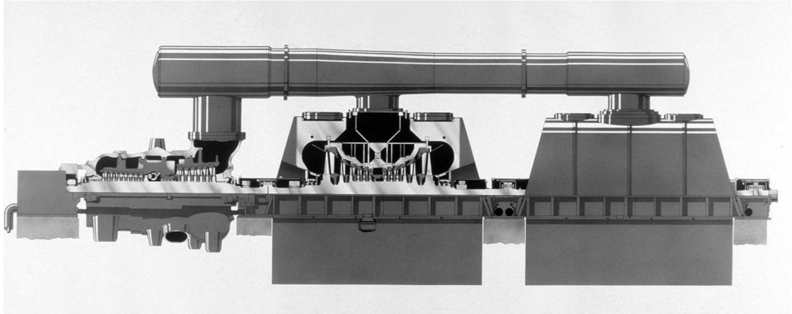


- Lower cost
- Reduced length
- Lower weight
- Reduced maintenance

A Typical 500 MW Class Steam Turbine

A Steam Turbine Used to Explain Details

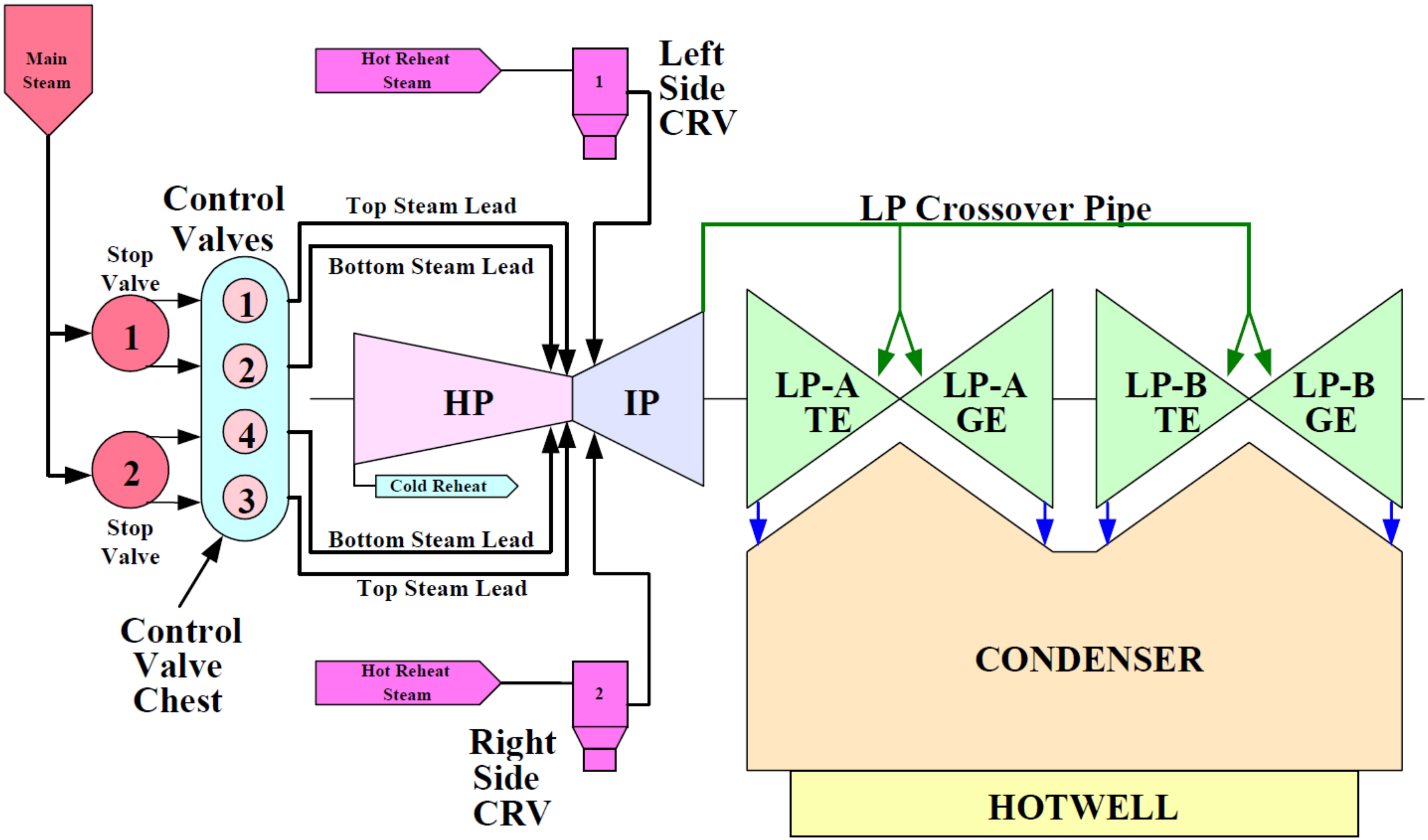
Turbine parameters	Values
Manufacturer	GE
Type	Tandem-compound opposed flow, reheat turbine with two double flow LP turbines
Number of stages	18
Steam conditions	2400 psig/1000°F/1000°F
Condenser pressure	1 in.Hga
rpm	3600
Steam flow	3,800,000 lb/h
Turbine capacity	512,094 kW



[3-Casing, 4-Flow ST]

Steam Flow [1/3]

A Typical 500 MW Class Steam Turbine



Steam Flow [2/3]

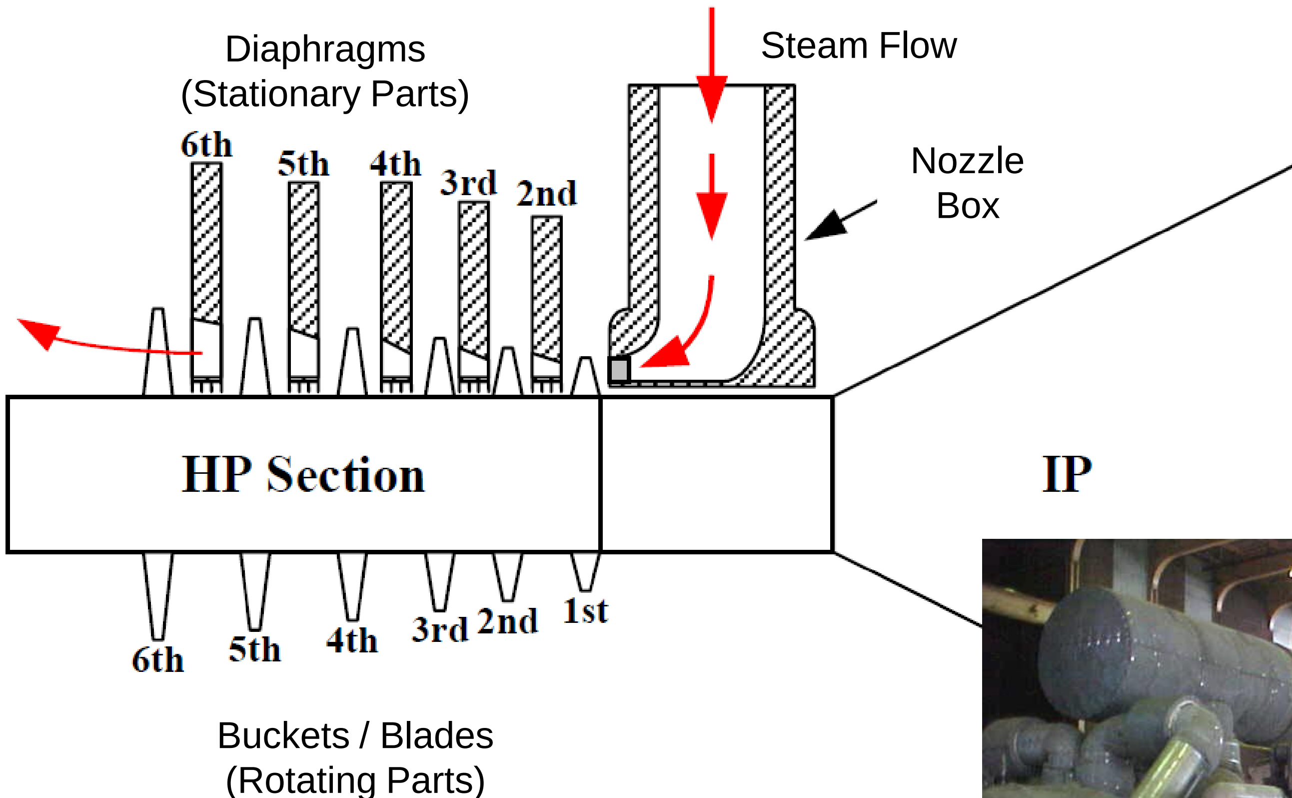
- High-pressure steam from the secondary superheater outlet is routed through the main steam line to the main stop valves.
- The main steam line splits into two individual lines upstream of the stop valves, passing the steam to the two main stop valves.
- The steam passes through the stop valves to the external control valve chest, where four control valves are located.
- The steam passes through the control valves, and to the main turbine through four lines called steam leads. Two of these steam leads enter the bottom of the high-pressure turbine, and two enter at the top.
- Each of the four steam leads pass steam to an individual 90 degree nozzle box assembly mounted in quarter segments around the periphery of the first stage of the high pressure turbine.
- High-pressure steam enters the turbine near the center of the HP section, flowing through the individual nozzle boxes and the six-stage HP turbine toward the front-end standard.
- The steam then leaves the HP turbine, and returns to the reheat section of the boiler.
- The reheated steam returns to the turbine through single hot reheat line, which splits into two individual lines upstream of the combined reheat intercept valves.
- Steam flows through the combined reheat intercept valves, and into the five-stage IP turbine.

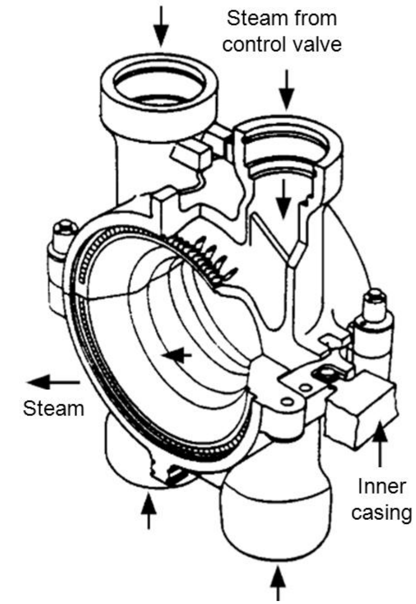
Steam Flow [3/3]

- The inlet end of the IP turbine is located near the center of the high-pressure section, next to the HP turbine inlet.
- Steam flow in the IP turbine is in the direction of the generator; this is opposite to the direction of flow in the HP turbine.
- Steam is exhausted from the IP turbine into a single crossover pipe, which routes steam from the IP turbine exhaust to the inlet of the two double-flow LP turbines.
- Steam then enters the center of each seven-stage LP turbine.
- The LP turbines consist of two identical sets of LP turbine stages.
- In each LP turbine; one-half of the steam flows through one set of LP turbine stages in the direction of the turbine front standard, the other half of the steam flows through the other set of LP turbine stages in the direction of the generator.
- The steam then exits the LP turbines and is exhausted into the condenser.
- The main turbine shaft is connected to and rotates the main generator.
- Controlling the steam flow to the main turbine controls the generator speed and/or load.

Steam Path

HP Turbine Section





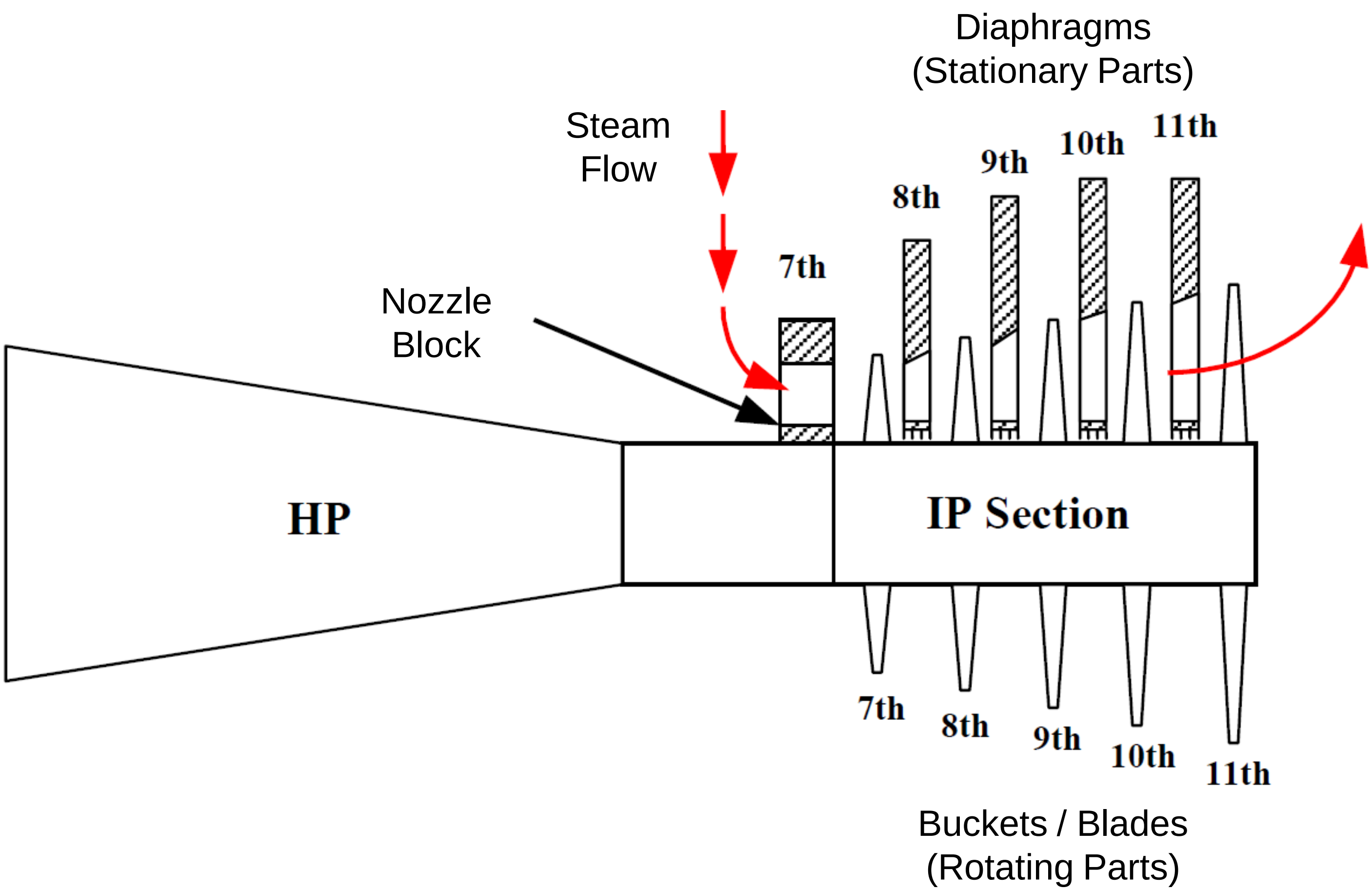
Steam Path

HP Turbine Section

- Steam enters the single-flow HP turbine through separately mounted stop valves and control valves. A steam lead from each of the control valves routes the steam to the center of the high-pressure casing. Two steam leads are connected to the upper half of the casing and two to the lower half. Steam is admitted to both casing halves allowing for uniform heating of the casing and thus minimizing distortion.
- Each control valve regulates the steam flow to one of four nozzle box-opening sections (nozzles/partitions). The nozzle boxes are located within the HP casing; thus containing the steam before it passes through the first stage nozzle openings.
- The steel alloy high pressure outer shell is supported on the front standard at the turbine end, and the middle standard at the generator end.
- The high-pressure inner shell is supported in the outer shell on four shims and is located axially by a rabbit fit. The inner shell is keyed on the upper and lower vertical centerlines to locate it transversely. This arrangement maintains accurate alignment of the inner shell under all operating conditions. The nozzle box steam inlets are equipped with slip ring expansion joints that permit the nozzle boxes to move with respect to the shells and still maintain a steam-tight fit.
- Buckets are placed in grooves machined into the rotor. Each bucket is pinned to ensure its position is fixed.
- The fixed blades are mounted in interstage diaphragms located between each stage of moving blades. The interstage diaphragms serve as nozzles to increase the velocity of the steam and to direct the steam flow onto the next stage of buckets. Each interstage diaphragm is constructed of two halves that are mounted in grooves in the upper and lower casings. When assembled in the turbine, the diaphragms are sandwiched in between the rotating wheels.
- Steam leaving the nozzle boxes is directed through the HP turbine blading, with the steam flowing toward the turbine front standard. The expanded steam exhausts through two nozzles at the bottom of the casing and is routed to the reheat section of the boiler through the cold reheat line.

Steam Path

IP Turbine Section



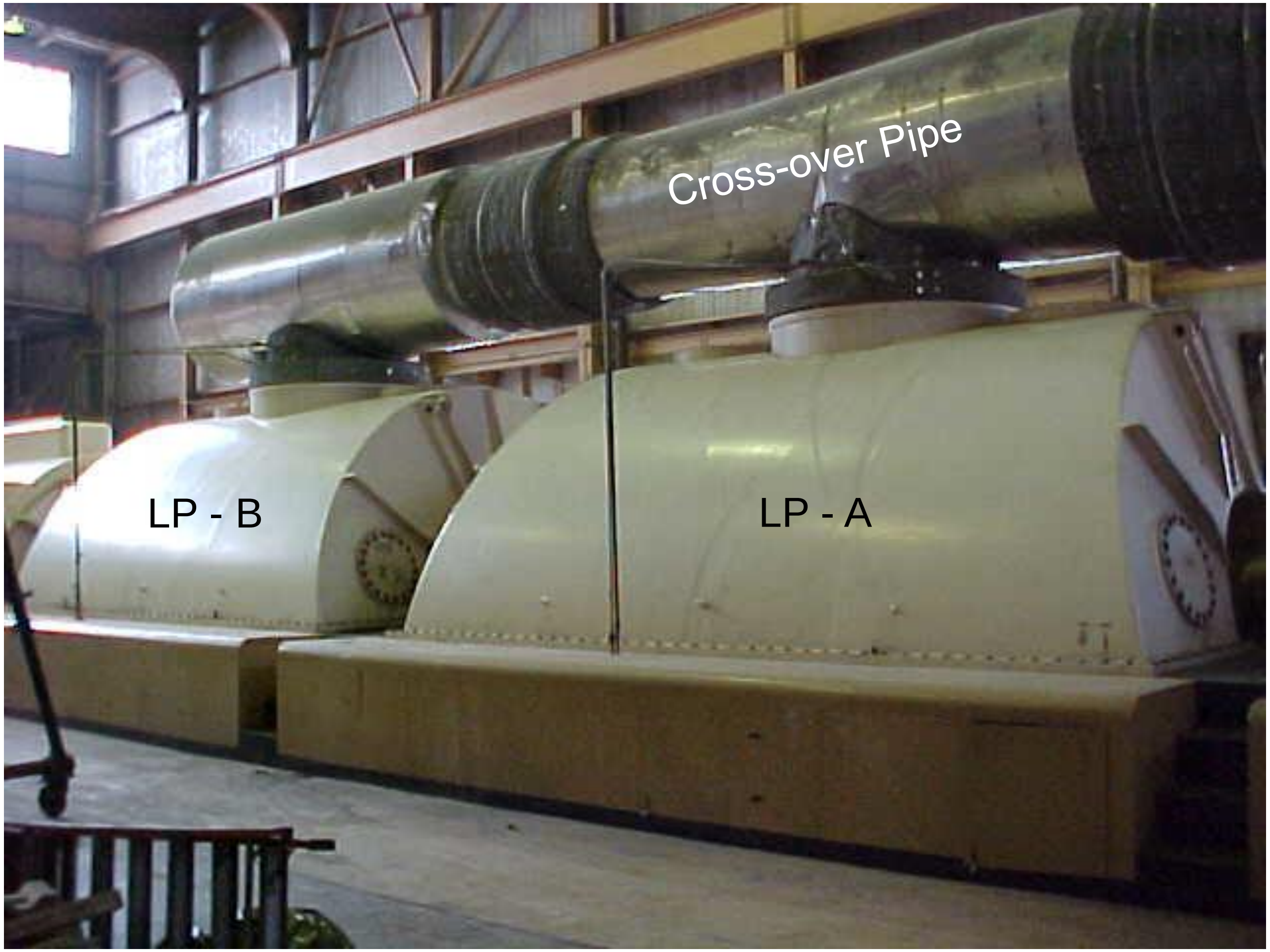
Steam Path

IP Turbine Section

- Steam is routed to the IP turbine through two parallel combined reheat intercept valves. During normal operation, the reheat stop and intercept valves are fully open.
- The outlets of the combined reheat intercept valves are welded directly to the bottom half of the HP turbine casing, near the center.
- Steam enters the IP turbine and passes through a nozzle block, which directs the steam onto the first stage of IP turbine blades. Throughout the turbine, the turbine stages are numbered sequentially beginning with the first stage of the HP turbine. Therefore, the first stage of the IP turbine is the seventh turbine stage.
- The IP turbine moving blades are attached to the common HP and IP turbine rotor. The blades are placed in grooves machined into the rotor and held in position by pinning. Interstage diaphragms are located between each stage of moving blades.
- The steam expands as it passes through each of the IP turbine stages and exhausts through a single crossover pipe in the upper casing. The crossover pipe directs the steam to the LP turbines. The steam flow through the IP turbine is toward the generator end, which is opposite to the flow in the HP turbine. By arranging the flows in the HP and IP turbines in opposite directions, the axial thrust caused by the pressure drop through the turbine stages is reduced.
- A portion of the steam flowing through the IP turbine is extracted at the 9th and 11th stages of the turbine and supplied to feedwater heaters 7-6A, 7-6B and deaerating heater No. 5 respectively. The 11th stage extraction steam is also the normal low-pressure steam supply to the boiler feed pump turbines and a source of fire protection to the mills.

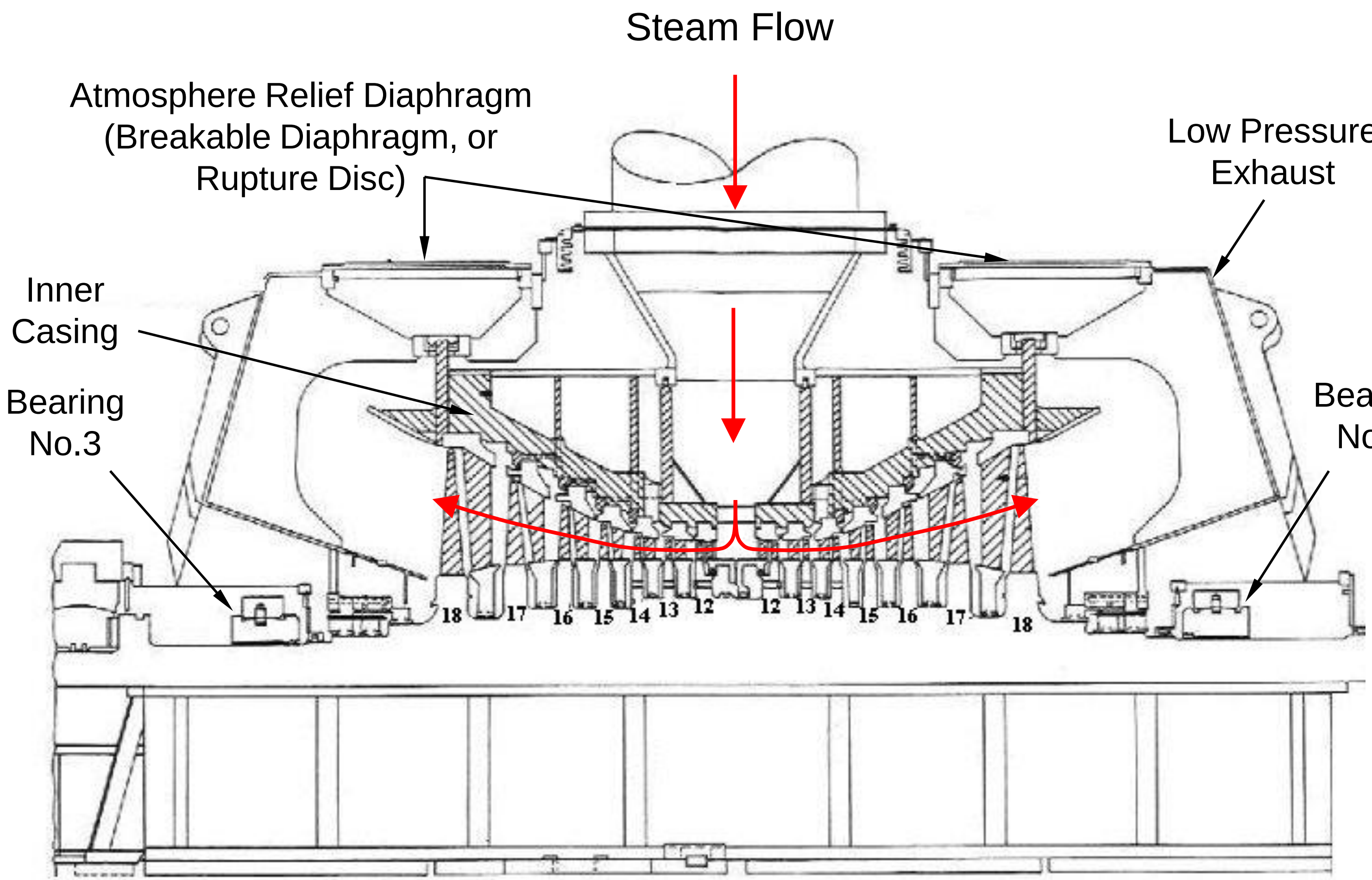
Steam Path

LP Turbine Section



Steam Path

LP Turbine “A” Section



Steam Path

LP Turbine Section

- The function of the LP turbines is to convert part of the remaining energy contained in the steam exhausted from the IP turbine to mechanical energy for rotating the generator.

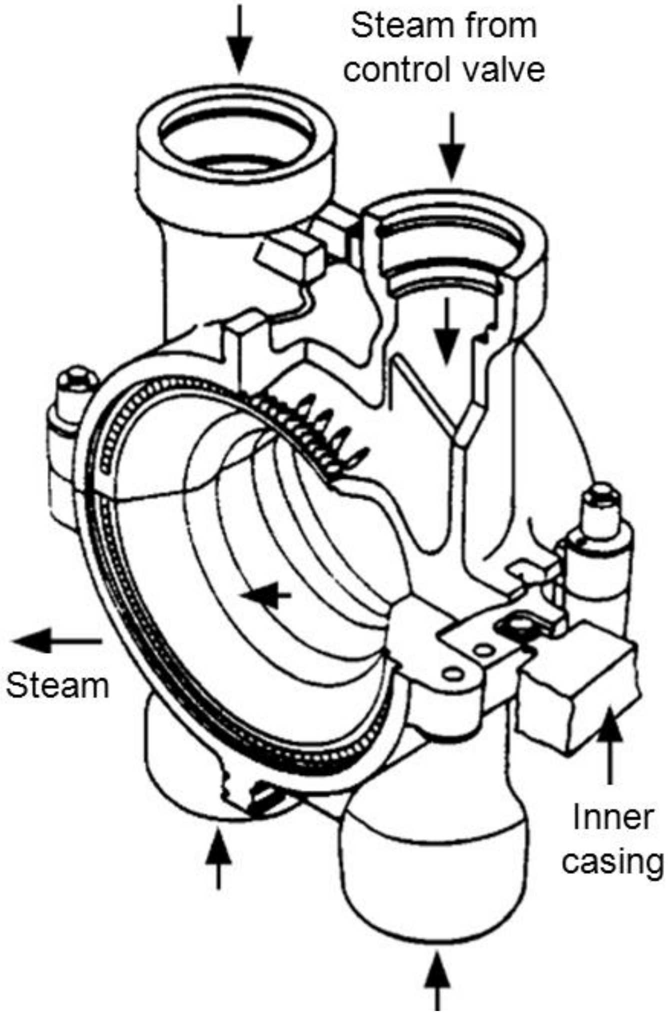
- The LP turbines are double-flow units with seven-stages. IP turbine exhaust steam flows through the crossover pipe to the LP turbines. This steam enters each LP turbine at the center of the casing. Inside the turbine, the steam flow is split, flowing across seven stages of blading to each end. The exhaust steam leaving the LP turbines is then drawn through the exhaust hood to the main condenser.

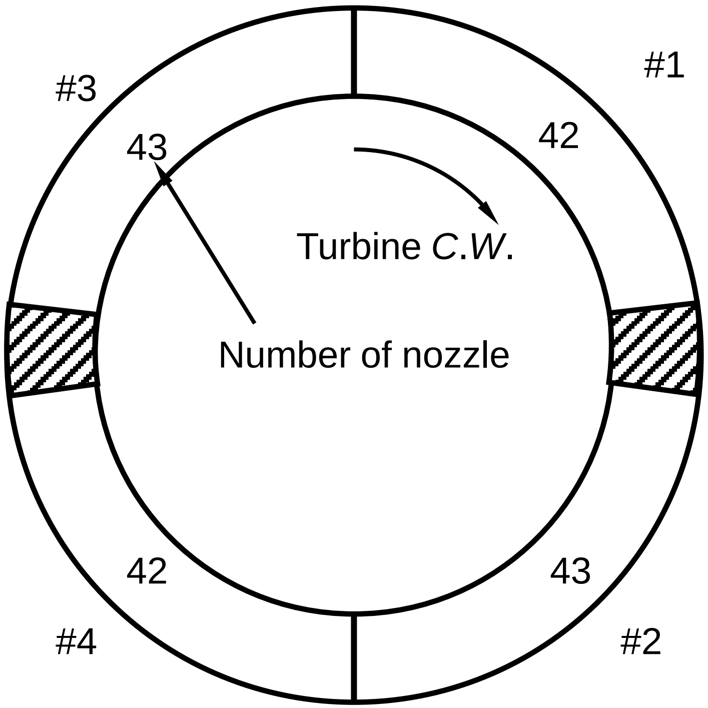
- The LP turbine casing consists of two halves, upper and lower. The casing halves are machined and bolted together to ensure a steam-tight fit. The upper half is provided with two rupture discs, which relieve to the turbine room atmosphere if the turbine exhaust pressure exceeds 5 psig. The lower casing half consists of an inner and outer casing. The inner casing is the exhaust hood. Exhaust steam enters the main condenser through this hood.

- Exhaust hood spray is required to limit exhaust hood temperatures during startup and low loads, since the steam flow through the turbine is not adequate to remove heat generated by the rotating turbine blades. The condensate system supplies water to the exhaust hood sprays.

- The LP turbine rotor is a single solid forging. The rotating blades are placed in grooves machined in the rotor. Each blade is pinned to ensure its position is fixed. The fixed blades are placed in grooves machined into the turbine casing. They are also pinned to ensure their positions are fixed.

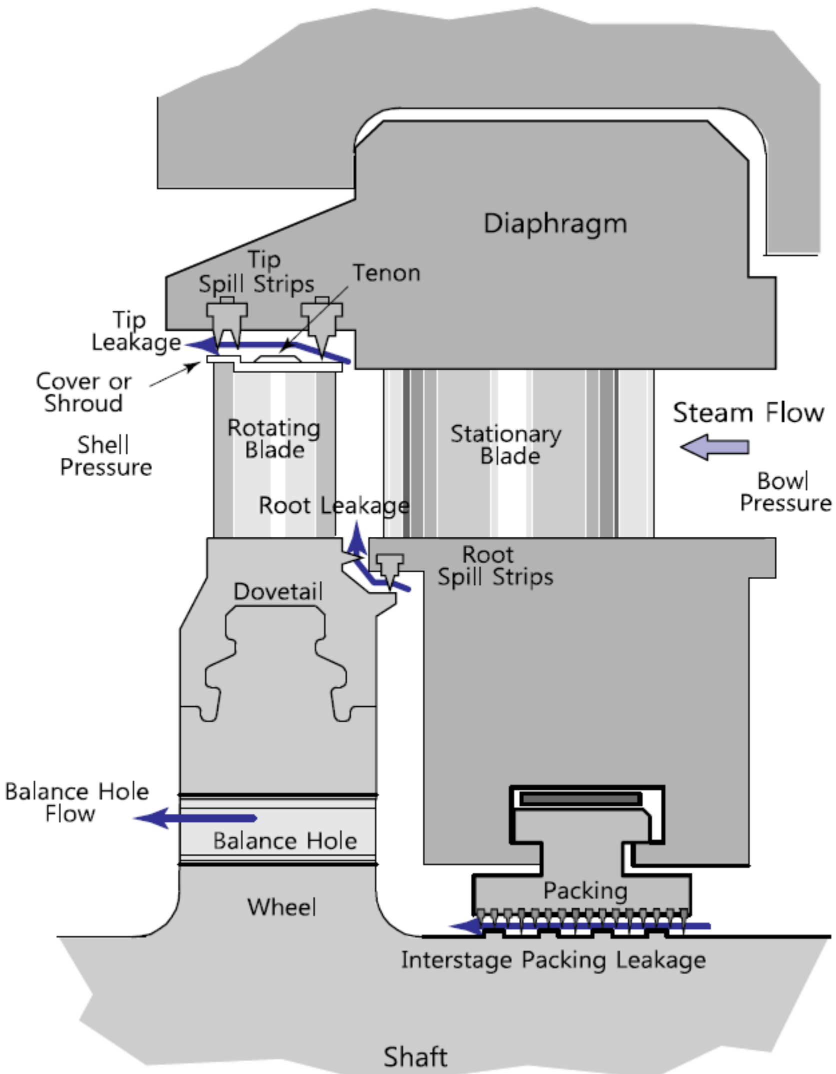
Nozzle Box





[500 MW (3,500 psig, 1,000°F)]

Stage



Stage = 1 row of nozzle + 1 row of bucket

Nozzle = Stationary blade

Bucket = Rotating blade

Bowl = Entrance of a stage

Shell = Exit of a stage

Dovetail = Rock the bucket with a rotor shaft

Seal = reduce the steam leakage

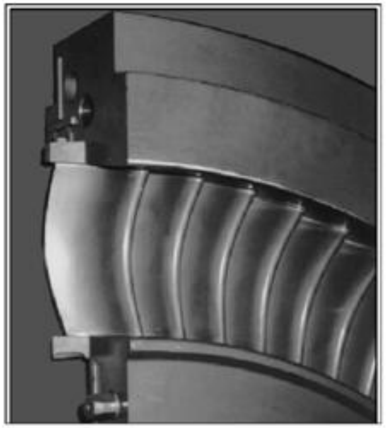
Diaphragm

Diaphragm : Partitions between two adjacent bucket rows in a turbine's casing are called diaphragms. They hold the nozzles and seals between the stages. Usually labyrinth-type seals are used. One-half of the diaphragm is fitted into the top of the casing, the other half into the bottom.

Diaphragms are fitted into the casing and contain the nozzles used to create the pressure drop and velocity increase at each stage of the turbine.

The rotor shaft passes through each diaphragm and a seal is created at each stage between the diaphragm and rotor by a labyrinth seal.

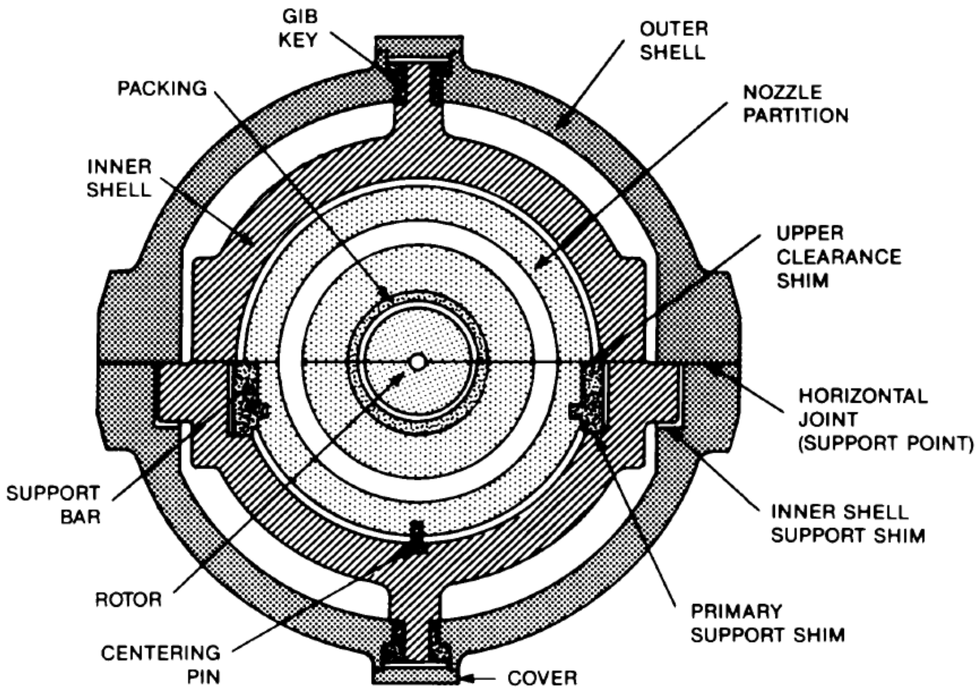
The diaphragms are supported within the casing by rugs and location keys that allow for expansion as the turbine heats and cools.

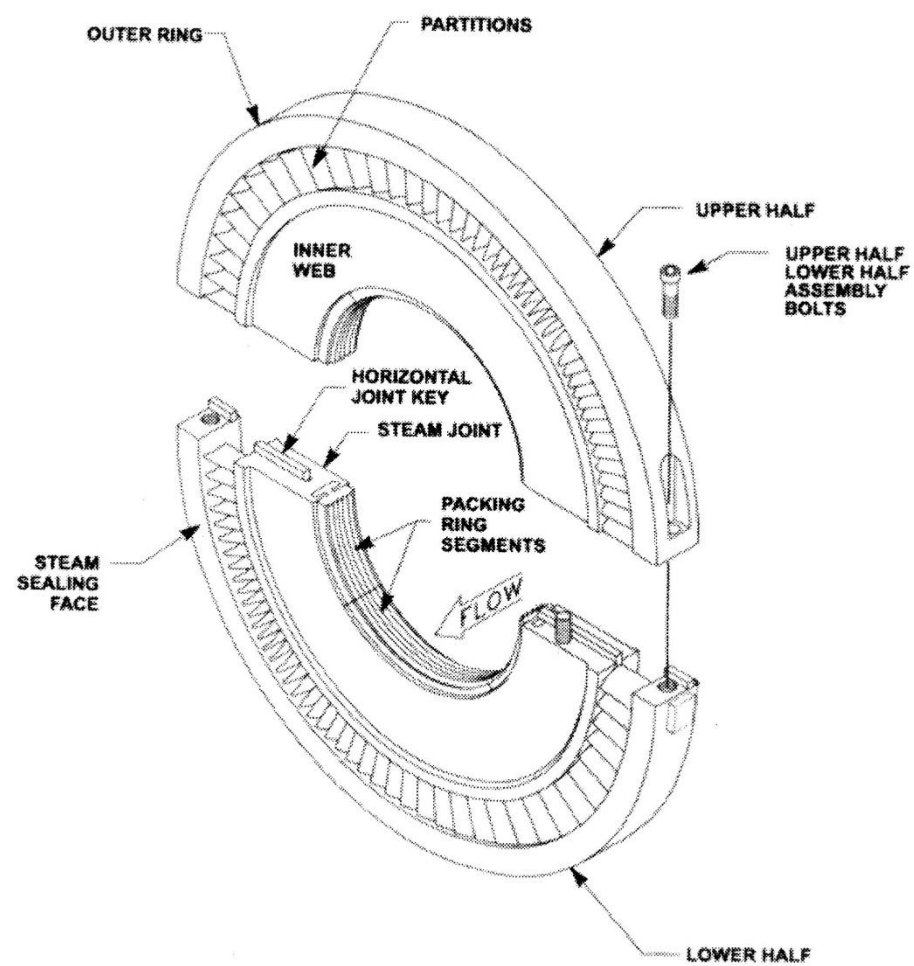


Diaphragm

다이아프램(Diaphragm)

- Inner ring과 outer ring 사이에 노즐을 조립한 하나의 열
- Outer ring은 터빈 케이싱에 조립되어 고정, inner ring은 축을 둘러싸고 있으며 labyrinth seal을 설치하여 증기누설 방지

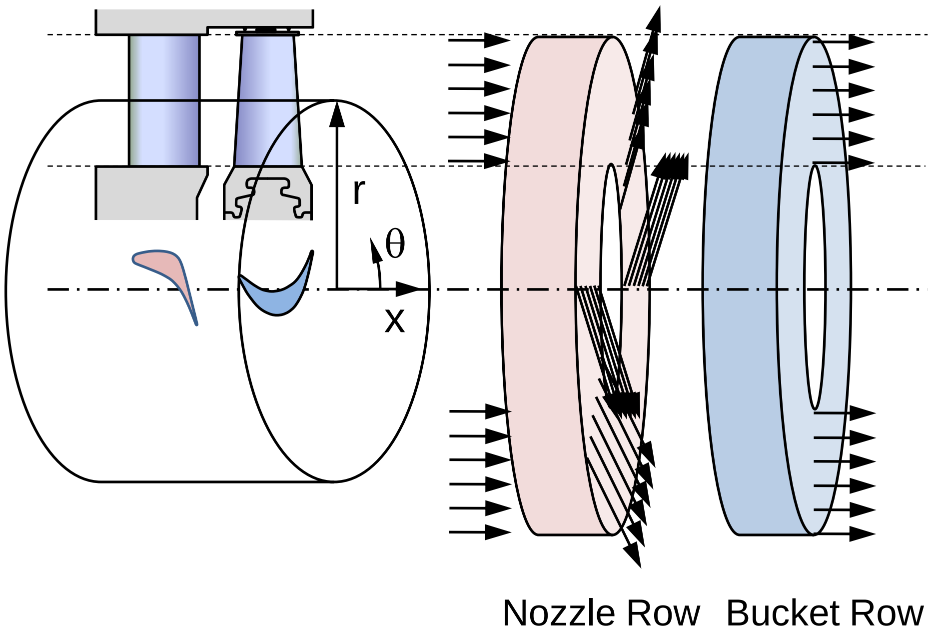


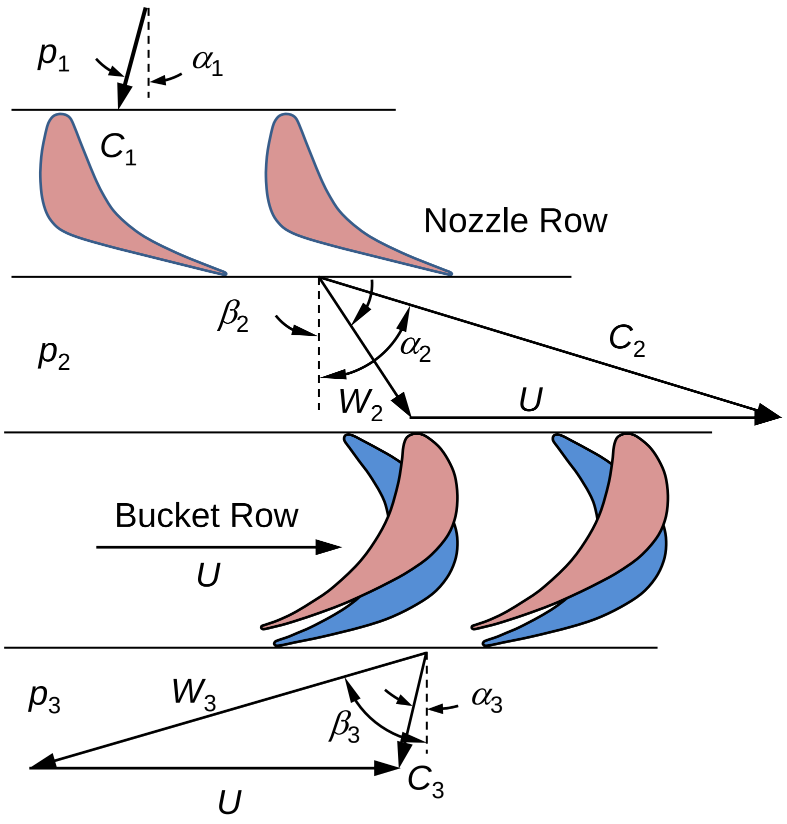


Nozzle

노즐(Nozzle)

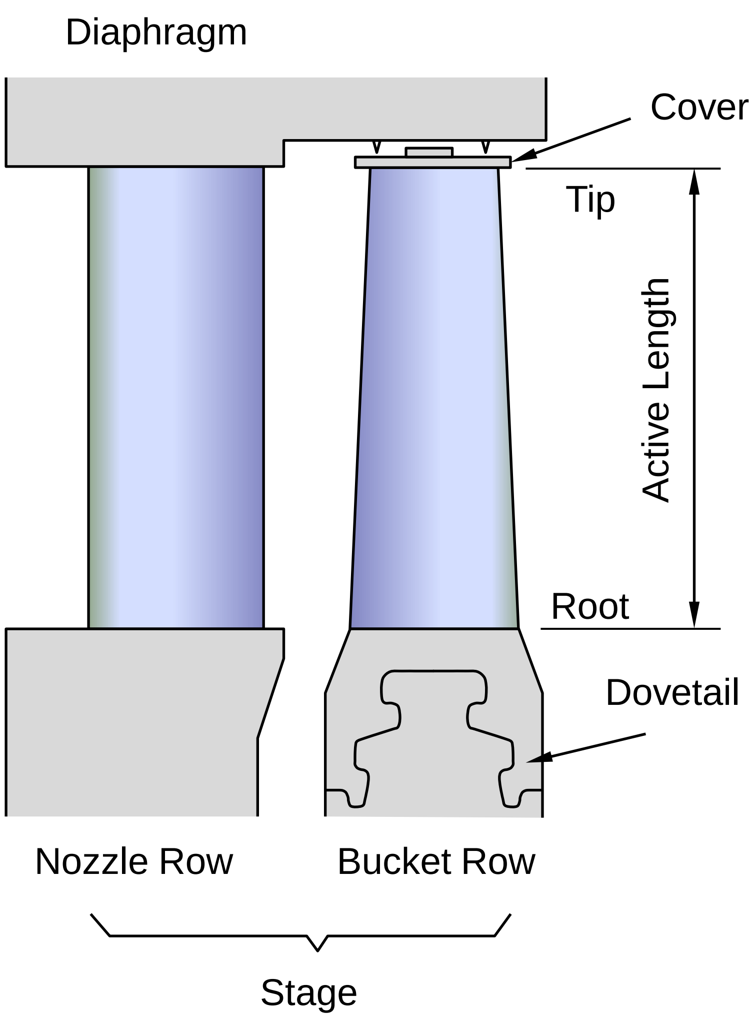
- 증기 가속을 통해 증기의 압력에너지를 운동에너지로 변환시킴
- 따라서 노즐 입구와 출구 사이에 압력 차이 발생하며, 압력 차이가 클수록 다이아프램을 튼튼하게 제작해야 함
- 노즐을 빠져나온 증기는 회전방향 운동성분이 매우 큰 운동에너지를 가짐





Bucket

Nomenclature



버켓(Bucket)

- Rotating blade를 의미
- 노즐을 빠져나온 고속의 증기에 포함되어 있는 운동에너지, 열에너지, 압력에너지를 기계적인 일로 변환
- 버켓은 로터를 회전시키며, 로터의 회전동력이 발전기를 구동하여 전기를 생산
- 발전기를 구동하기 위한 회전동력 발생

Short bucket	Long bucket
• Active length is less than 10 inches.	• Active length is longer than 10 inches. • Bucket vibration should be considered carefully. • Radial velocity component is employed in the design stage.

1. Classification by Exhaust Type

1) Condensing Steam Turbine

❖ The primary type of turbine used for central power generation is the condensing turbine.

❖ Condensing turbines exhaust steam directly to condensers that maintain vacuum condition, that is significantly below atmospheric pressure.

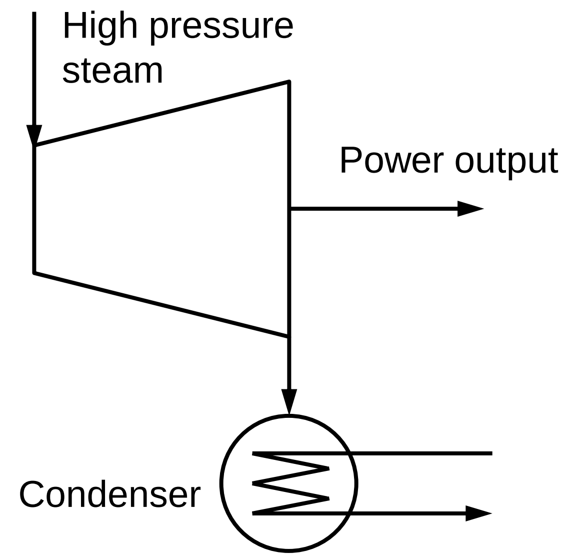
❖ An arrays of tubes, cooled by cooling water, condensates the steam into water and creates condenser vacuum.

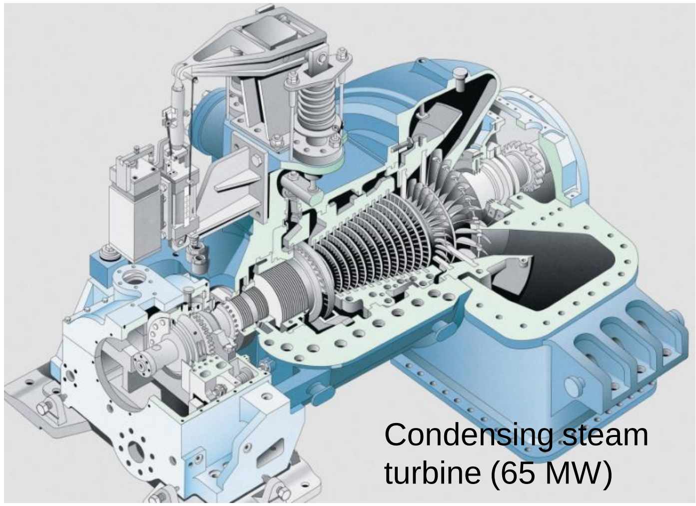
❖ As a result of condensation, the volume of the exhaust steam reduces by several order of magnitude, and since the process takes place in a closed vessel, a steady-state vacuum is created and maintained, which keeps the process and cycle going.

❖ The term 'condensing' refers to the condensing system that is attached to the unit and acts to condense the exhaust steam.

❖ The condensing turbines have large exhaust areas since the steam is expanded to low pressures, extracting as much of the useful energy as reasonably possible to being exhausted.

❖ Under the vacuum pressure, specific volume of steam is very high, thus longer blades are required at the last stage before steam goes into the condensers.





Condensing steam turbine (65 MW)

1. Classification by Exhaust Type

1) Condensing Steam Turbine

- ❖ An exhaust hood or diffuser is provided downstream last stage blade to minimize exhaust loss by reduction of the steam velocity.
- ❖ The steam exhausted into condenser has a quality of near 90%, and this is the main cause of the water droplet erosion of blades.
- ❖ The large power plants for electricity generation are this type of turbine because of maximum power output and electrical generation efficiency.
- ❖ The power output of condensing turbines is sensitive to ambient conditions.
- ❖ Condensing turbines are used for all coal-fired, oil- and gas-fired steam turbines, all nuclear steam turbines, and most of combined cycle plants.
- ❖ The size range of the condensing turbines is from as small as 5 MW, up to 1500 MW units employed in power utility.
- ❖ For combined cycle plants, the maximum size will be 200~250 MW.
- ❖ Typical condensing pressure are 0.75 in.Hga for the coldest condensing systems, up to a maximum of 10 in.Hga for air-cooled condensing system.
- ❖ As a small amount of air leaks into the system when it is below atmospheric pressure, a relatively small pump removes non-condensable gases from the condenser.

1. Classification by Exhaust Type

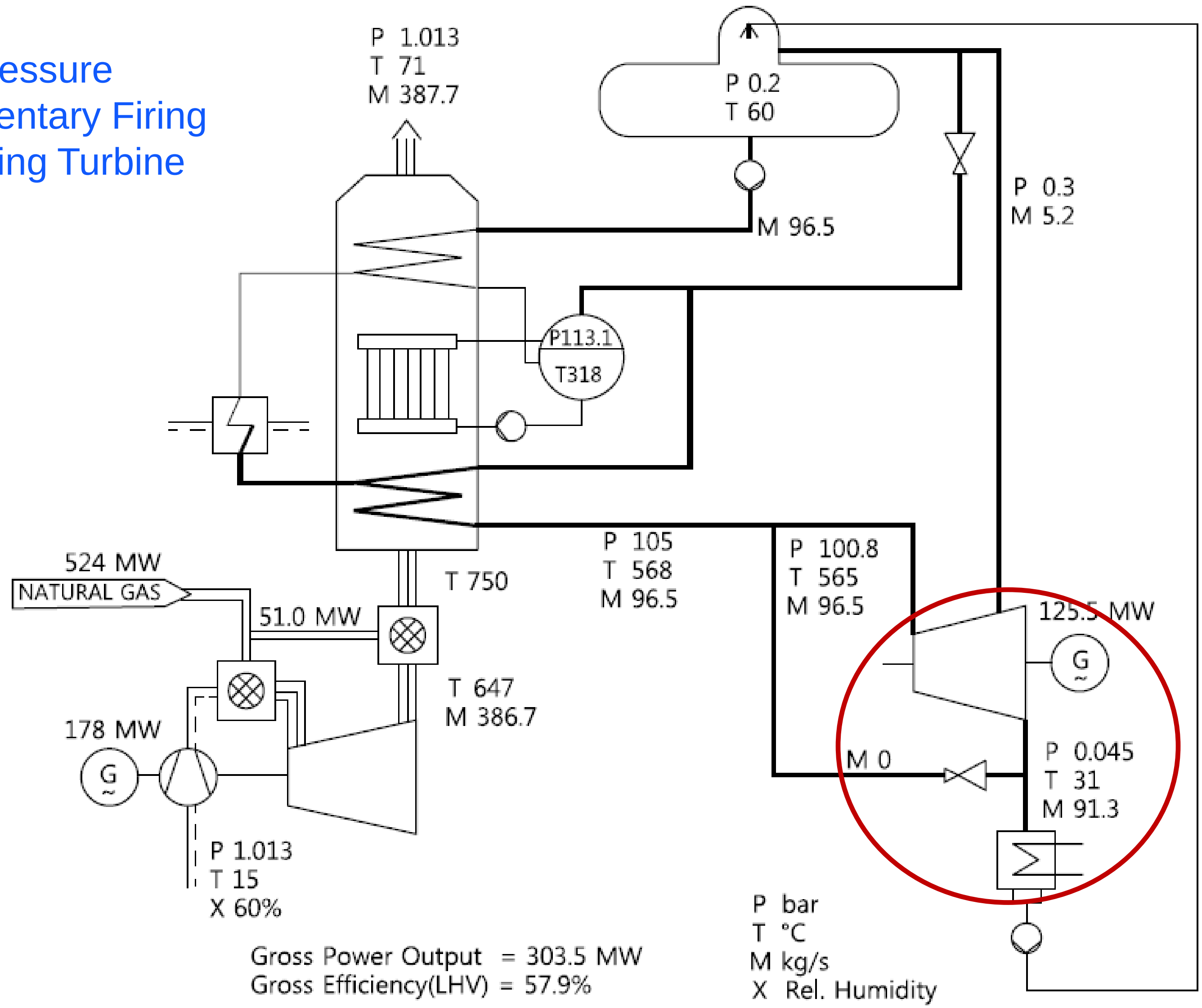
1) Condensing Steam Turbine

- Condensing turbines are used for all coal-fired, oil- and gas-fired steam turbines, all nuclear steam turbines, and most of combined cycle plants.
- The size range of the condensing turbines is from as small as 5 MW, up to 1500 MW units employed in power utility.
- For combined cycle plants, the maximum size will be 200~250 MW.
- Typical condensing pressure are 0.75 in.Hga for the coldest condensing systems, up to a maximum of 10 in.Hga for air-cooled condensing system.
- As a small amount of air leaks into the system when it is below atmospheric pressure, a relatively small pump removes non-condensable gases from the condenser.

1. Classification by Exhaust Type

Heat Balance for a Condensing Turbine

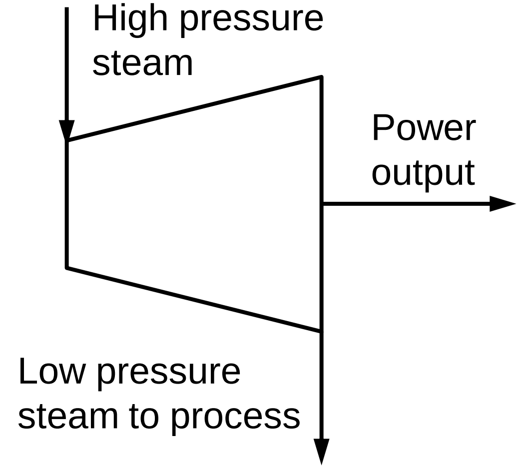
Single Pressure
Supplementary Firing
Condensing Turbine

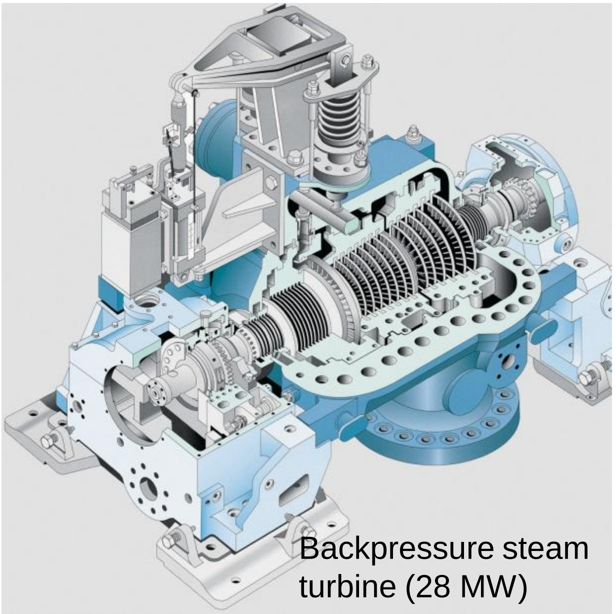


1. Classification by Exhaust Type

2) Back Pressure Steam Turbine

- The term “back-pressure” refers to turbines that exhaust steam at atmospheric pressures and above.
- At these pressure, the specific volume of the steam is relatively small, and consequently blade height and exhaust piping are also relatively small.
- Backpressure steam turbines do not have condenser, and this is the reason why the backpressure turbine is called as non-condensing turbine.
- Backpressure turbine exhausts its entire steam flow to the industrial process steam.
- Usually, the steam sent for process is not much above saturation temperature.
- Backpressure turbine has less number of turbine stage and smaller casing. Thus, it is cost effective.





Backpressure steam turbine (28 MW)

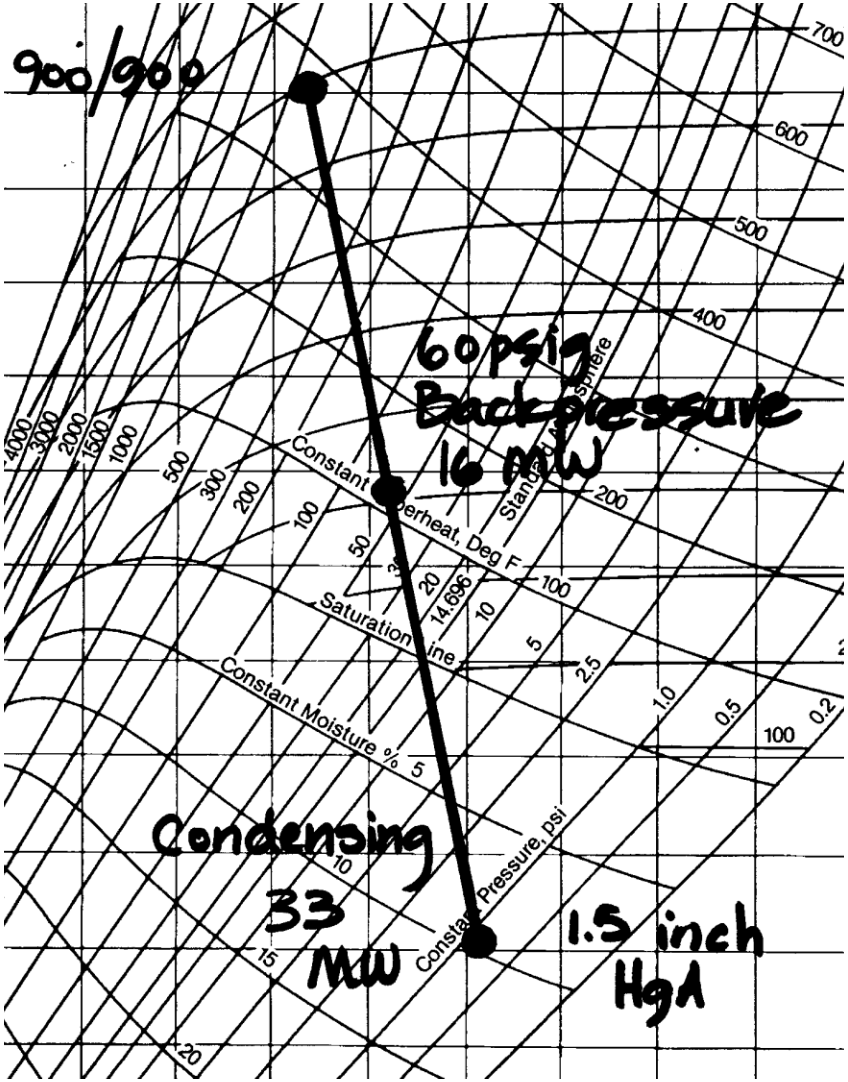
1. Classification by Exhaust Type

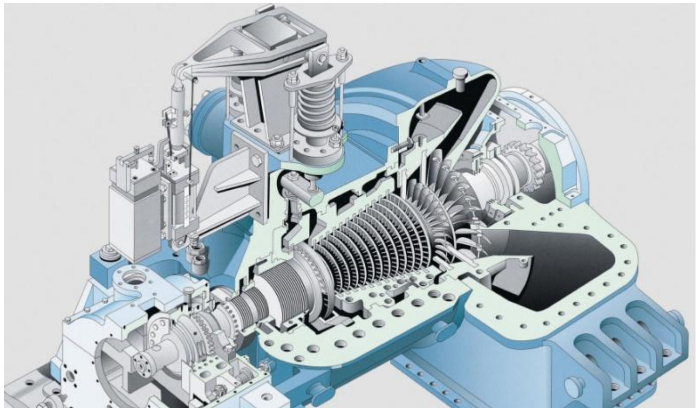
2) Back Pressure Steam Turbine

- ❖ The specific application establishes the discharge pressure, and 50, 150, and 250 psig are the most typical pressure levels.
- ❖ District heating system most often use the lower pressures, and industrial processes use the higher pressures.
- ❖ Industrial processes often include further expansion for mechanical drives, using small steam turbines for driving heavy equipment that runs continuously for long periods.
- ❖ Power generation capability reduces significantly when steam is used at appreciable pressure rather than being expanded to vacuum in a condenser.
- ❖ Discharging steam into a steam distribution system at 150 psig can sacrifice slightly more than half the power that could be generated when the inlet steam conditions are 750 psig and 800°F, typical of small steam turbine systems.
- ❖ The exhaust pressure is controlled by a regulating valve to suit the needs of the process steam pressure.
- ❖ These are commonly found at facilities where large amount of low pressure process steam is needed.

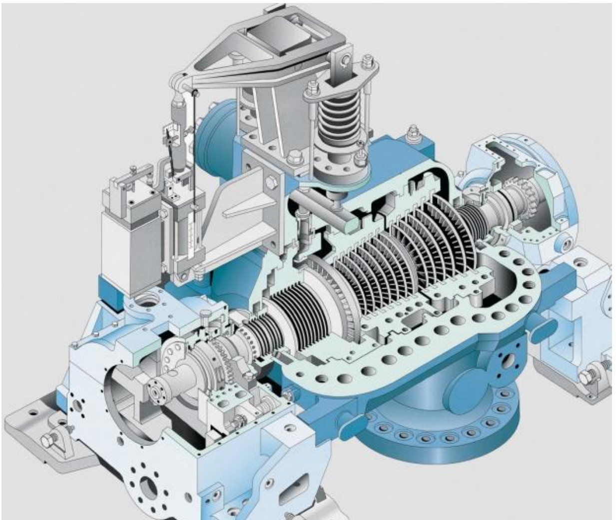
1. Classification by Exhaust Type

Condensing vs. Backpressure Turbine





Condensing steam turbine (65 MW)

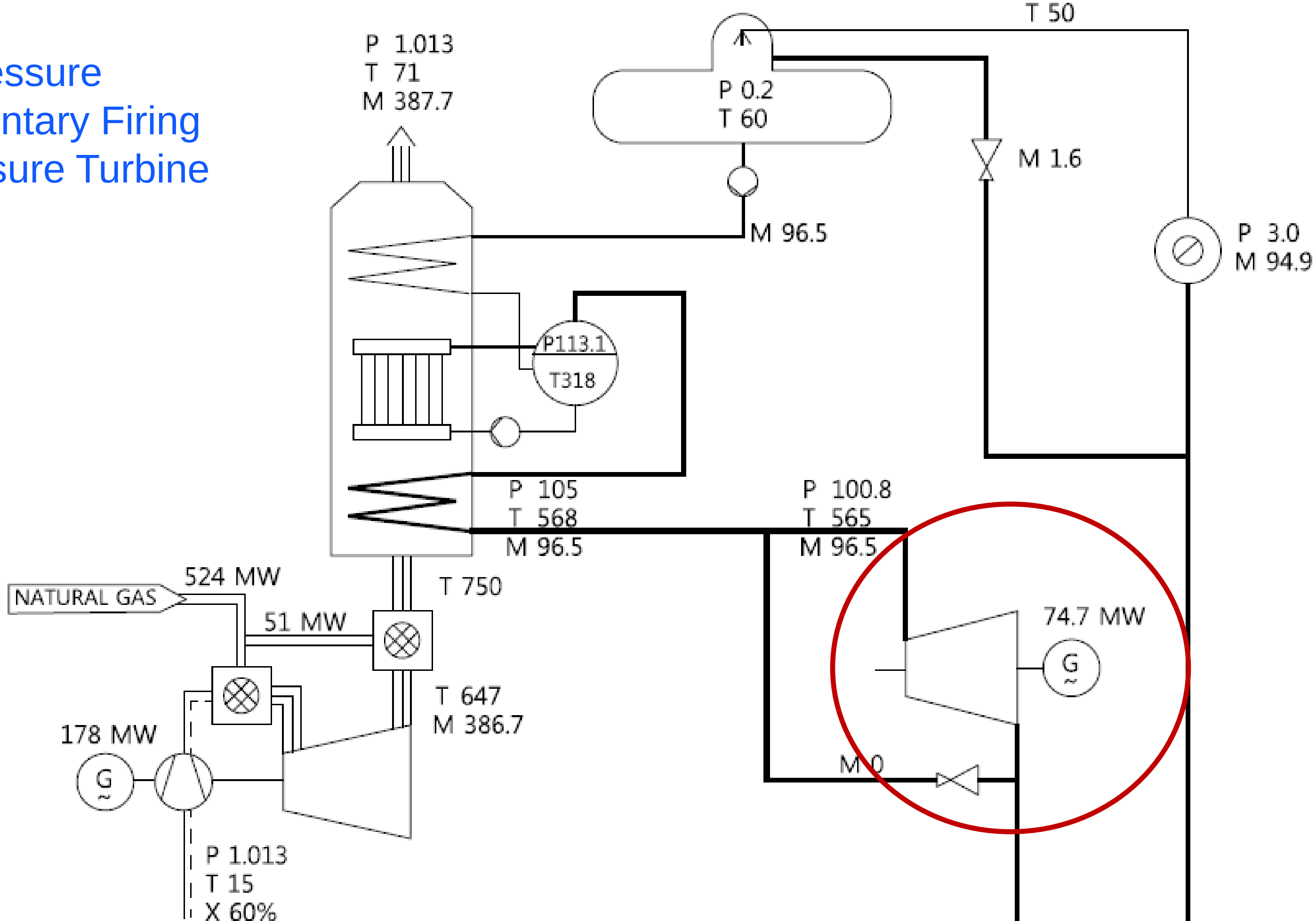


Backpressure steam turbine (28 MW)

1. Classification by Exhaust Type

Heat Balance for a Backpressure Turbine

Single Pressure
Supplementary Firing
Backpressure Turbine

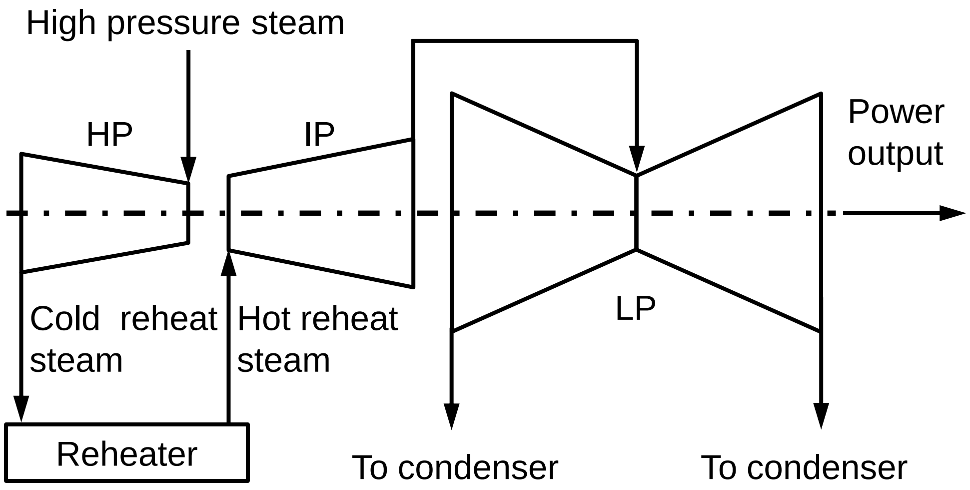


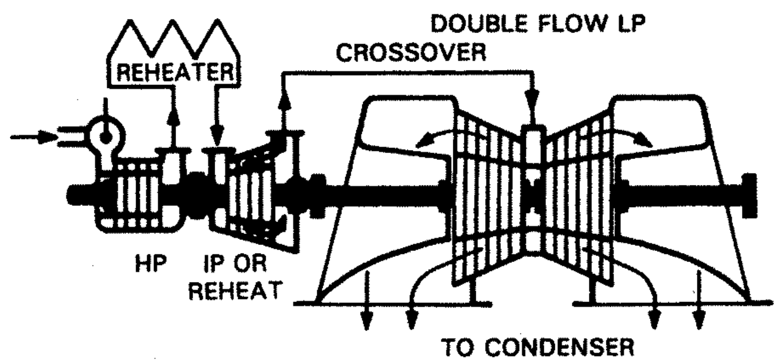
Gross Electrical Output =252.7 MW
Gross Electrical Efficiency(LHV) =48.3 %
Process Energy =239.7 MJ/s
Gross Fuel Utilization(LHV) =93.9 %

P bar
T °C
M kg/s
X Rel. Humidity

2. Classification by Cycle

1) Reheat Turbine [1/4]





(D) SINGLE REHEAT CYCLE

❖ Reheat turbines are special condensing units applied to large, high pressure power plants.

❖ Reheat is becoming common for the large combined cycle power plants, where inlet pressures and temperatures are rising to those commonly found in traditional fossil power plants.

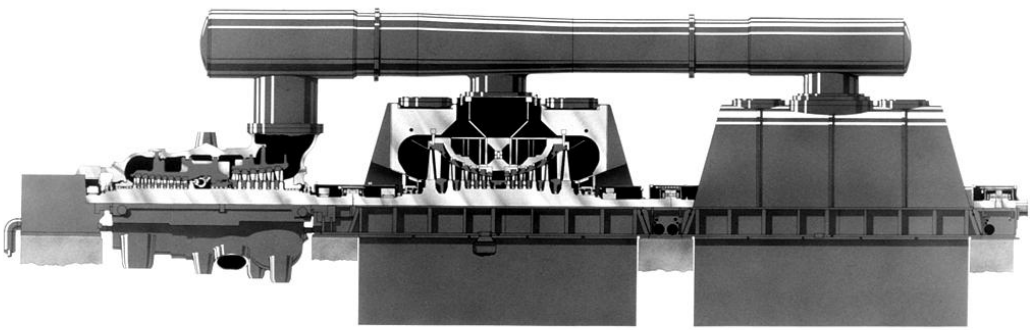
2. Classification by Cycle

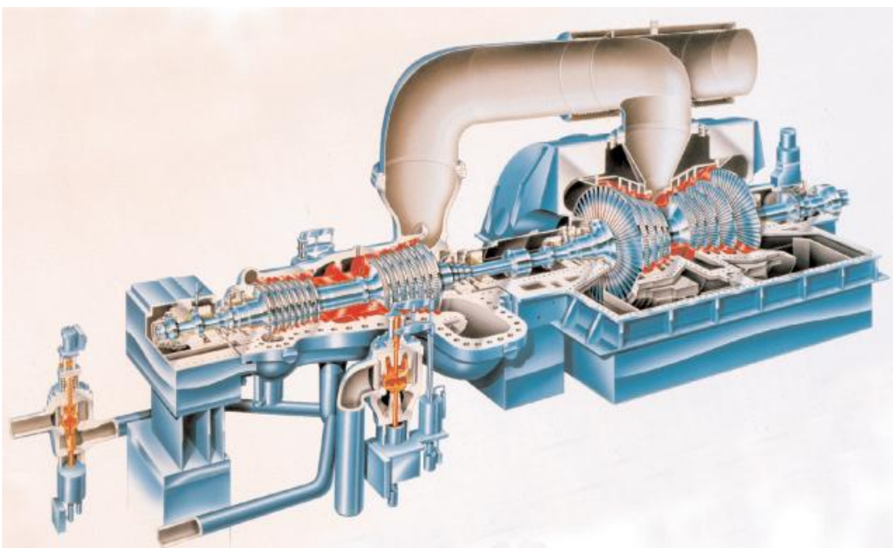
1) Reheat Turbine [2/4]

- ❖ In the reheat turbine, all the steam expanded through the high pressure turbine is removed from the unit, and taken as cold-reheat to the reheater of a boiler or HRSG for reheating.
- ❖ Usually, cold-reheat steam is reheated back to the original inlet steam temperature, and admitted back into the IP turbine as hot-reheat steam, at the same temperature as the inlet although at a lower pressure.
- ❖ Reheat turbines maintain acceptable levels of wetness in the LP turbine, while the increased length of steam expansion line results in increased power and efficiency although it requires a significant increase in equipment cost.
- ❖ The reheat steam flows to the IP turbine or reheat turbine where it expands and exhausts into a crossover pipe that supplies the steam to the LP turbine.
- ❖ The steam expands through the LP turbine and exhausts to a condenser.
- ❖ Thus, the single reheat cycle has HP, IP, LP turbines.
- ❖ It requires reheat stop valve and intercept valve to control the unit during startup and transients.

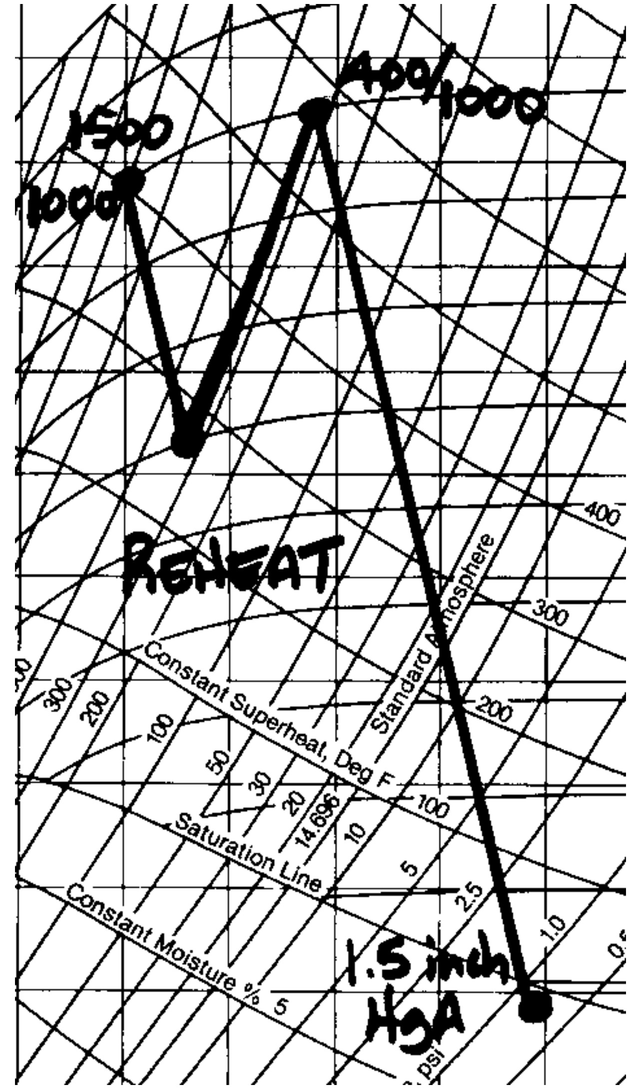
2. Classification by Cycle

1) Reheat Turbine [3/4]



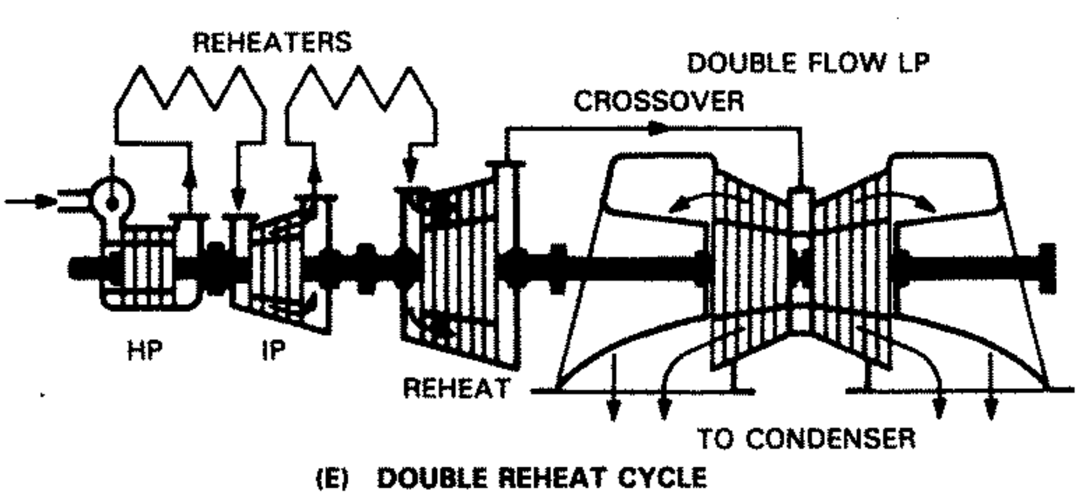


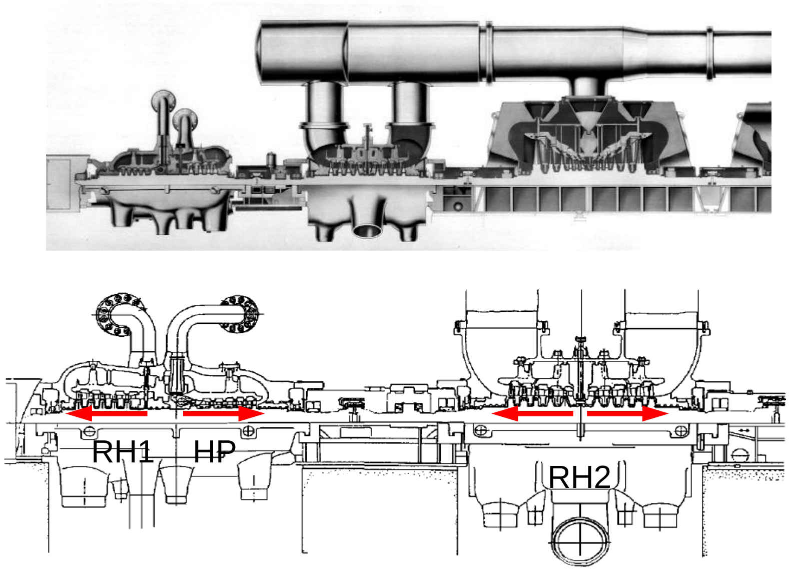
GE D11 reheat steam turbine
for combined cycle application



2. Classification by Cycle

1) Reheat Turbine [4/4]



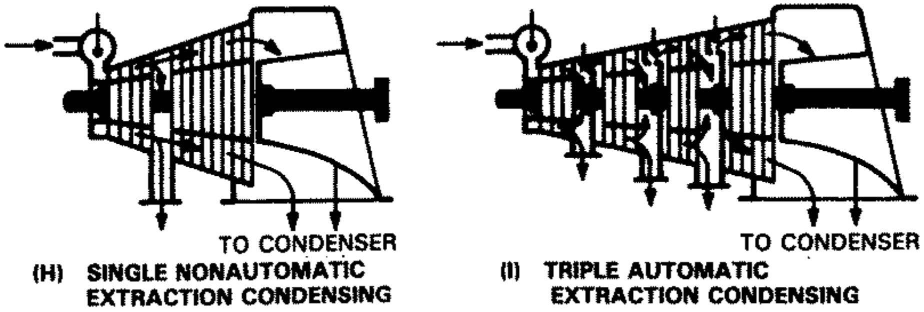


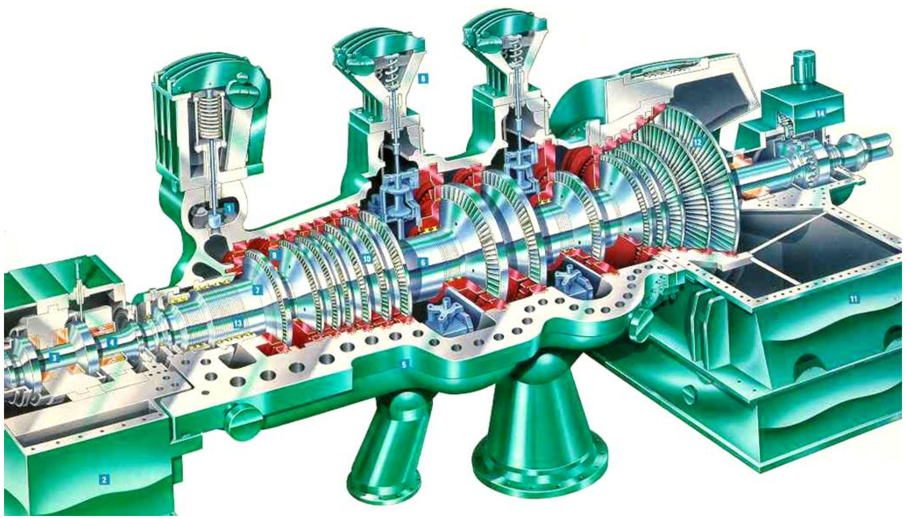
- ❖ In a double reheat cycle, the steam from the boiler flows to the HP turbine where it expands and is exhausted back to the boiler for reheating.
- ❖ The reheat steam flows to the IP turbine or the first reheat turbine where it expands and is exhausted back to the boiler again for reheating.
- ❖ The second stage of reheated steam flows to the IP turbine or the second reheat turbine where it expands and exhausts into a crossover pipe that supplies the steam to the LP turbine.
- ❖ The steam expands through the LP turbine and exhausts to a condenser.

2. Classification by Cycle

2) Extraction Turbine

- The extraction turbine has opening(s) it its casing for extraction of a portion of the steam at some intermediate pressure before condensing the remaining steam.
- The term extraction means that the removing steam from an intermediate stage of the turbine during the expansion of the steam through a turbine,
- In most power plants, some steam is extracted from the turbine expansion process and supplied to heat exchangers for feedwater heating.
- In this case, the turbine is also called as a regeneration turbine.
- This type of extraction varies in pressure and flow as a function of load.
- This variation is acceptable and therefore no effect is made to regulate the pressure.
- This type of extraction called uncontrolled, or non-automatic extraction.

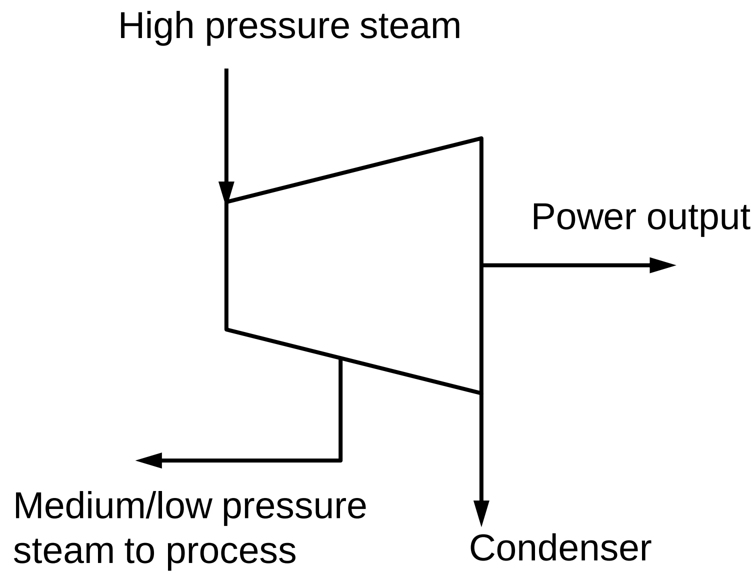




2. Classification by Cycle

2) Extraction Turbine

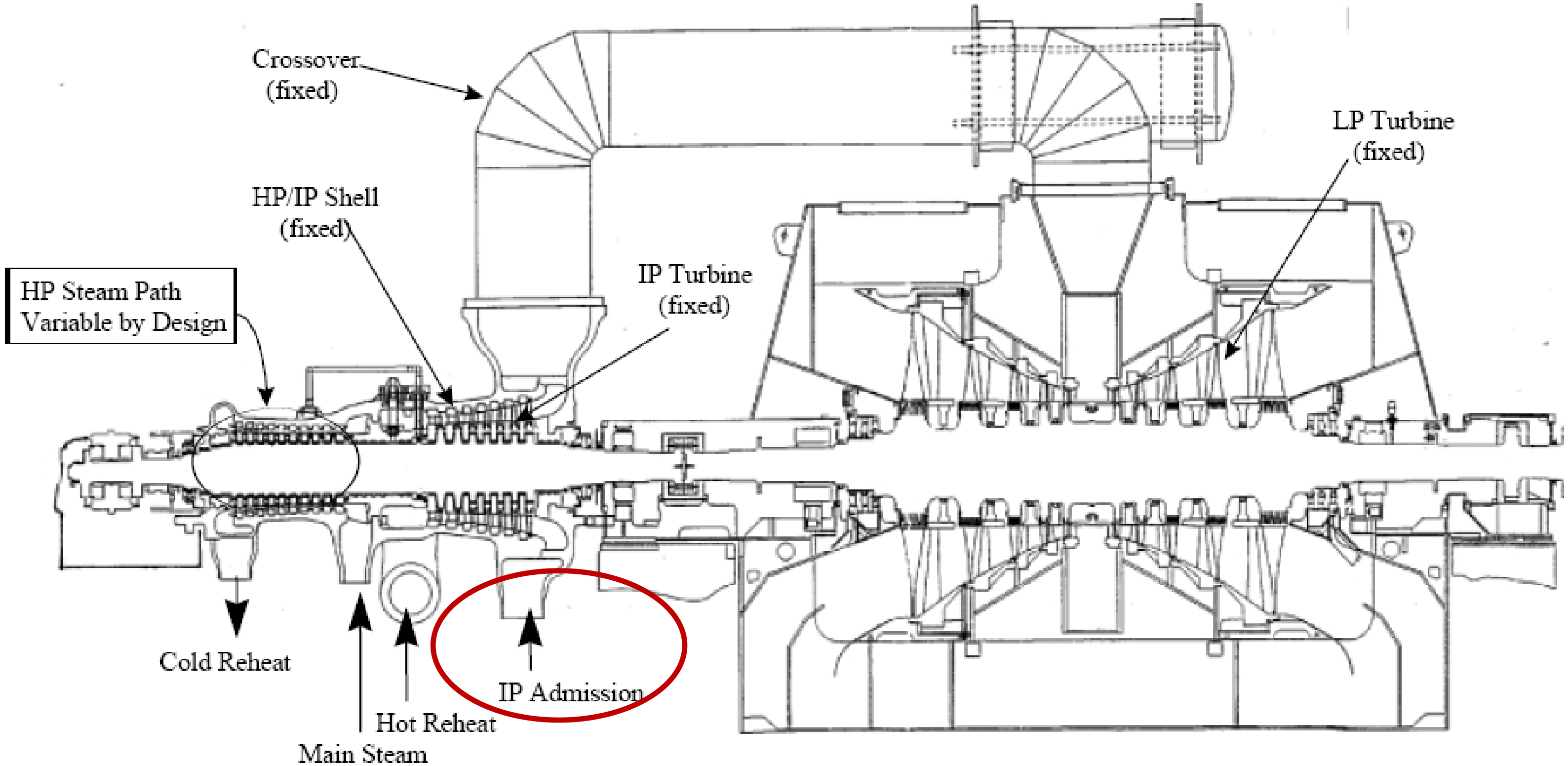
- ❖ The steam extraction pressure may or may not be automatically regulated.
- ❖ Turbines supplying steam for process applications typically must supply steam at a constant pressure.
- ❖ Since the steam pressure varies with load unless controlled, valve is included in the turbine steam expansion path to control the pressure.
- ❖ This valve restricts the flow to the downstream stages as required to maintain the pressure of the extraction stage.
- ❖ This type of turbine is called a controlled or automatic extraction turbine.



- ❖ If several controlled extraction points are required in any one turbine, multiple internal control valves are provided.
- ❖ Regulated extraction permits more steam to flow through the turbine to generate additional electricity during periods of low thermal demand by the CHP system.

2. Classification by Cycle

3) Admission Turbine



- ❖ In large, often complex, industrial plants, additional steam at intermediate pressures may be admitted (flows into the casing and increases the flow in the steam path) to the steam turbine for additional power generation.
- ❖ Often this happens when using multiple boilers at different pressure, because of their historical existence. These steam turbines are referred to as admission turbines.

2. Classification by Cycle

3) Admission Turbine

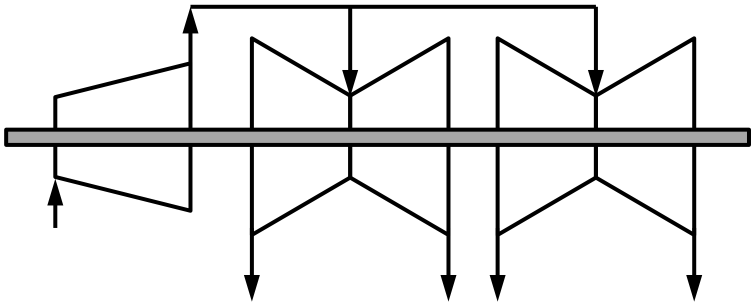
GEA18786 (June/2011)

207D-17 Steam Turbine

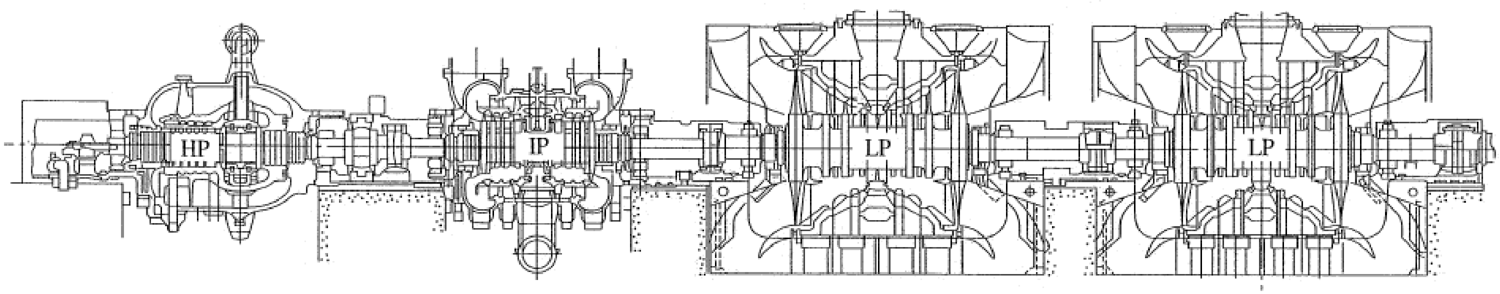
109D-14 Steam Turbine

3. Classification by Rotor Arrangement

1) Tandem-Compound Turbine



[Tandem-compound]

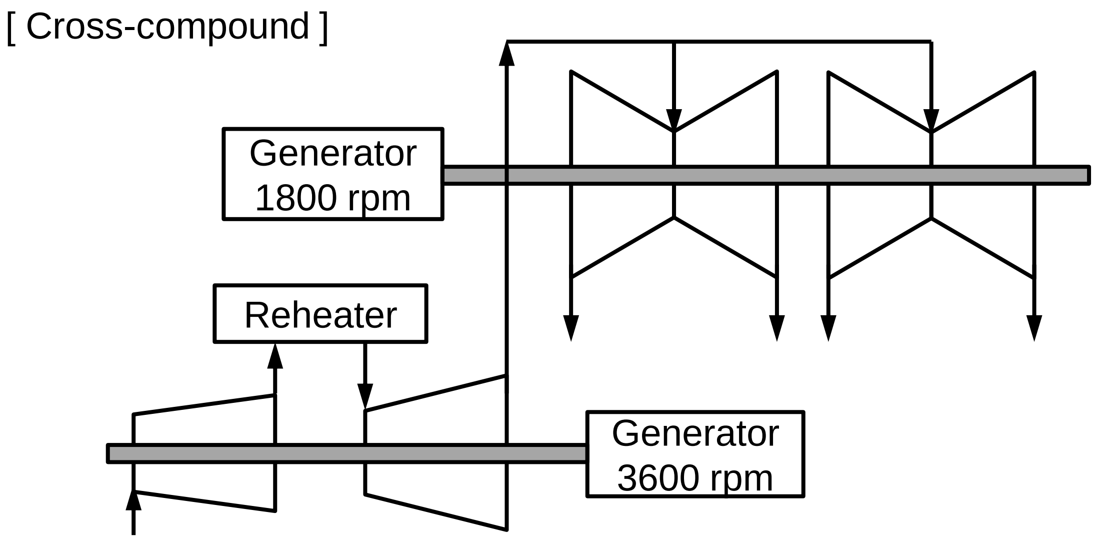


Sectional Arrangement of TC4F-40 1,000 MW Steam Turbine for 60 Hz Use

- ❖ The tandem-compound unit has all turbines and generator in-line, connected to the same shaft.
- ❖ All turbines drive the same generator and thus operate at the same speed.
- ❖ Units typically are tandem-compound because the cross-compound arrangement cannot be justified economically.
- ❖ The cost of the cross-compound units is significantly higher than tandem-compound unit because of the need for separate generators and larger foundations.

3. Classification by Rotor Arrangement

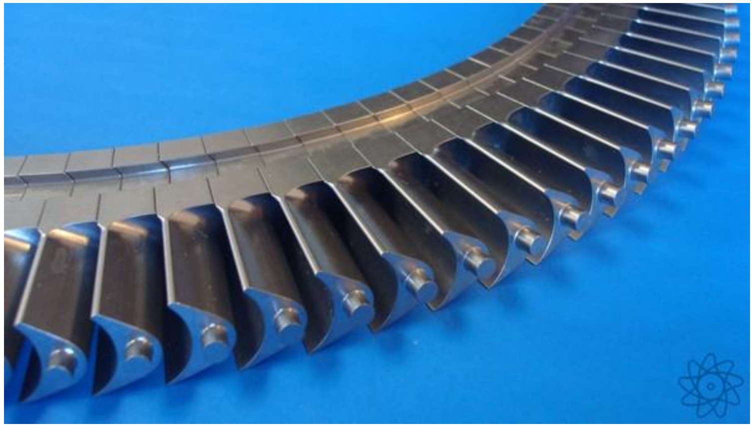
2) Cross-Compound Turbine



- ❖ The cross-compound unit has two turbine generator alignments.
- ❖ This type of arrangement is used to increase turbine efficiency.
- ❖ The cross-compound arrangement typically consists of HP and IP turbines operating at 3600 rpm driving a generator.
- ❖ The exhaust steam of the IP turbine crosses over to a LP turbine that operates at 1800 rpm, driving a separate generator.
- ❖ The LP turbine operating at the slower speed allows the use of longer LSBs with expansion to higher moisture percentages and less exhaust losses.

4. Classification by Blade Type

Impulse Type vs. Reaction Type



[Impulse Turbine, ξ = 0%]

[Reaction Turbine , ξ = 50%]

$$\xi = \frac{\text{enthalpy change in the rotor}}{\text{enthalpy change in the stage}} \times 100\ (\%)$$

$$\xi = \frac{h_2 - h_3}{h_1 - h_3} \times 100(\%)$$

$$\xi = \frac{T_2 - T_3}{T_1 - T_3} \times 100(\%)$$

$$\xi = \frac{p_2 - p_3}{p_1 - p_3} \times 100(\%)$$

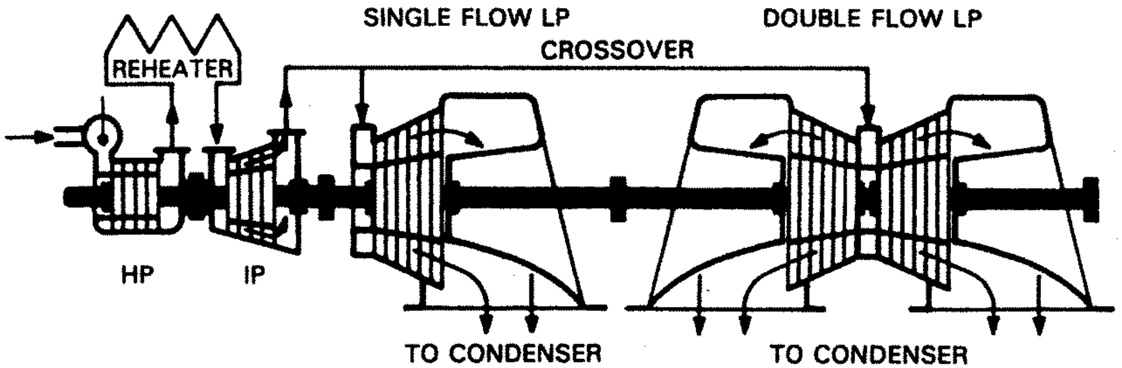
$$\delta q = dh - \frac{dp}{\rho}$$

Thermodynamic process occurred in compressor and turbine is adiabatic process. And ignoring density changes.

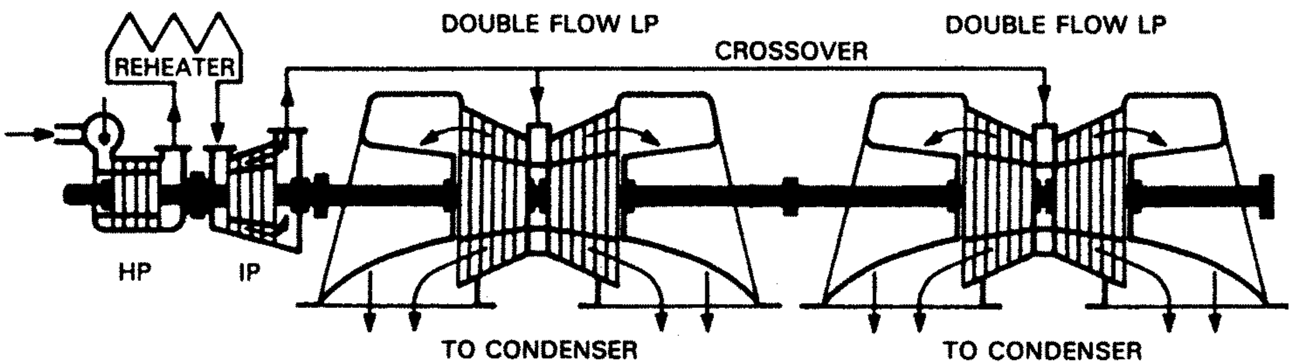
$$dh \propto dp$$

5. Classification by Flow Designation

- The turbine can be classified by the number of directions steam flows to exhaust from the turbine.
- The number of directions (paths) required depends on the amount of steam and specific volume of the steam.
- Double-flow turbines have two steam flow paths.
- The steam enters the center of the turbine and flow in two opposite directions, thus this type of turbine is also called an opposed-flow turbine.



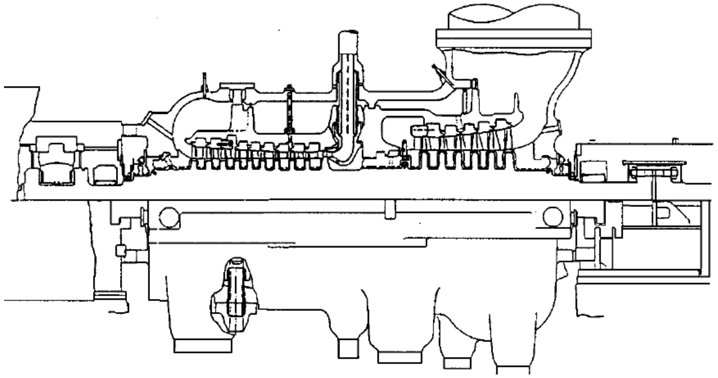
(F) TRIPLE FLOW LOW-PRESSURE TURBINE CYCLE



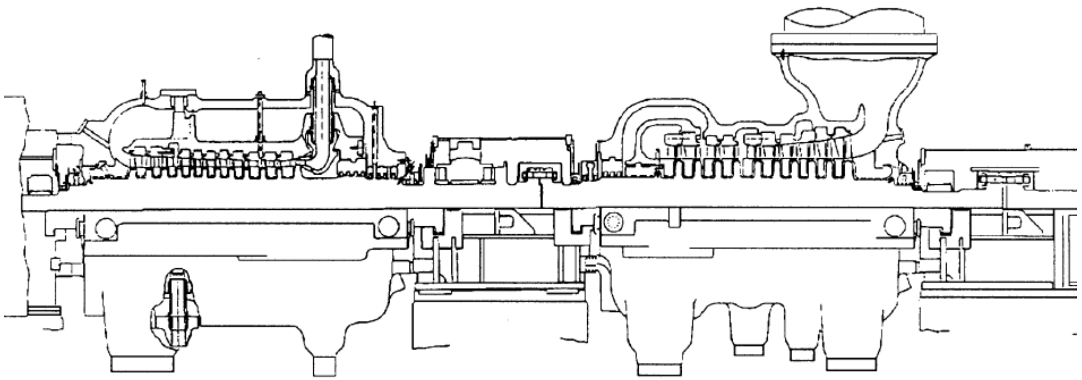
(G) FOUR FLOW LOW-PRESSURE TURBINE CYCLE

Flow Designation

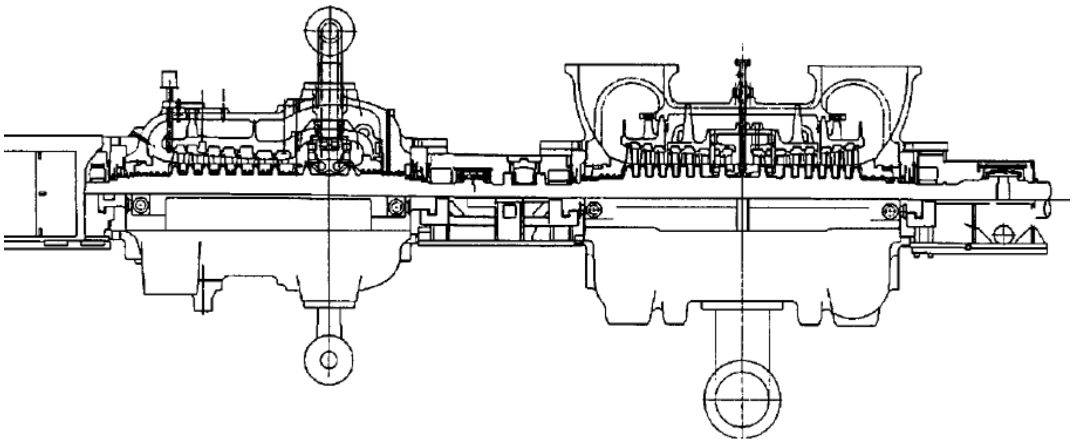
HP/IP Steam Turbine Arrangement



Combined opposed-flow HP/IP



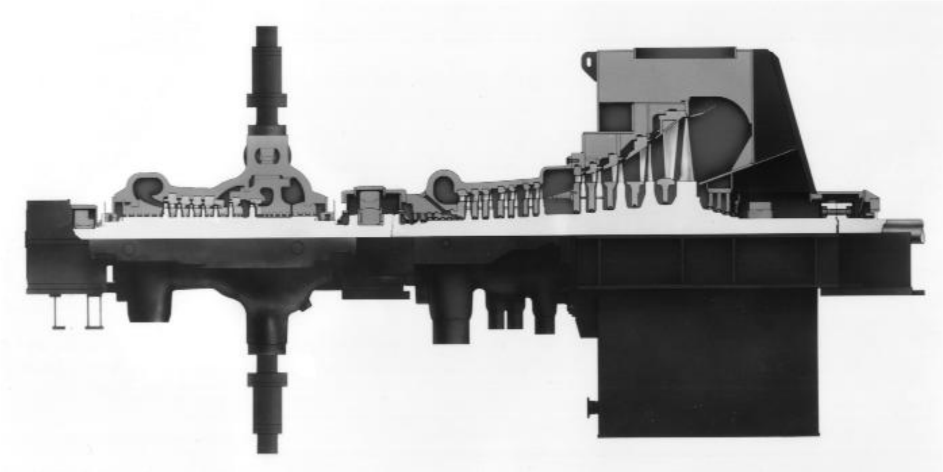
Separate HP and IP



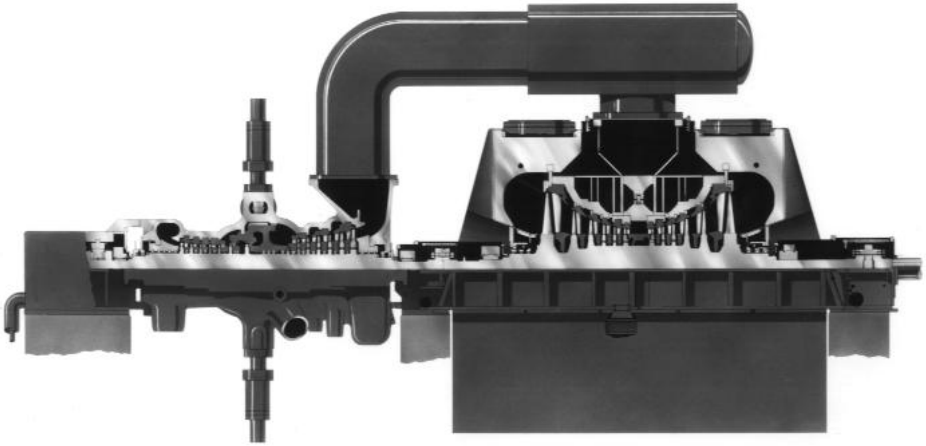
Separate HP and double-flow IP

Flow Designation

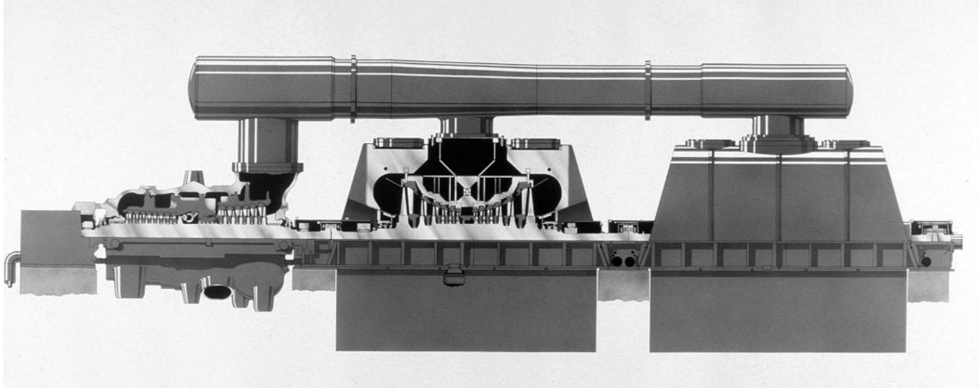
Steam Turbine Arrangement



Two-casing, single-flow ST



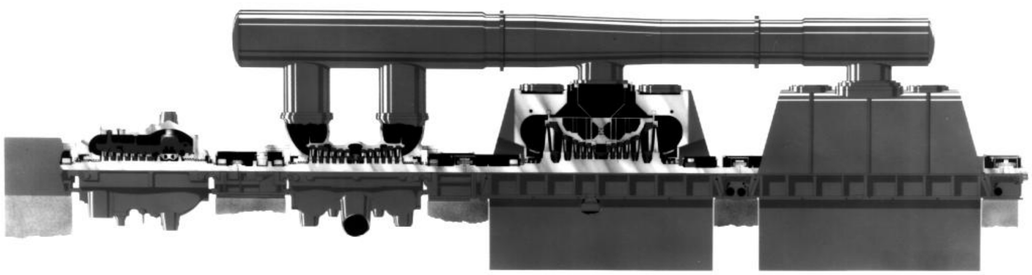
Two-casing, double-flow ST



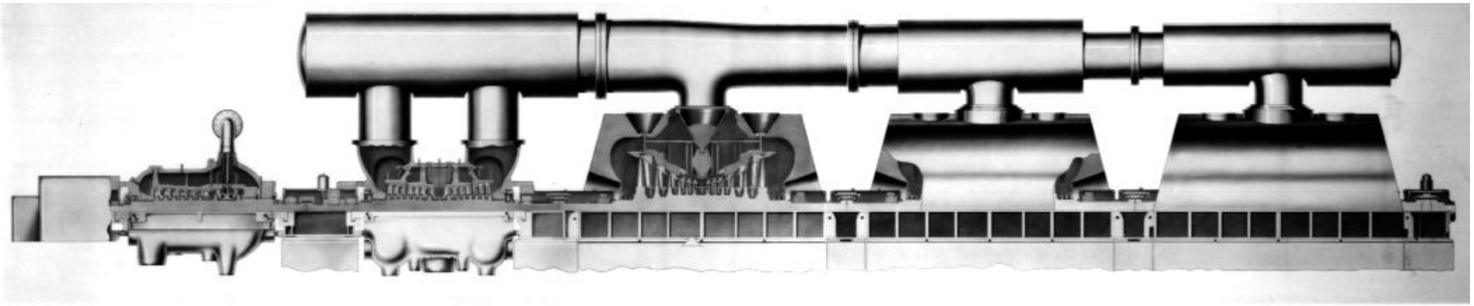
Thee-casing, 4-flow ST

Flow Designation

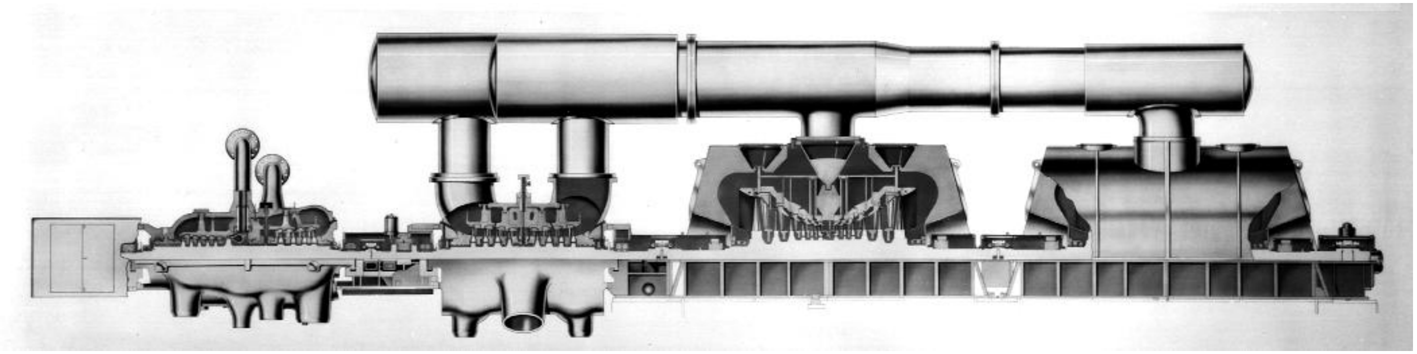
Steam Turbine Arrangement



Four-casing, 4-flow ST



Five-casing,
6-flow ST



Four-casing, 4-flow ST,
double reheat ST

Flow Designation

Typical Steam Turbine Arrangement

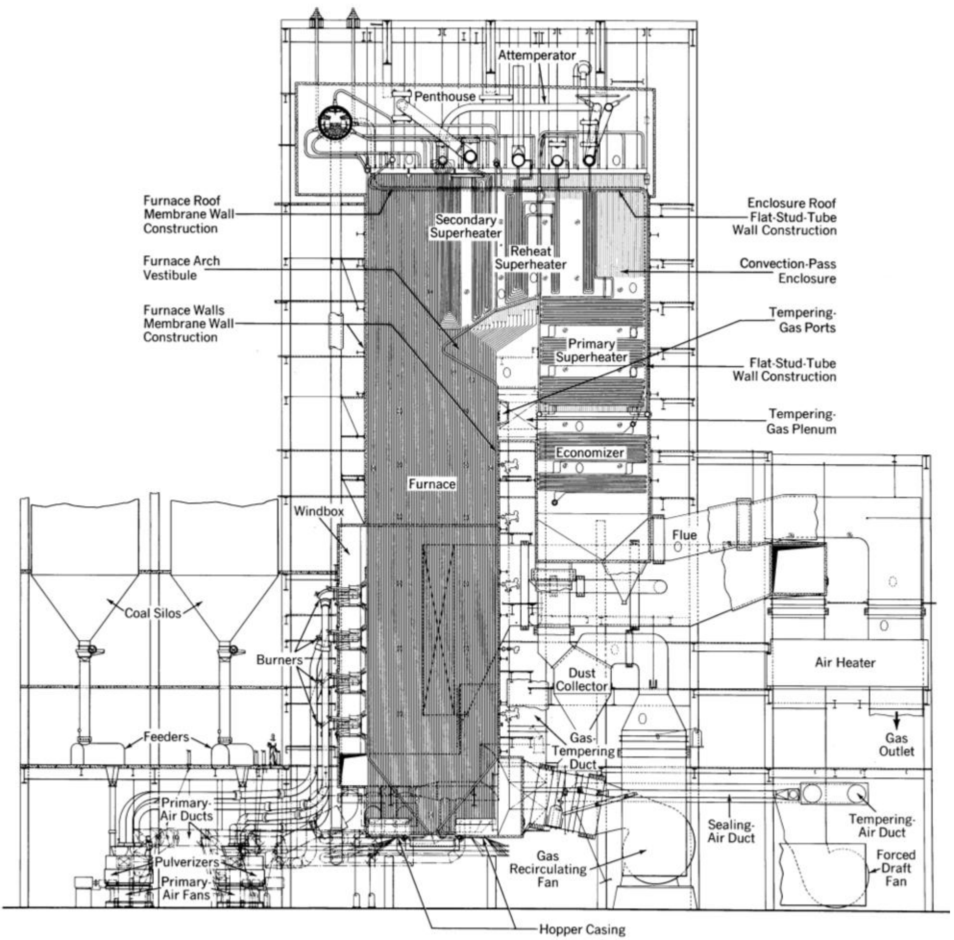
	Gross Output (MW)	Number of Reheat Stages	Steam Pressure, psig (MPa)	Turbine Pressure Sections			
				HP	IP	RH	LP
Fossil	50~150	0 or 1	1,450 (10.1)	1SF	--	--	1SF
	150~250	1	1,800 (12.5)	1SF	1 SF	--	1DF
	250~450	1	2,400 (16.6)	1SF	1 SF	--	1DF
	450~600	1	2,400 or 3,500 (16.6 or 24.2)	1SF	1 SF	--	2DF
	600~850	1	2,400 (16.6)	1DF	1 DF	--	2DF
		1 or 2	3,500 (24.2)	1SF	1 SF	1 DF	2DF
	850~1100	1	2,400 (16.6)	1DF	1 DF	--	3DF
		1 or 2	3,500 (24.2)	1SF	1 SF	1 DF	3DF
Nuclear	600~900	--	1,000 (7.0)	1DF	--	--	2DF
	900~1300	--	1,000 (7.0)	1DF	--	--	3DF

Data is for tandem-compound units.
1SF = one single-flow turbine; 1DF = one double-flow turbine; 2DF (3DF) = two (three) double-flow turbines

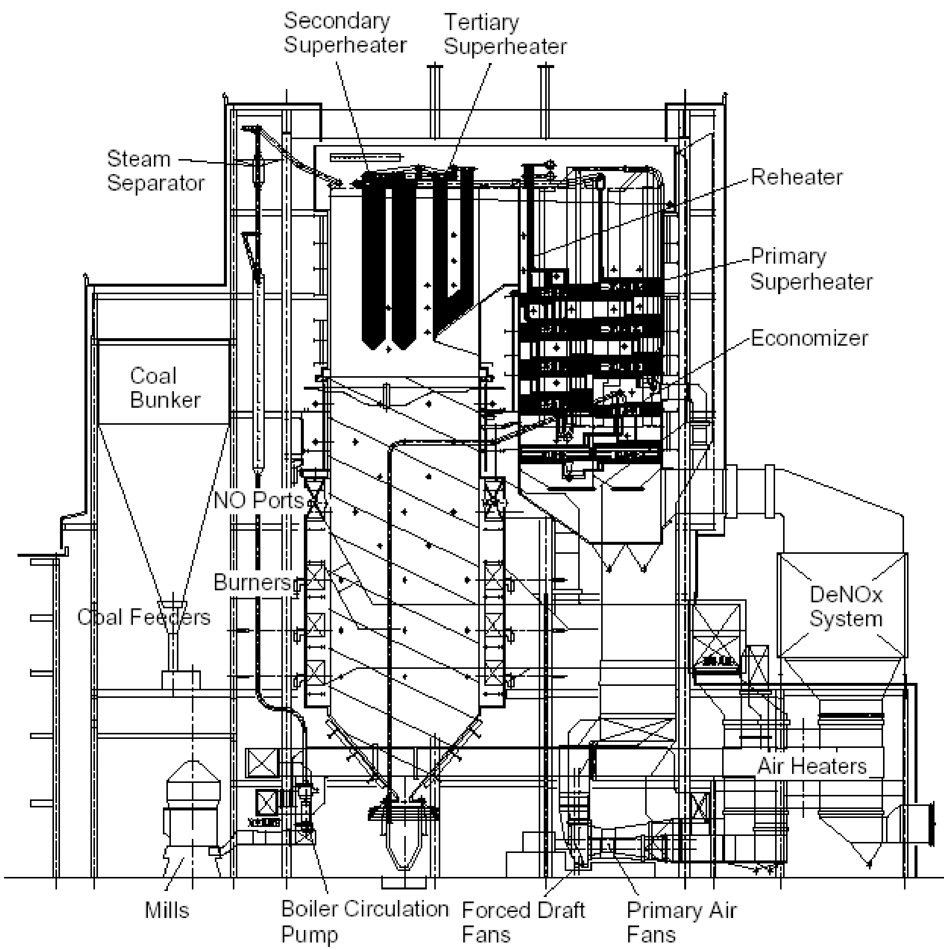
1. Introduction to Power Plants
2. Steam Turbine Arrangement
3. Steam Path Parts
4. Types of Steam Turbines
5. Pulverized Coal-Fired Boilers
6. Nuclear Steam Supply System

Boiler

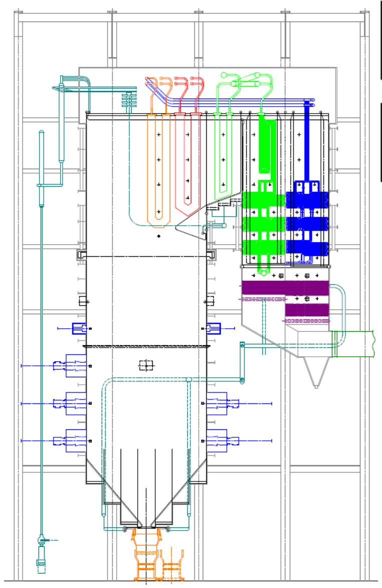
Drum-Type Boiler



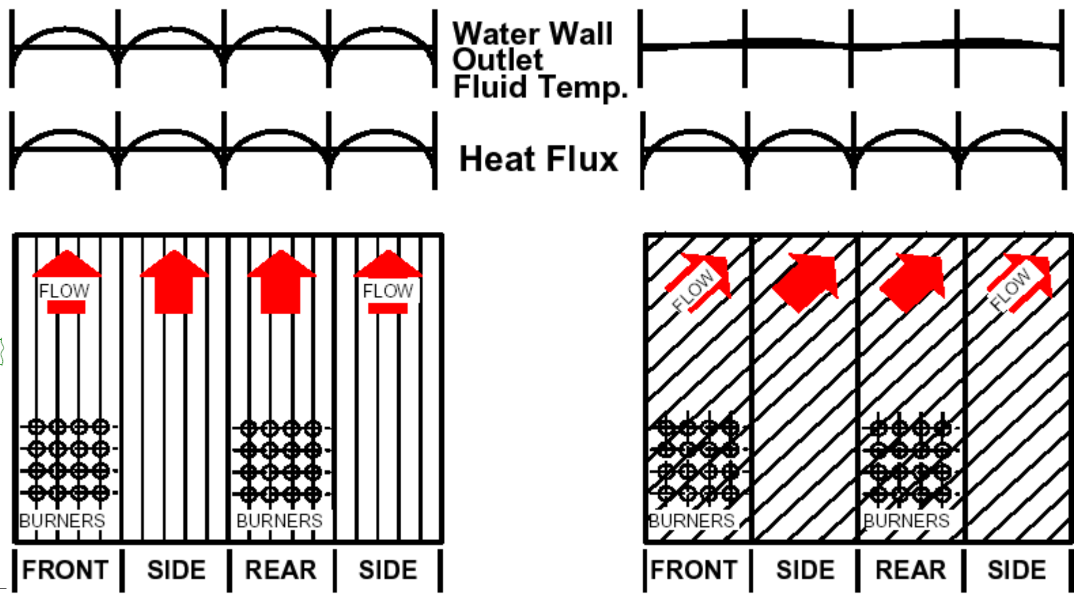
Once-through Boiler



Spiral Furnace Design

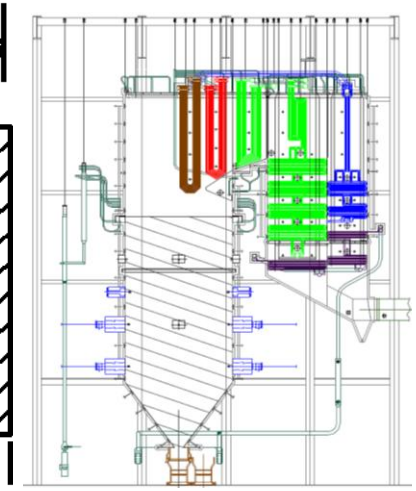


[Vertical Tube Design]



[Vertical Type water Wall]

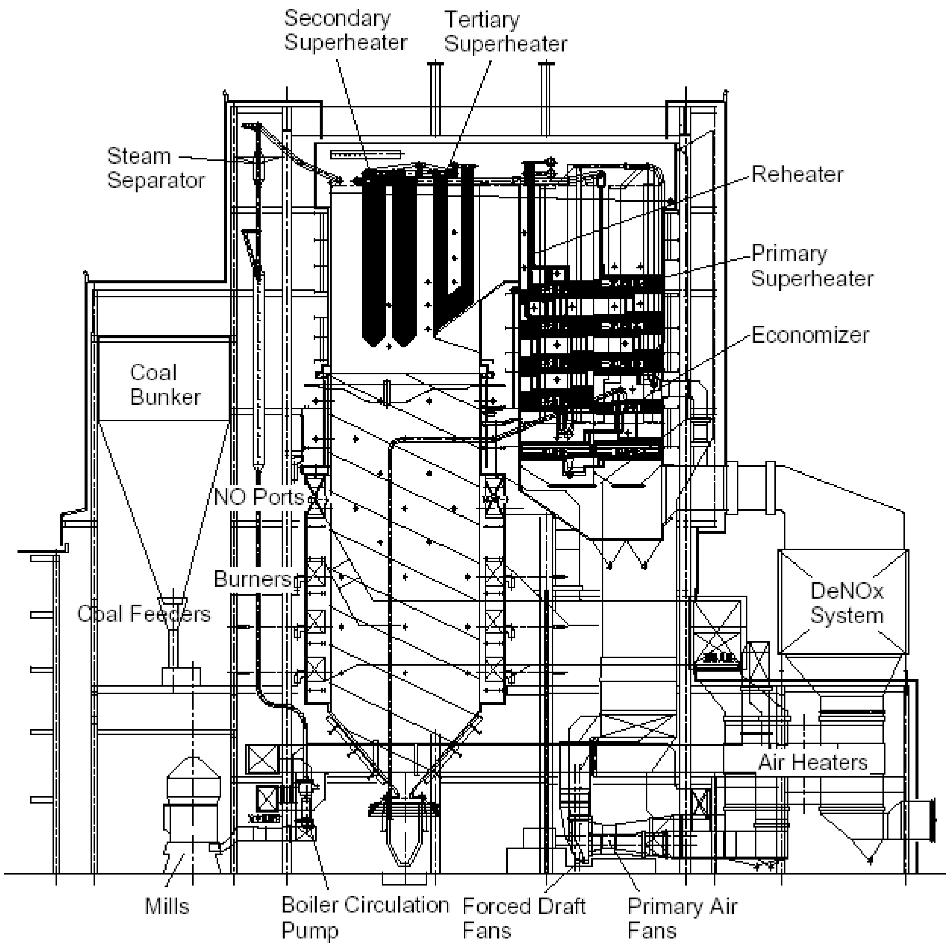
[Spiral Type water Wall]



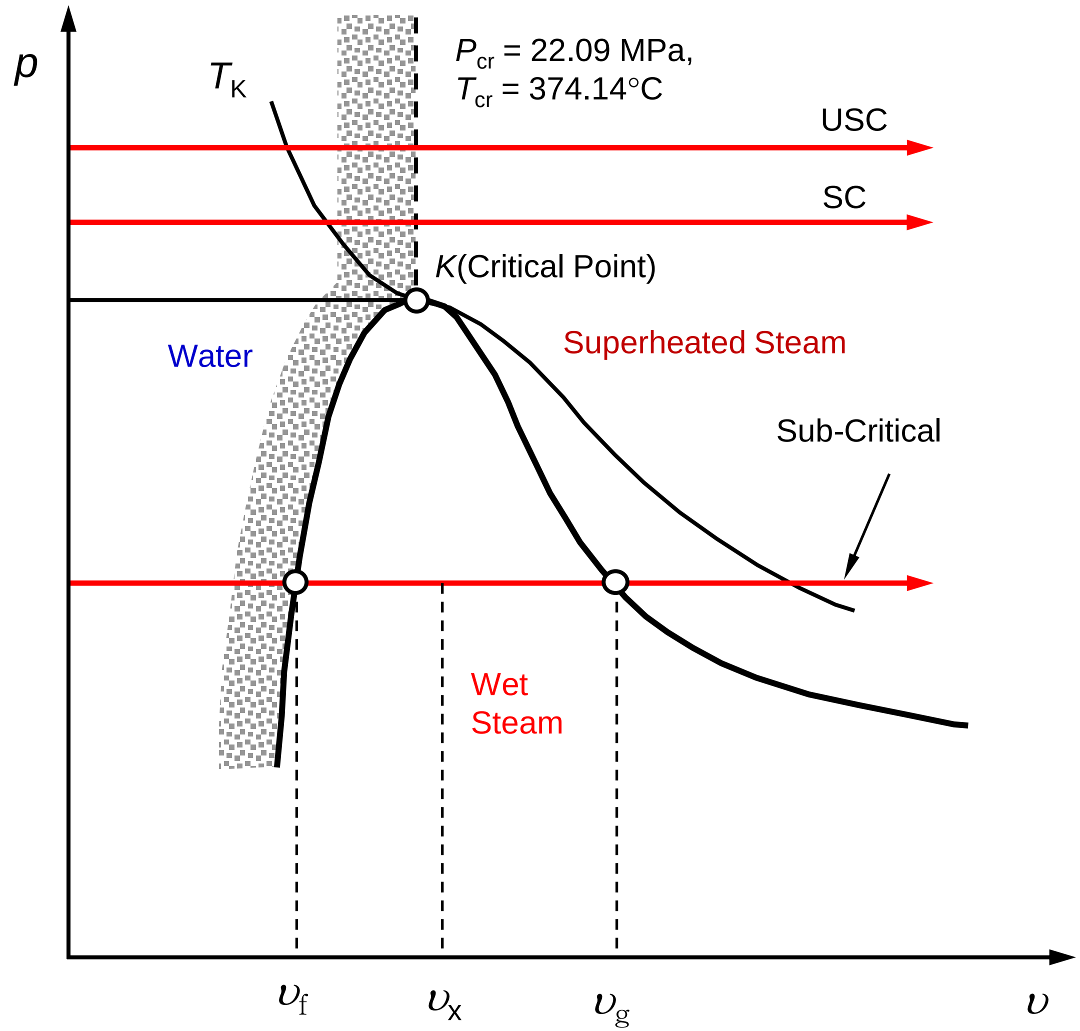
[Spiral Wound Design]

Once-through Boiler

- ❖ There is no boiler drum in the once-through boiler.
- ❖ Water flows through the evaporation section without any recirculation.
- ❖ The steam separator ensures safe operation and control of the boiler.
- ❖ It will prevent water from entering the superheater, and provides a means of blow down for the HP section during low loads and transient conditions.
- ❖ The separator is dry in normal operating conditions.

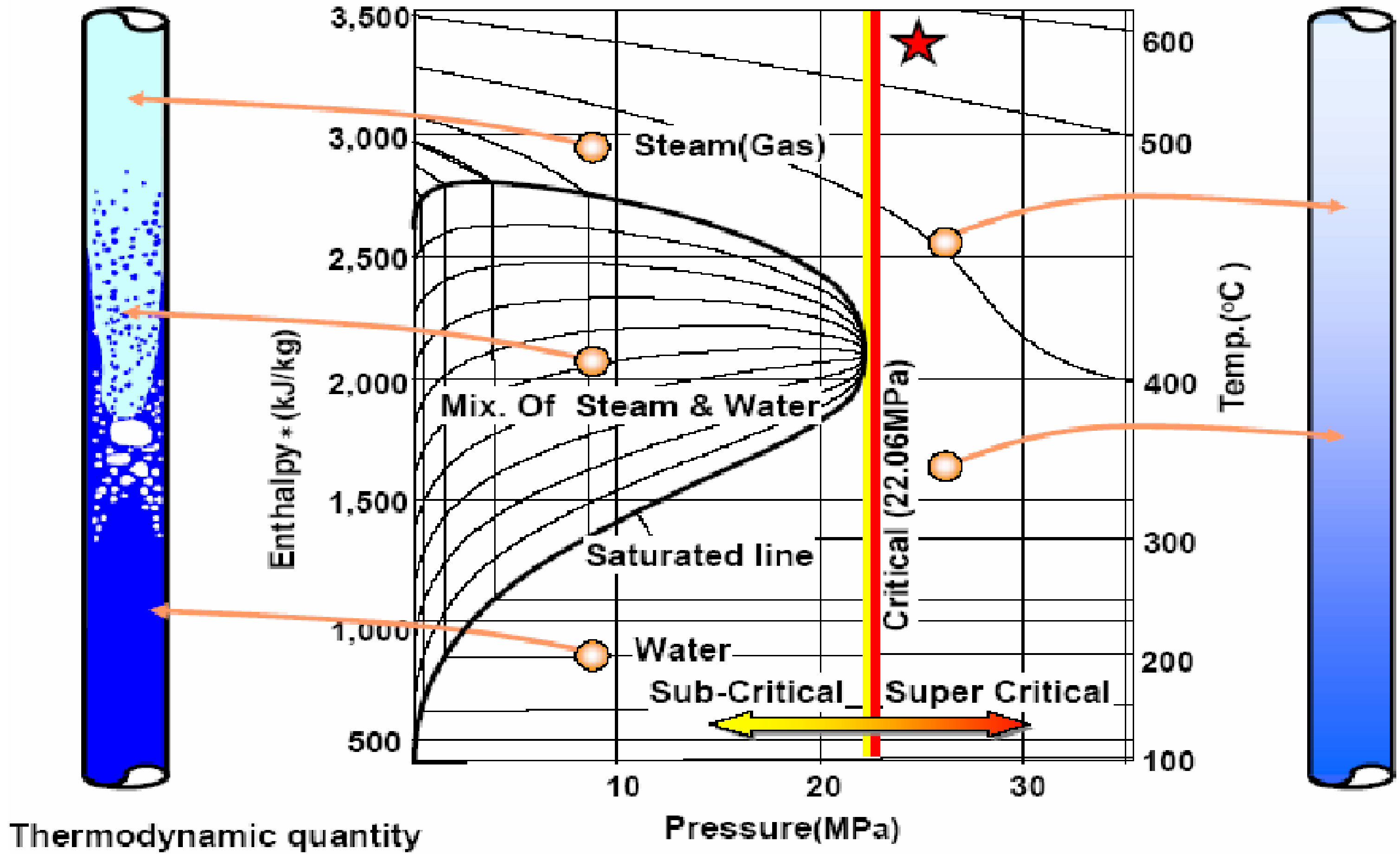


Concept of USC

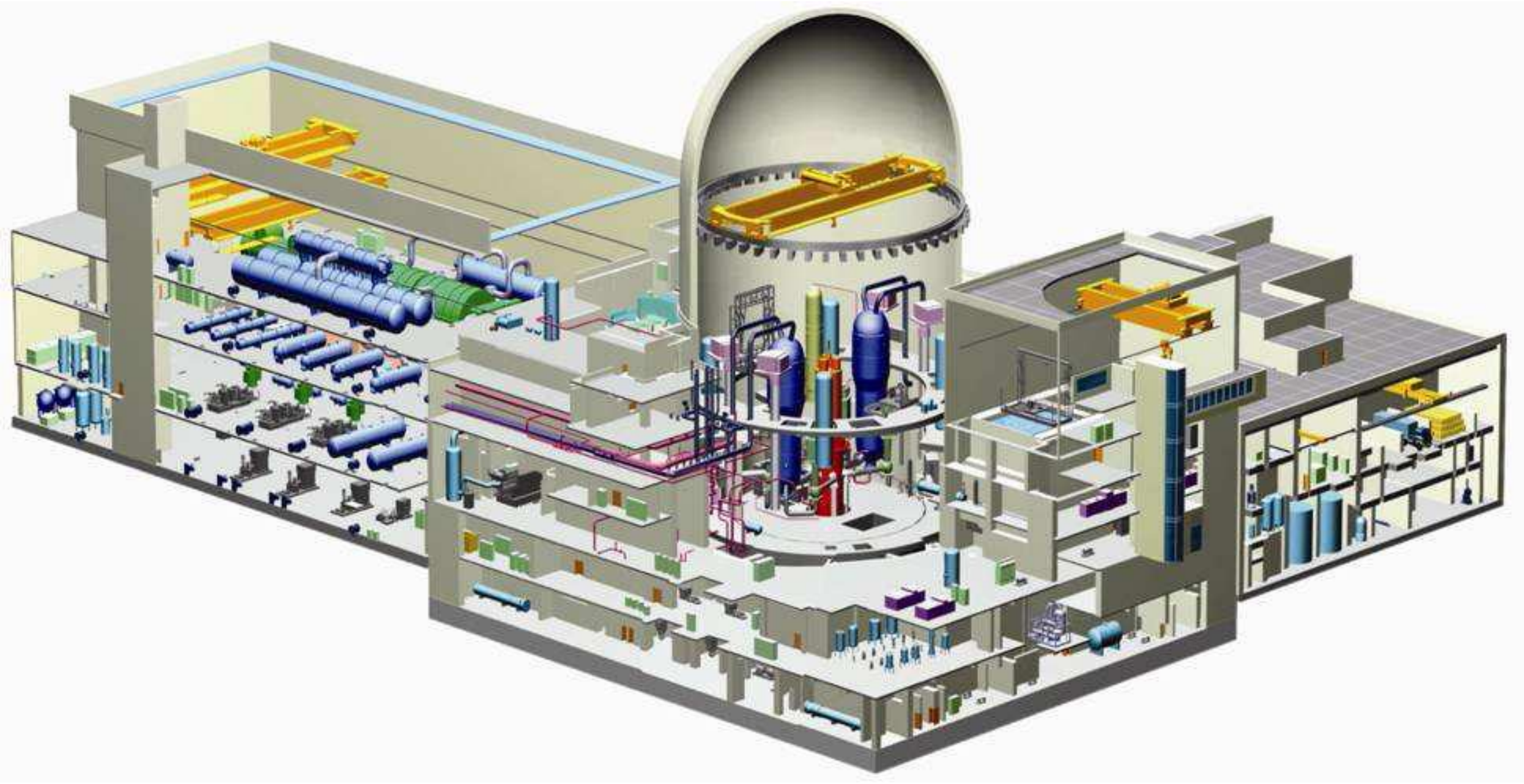


Characteristics of Supercritical

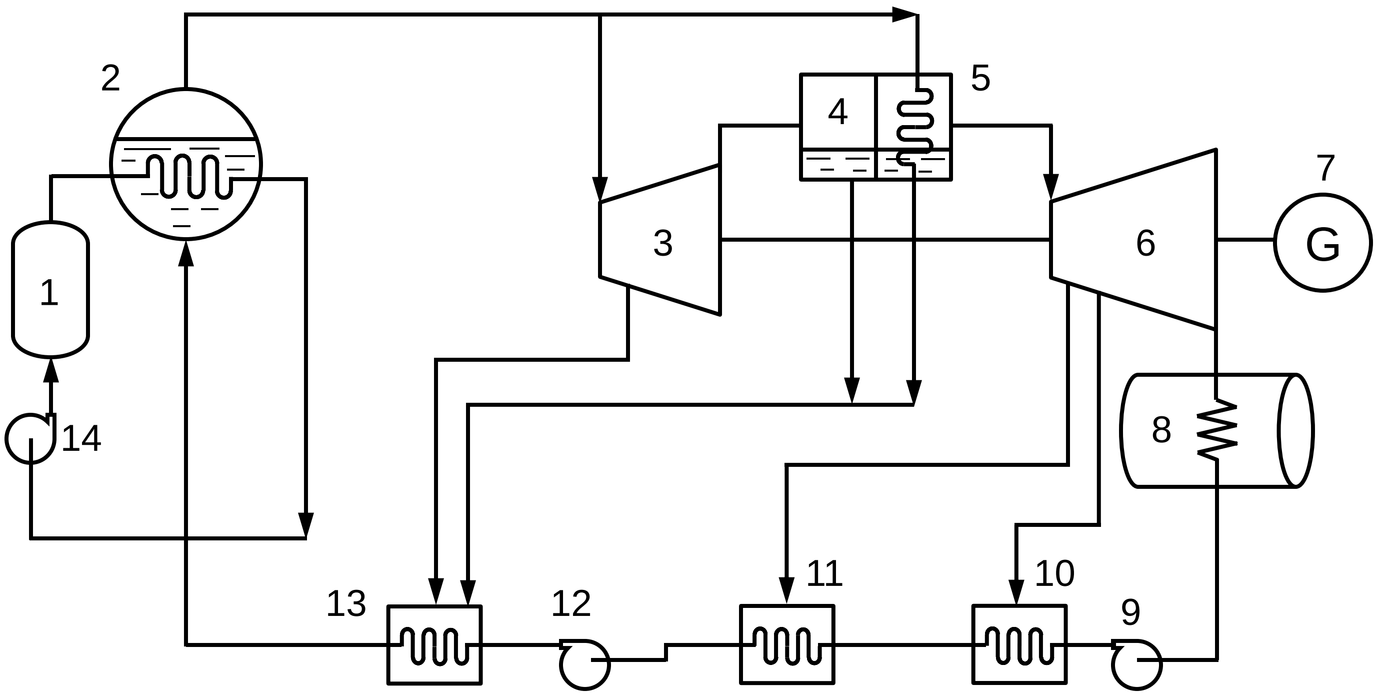
There is no distinction between water and steam in supercritical units



Arrangement of Nuclear Power Plant

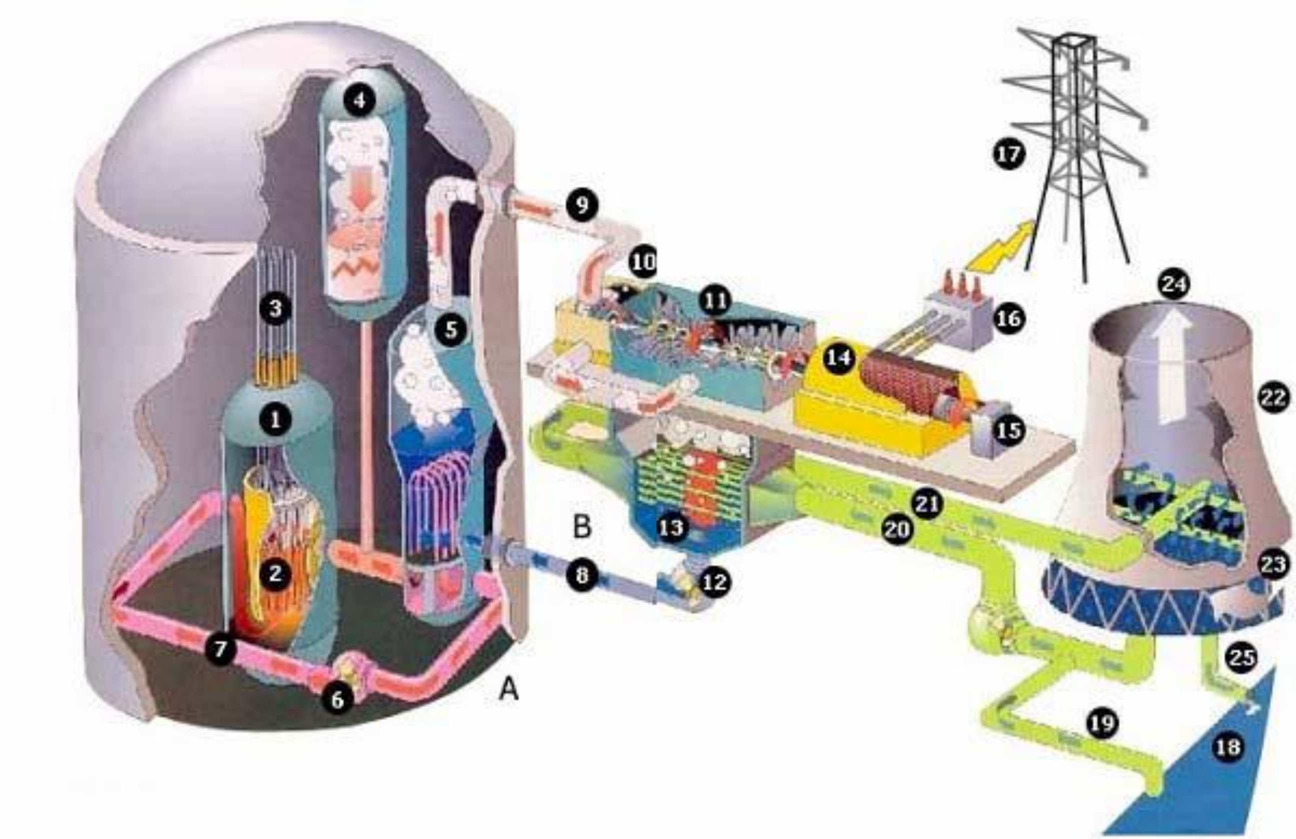


Fluid Flow in a Nuclear Power Plant



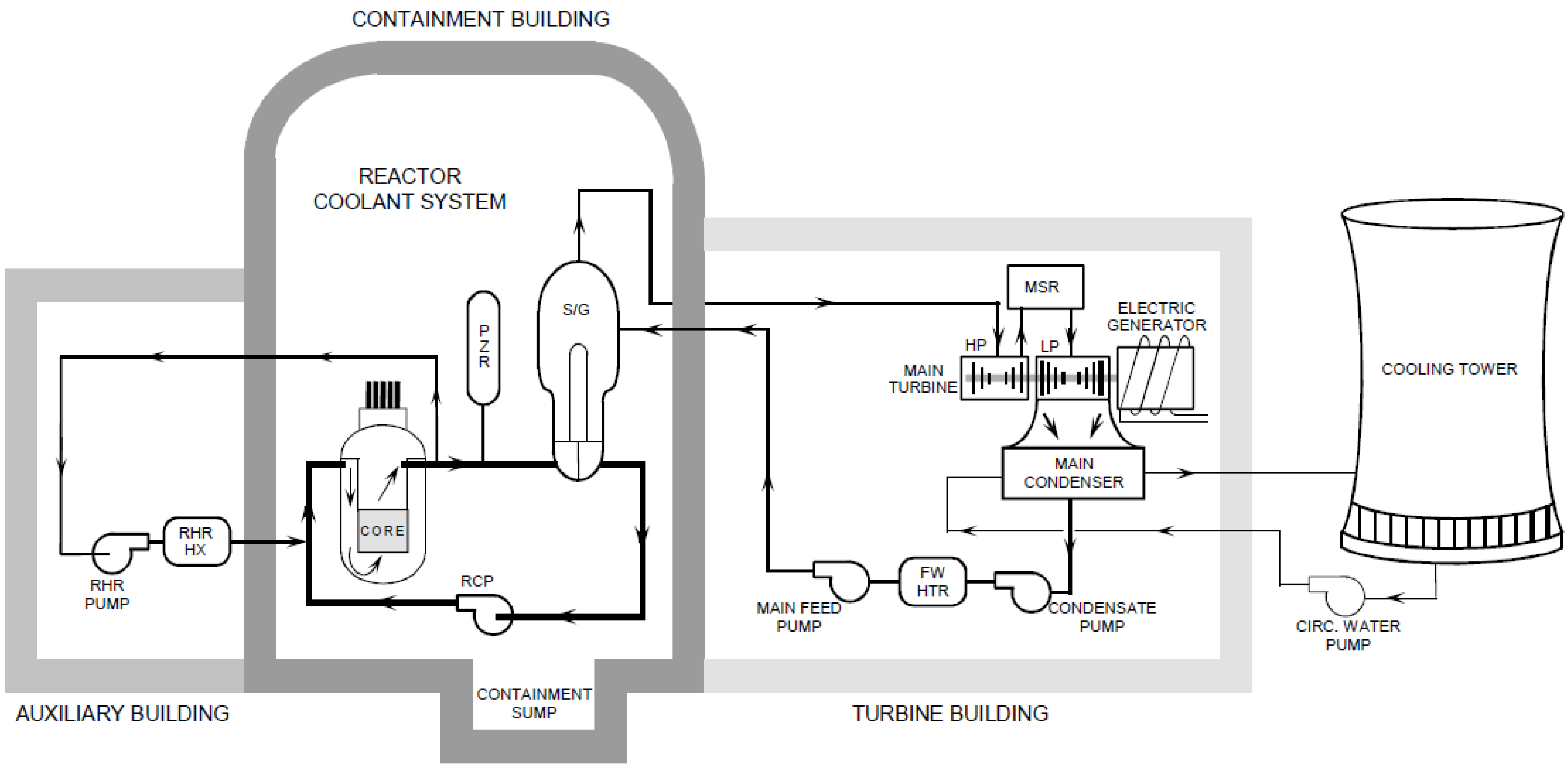
1-nuclear reactor, 2-steam generator, 3-HP turbine, 4-steam separator, 5-reheater, 6-LP turbine, 7-generator, 8-condenser, 9 -condensate pump, 10-LP FWH, 11-LP FWH, 12-BFP, 13-HP FWH, 14-main circulating pump

Schematic of a Nuclear Power Plant

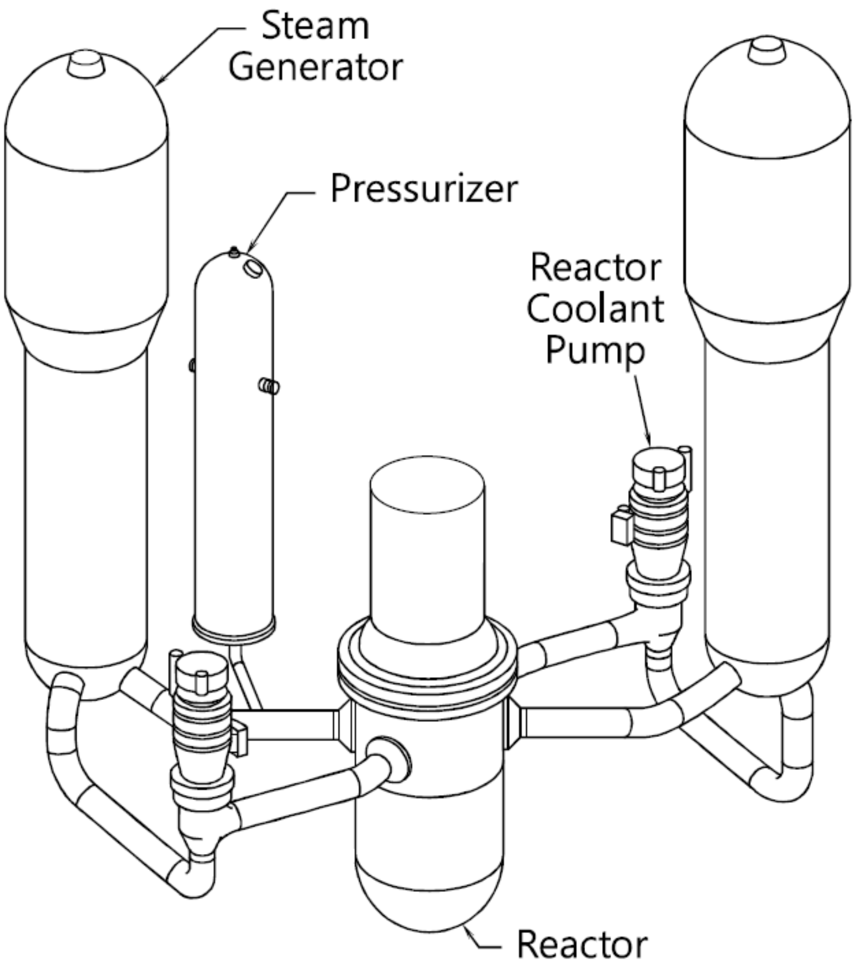


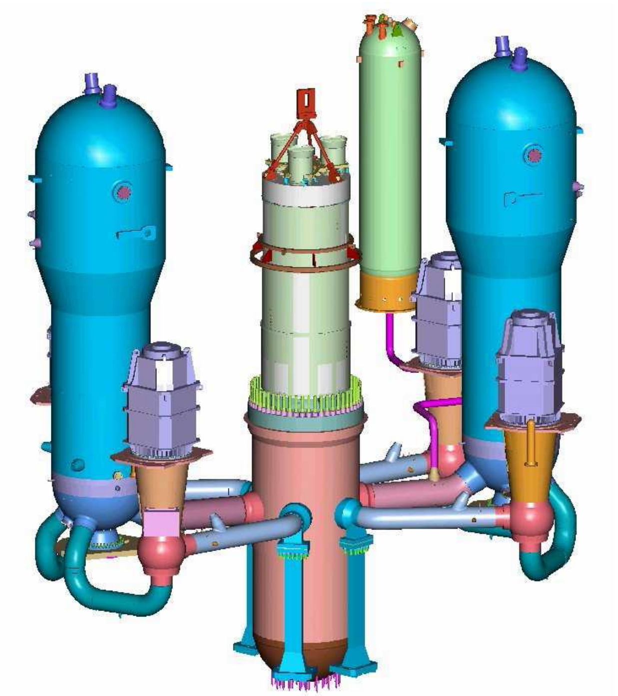
A. Primary circuit B. Secondary circuit C. Tertiary circuit 1. Reactor 2. Fuel assemblies 3. Control rods
4. Pressurizer 5. Steam generator 6. Primary pump 7. Feedwater primary circuit
8. Feedwater secondary circuit 9. Steam secondary circuit 10. High- pressure turbine
11. Low-pressure turbine 12. Condenser 13. Feedwater pump 14. Generator 15. Exciter 16. Transformer
17. High voltage line 18. River 19. Intake cooling water 20. Cold cooling water 21. Warm cooling water
22. Cooling water 23. Upward airflow 24. Steam 25. Outlet cooling water

Schematic of a Nuclear Power Plant



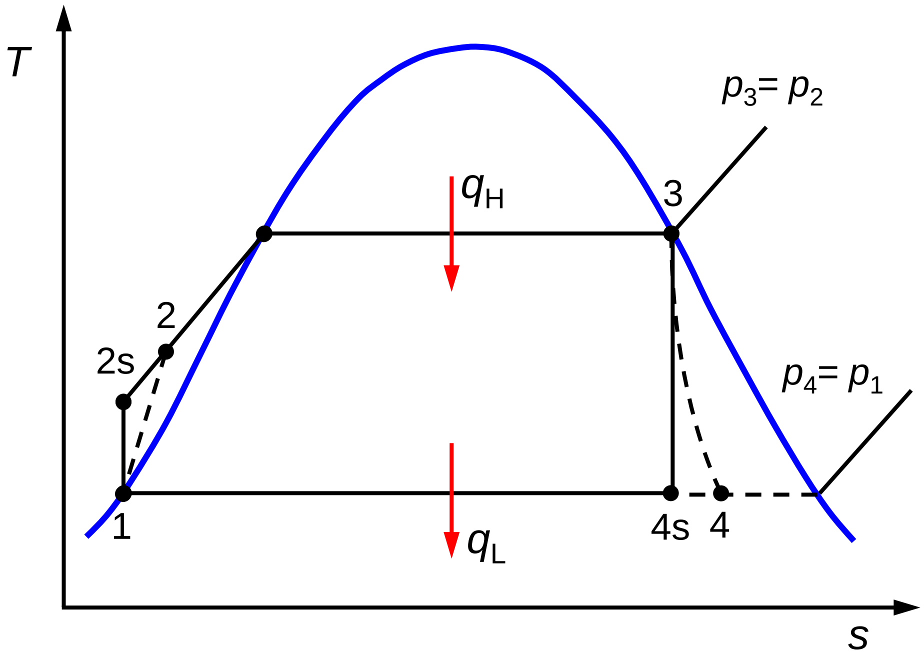
NSSS

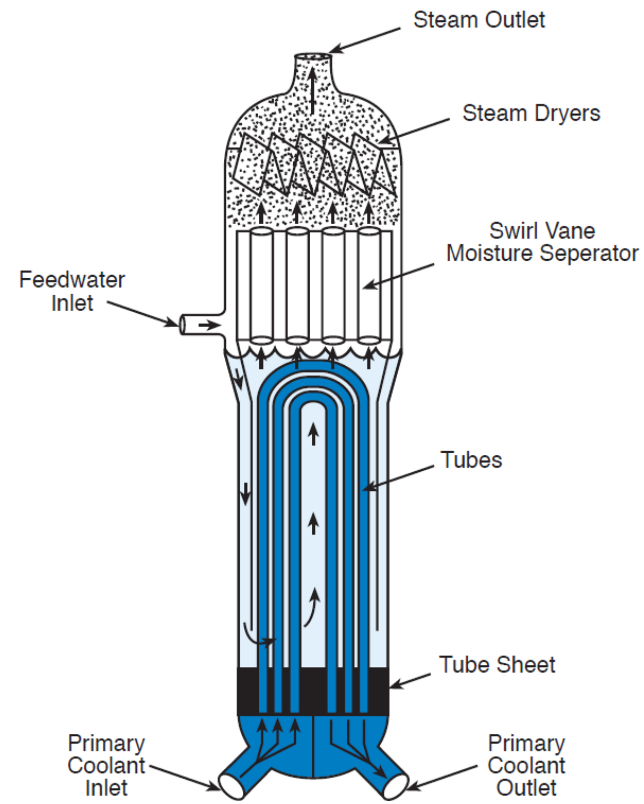




APR 1400

Ideal Rankine Cycle – Nuclear





Process 1→2s : Isentropic compression in pump

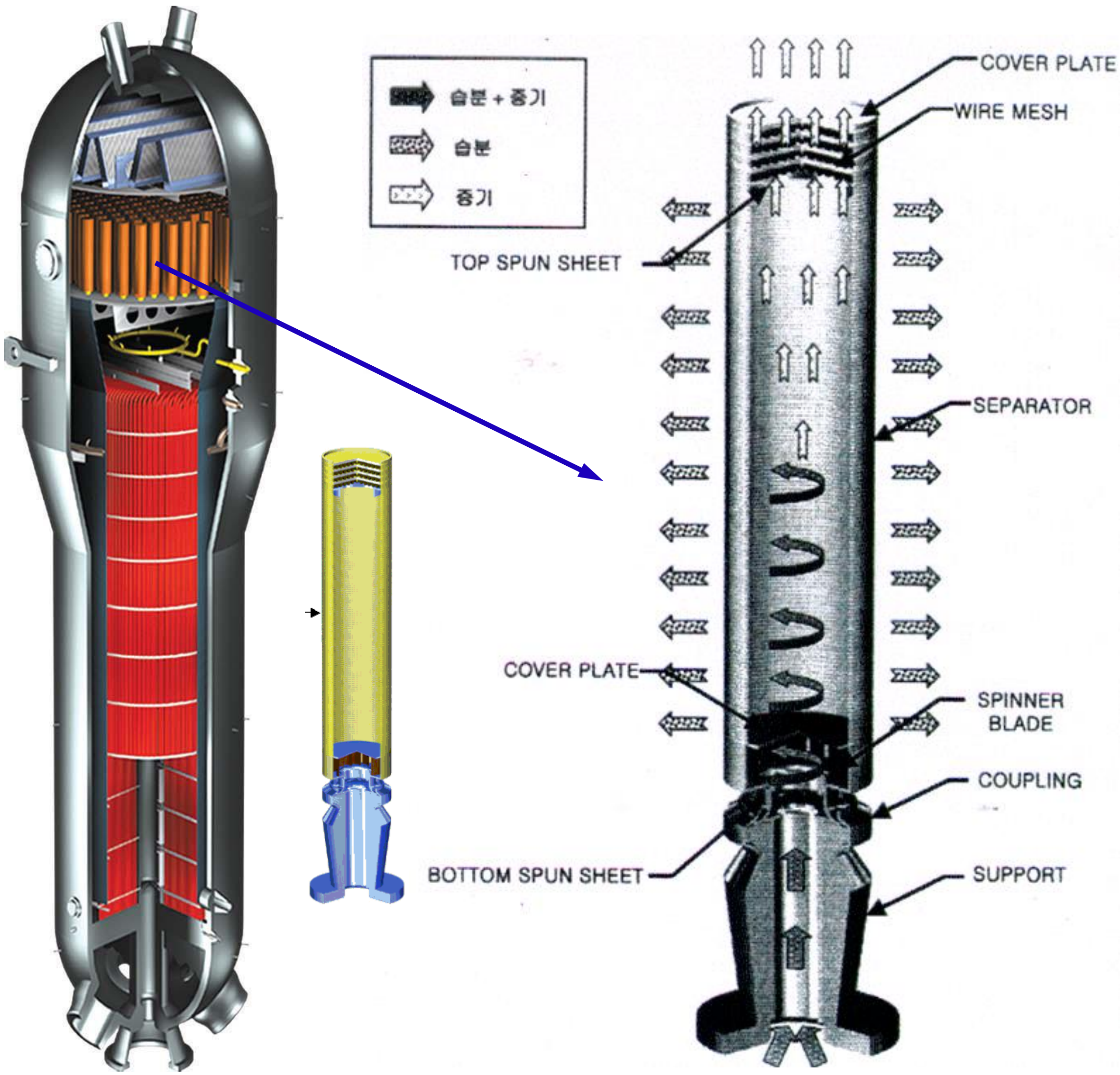
Process 2s→3 : Constant pressure heat addition in steam generator

Process 3→4s : Isentropic expansion in turbine (adiabatic turbine)

Process 4s→1 : Constant pressure heat rejection in condenser ($h_4 >> h_1$)

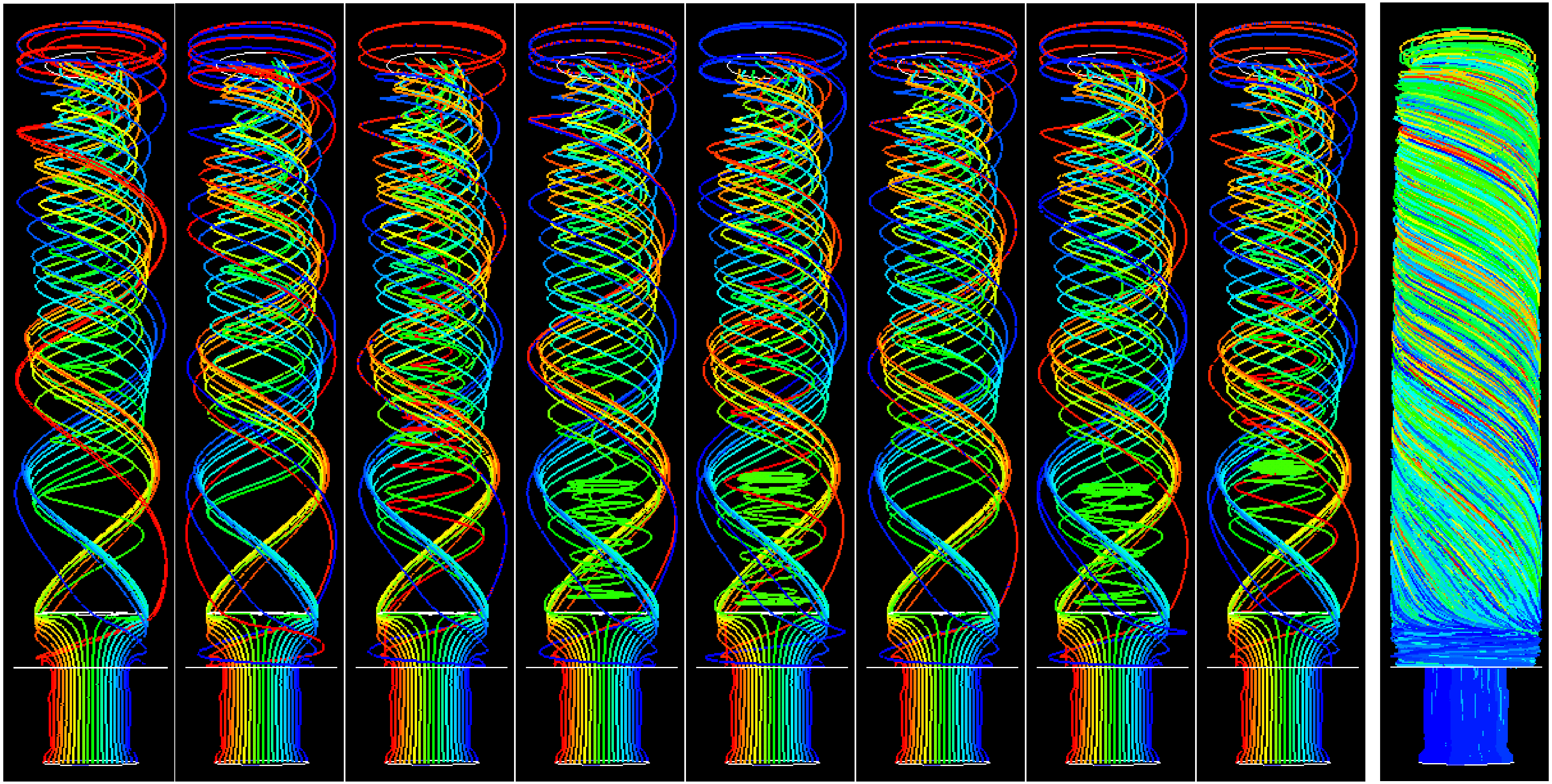
This saturated-steam cycle is a basic Rankine cycle for nuclear power plants with non-reheat system.

Moisture Separator



Spinner Blades
(Swirler)

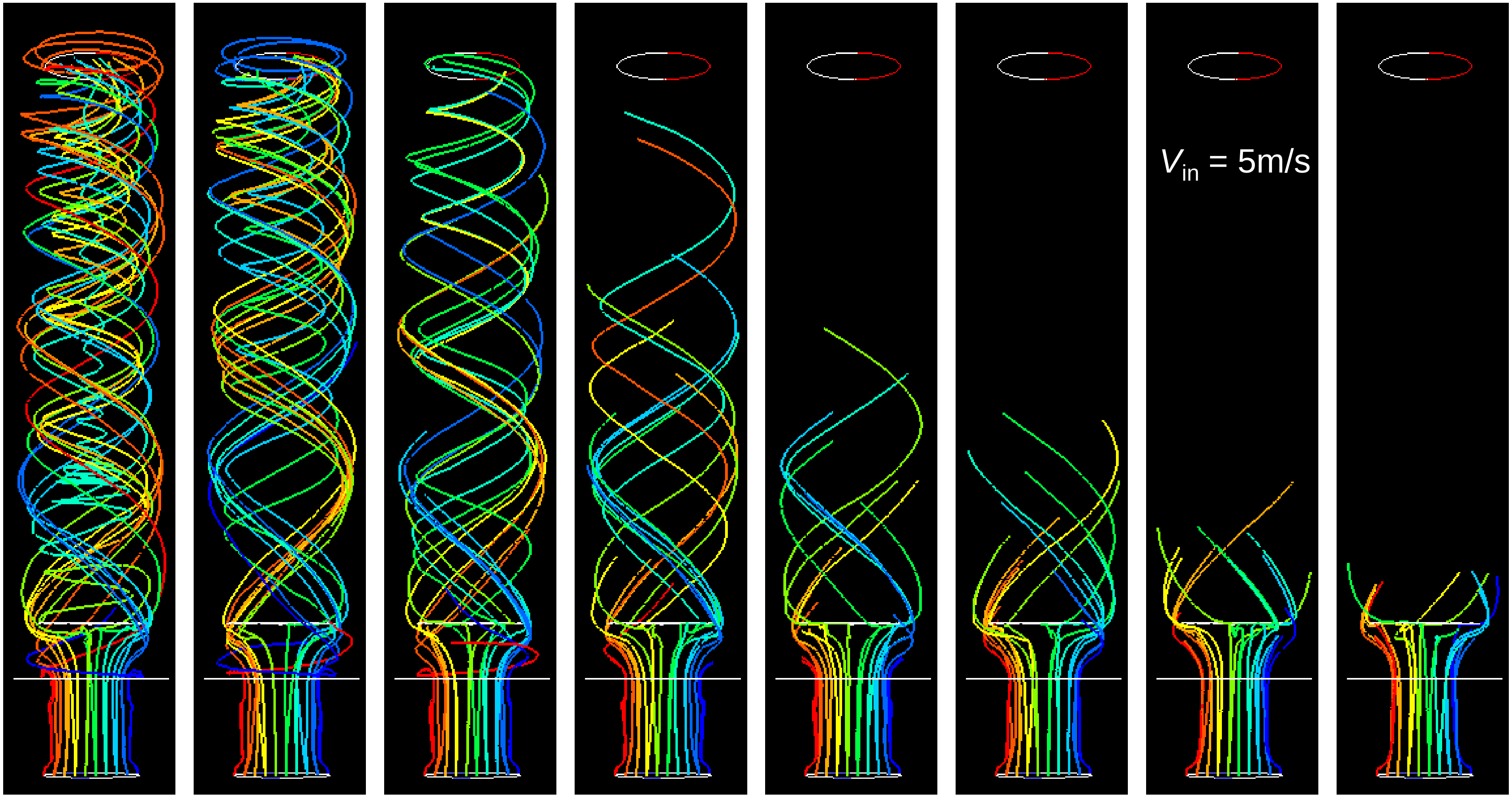
Path Lines of Steam Flow



V_{in} (m/s) =

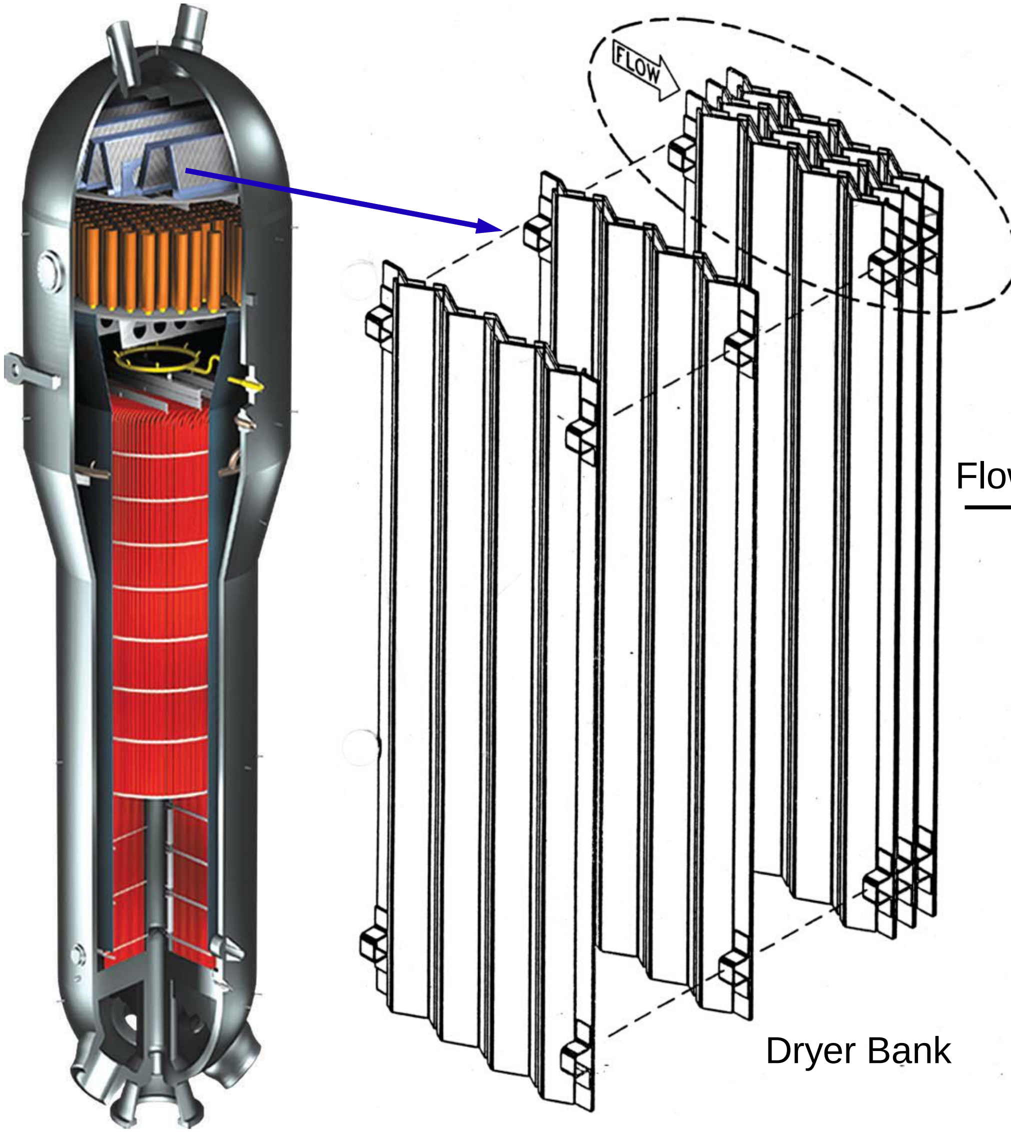
2 3 4 5 6 7 8 9 6

Water Droplet Trajectories

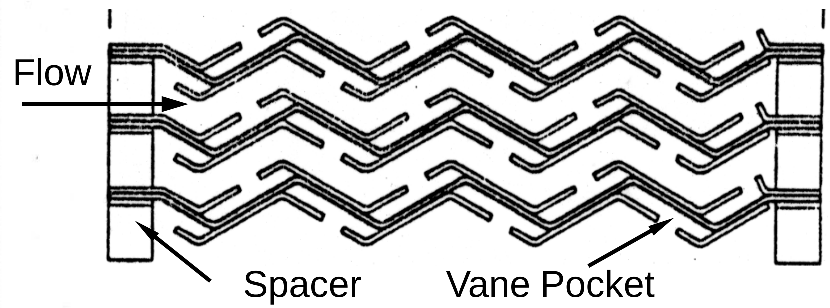


d_p (μm) =
5 10 20 30 40 50 70 100

Steam Dryer



Dryer Bank



Cross Section of Dryer Vane
(Chevron Vane)

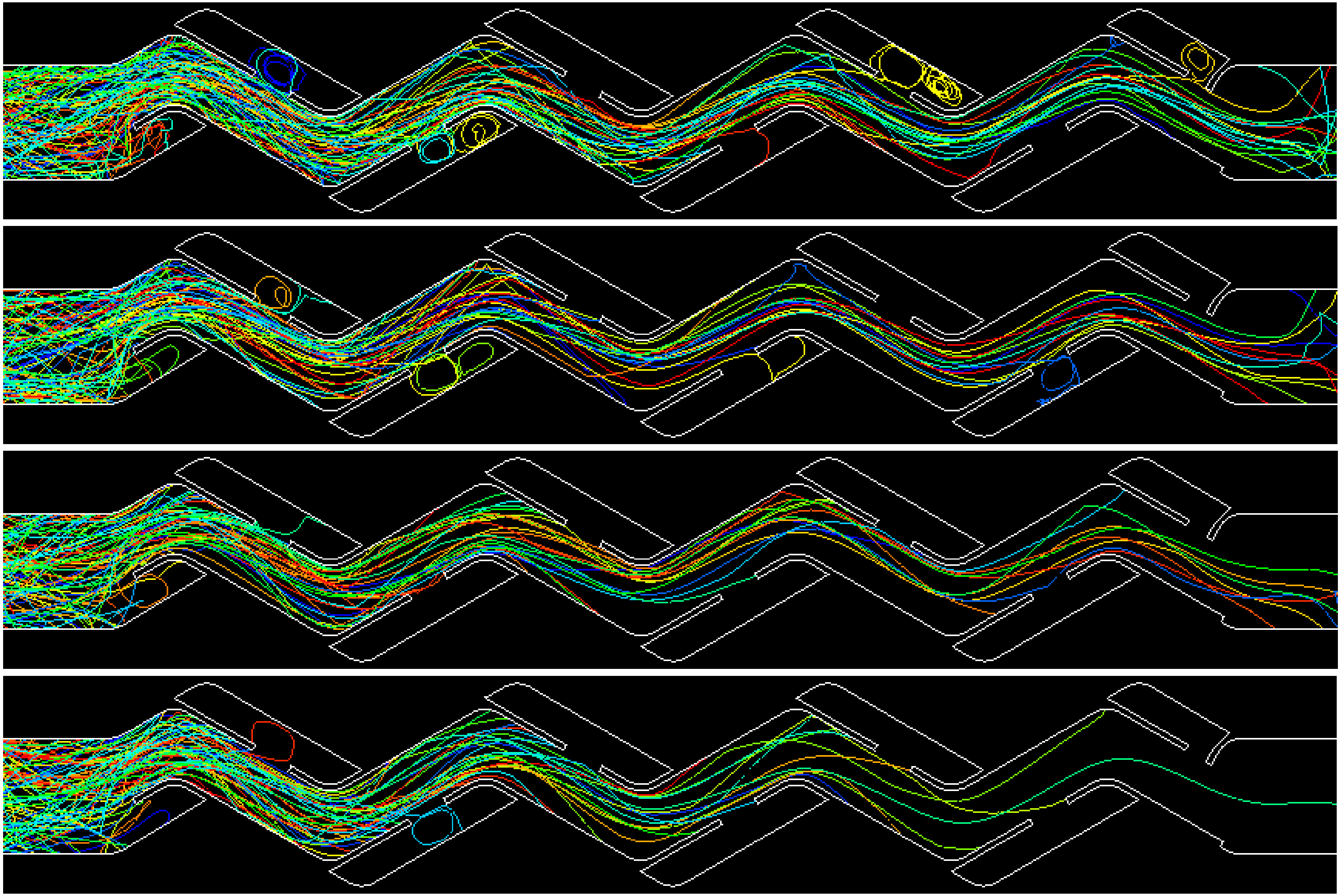
Droplet Trajectories in a Dryer Vane

d_p =
4 μm

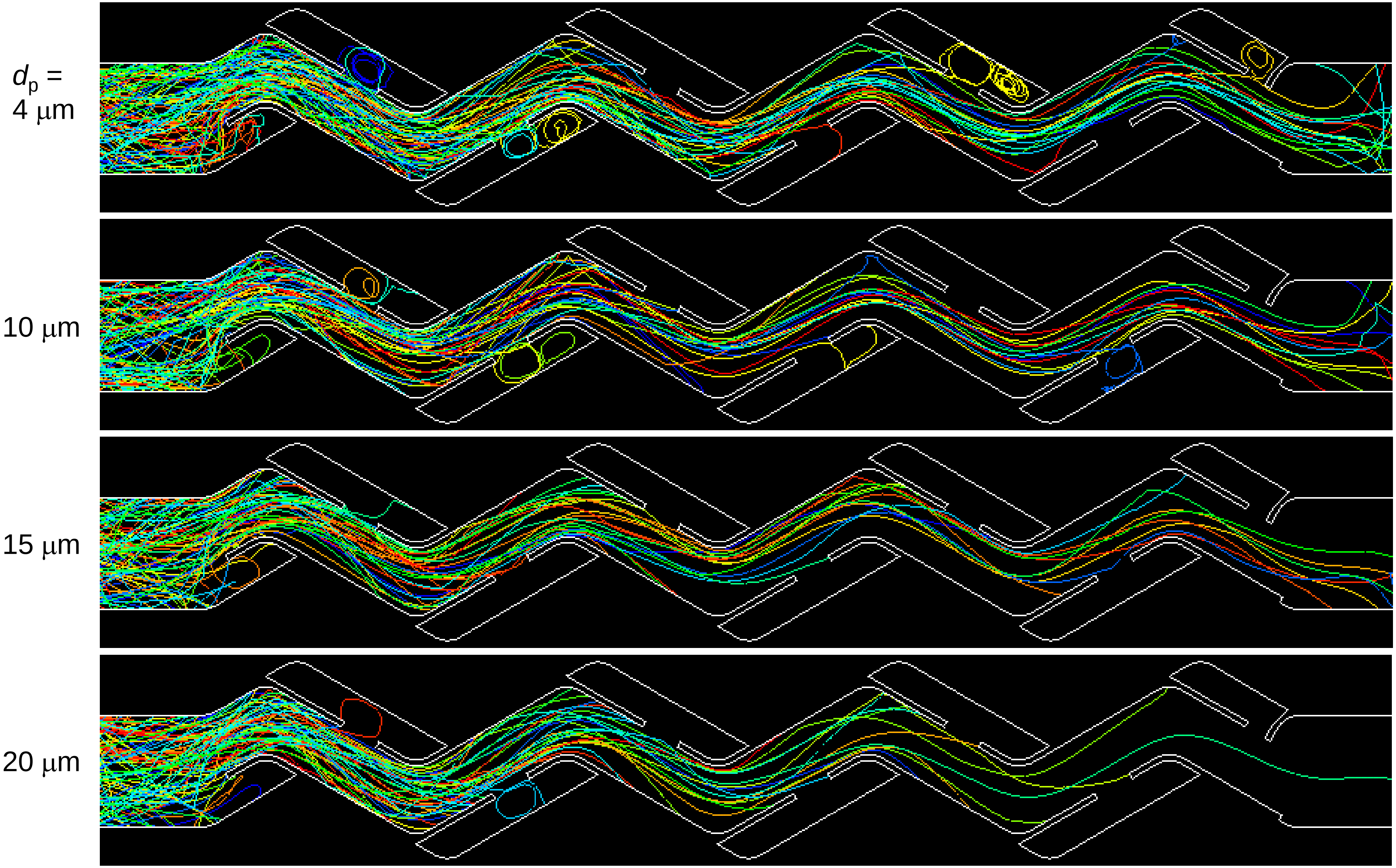
10 μm

15 μm

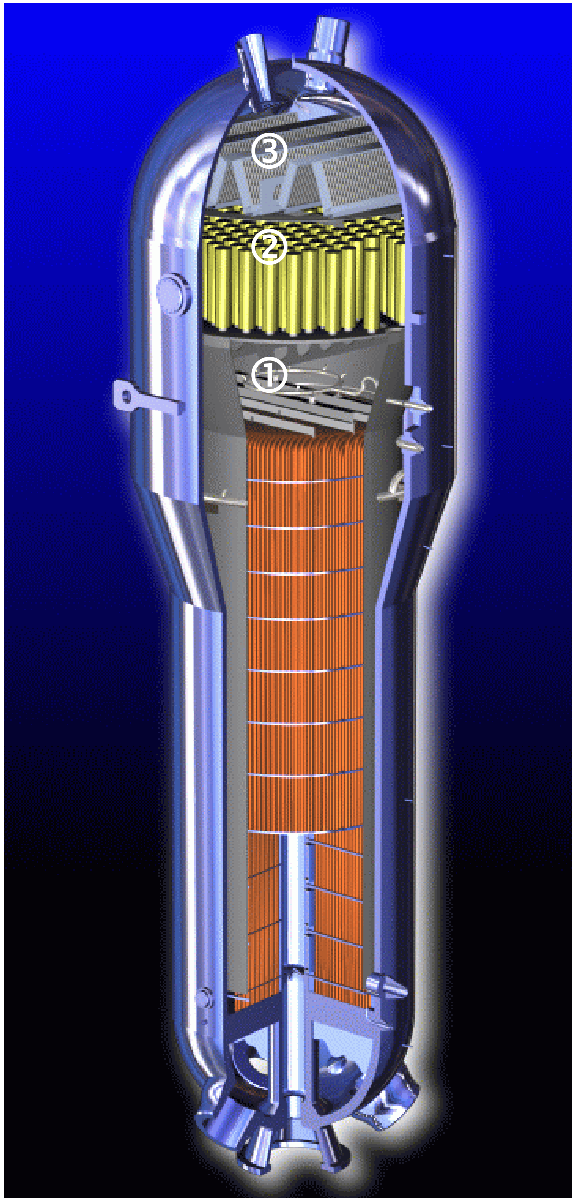
20 μm



Droplet Trajectories in a Dryer Vane



Quality

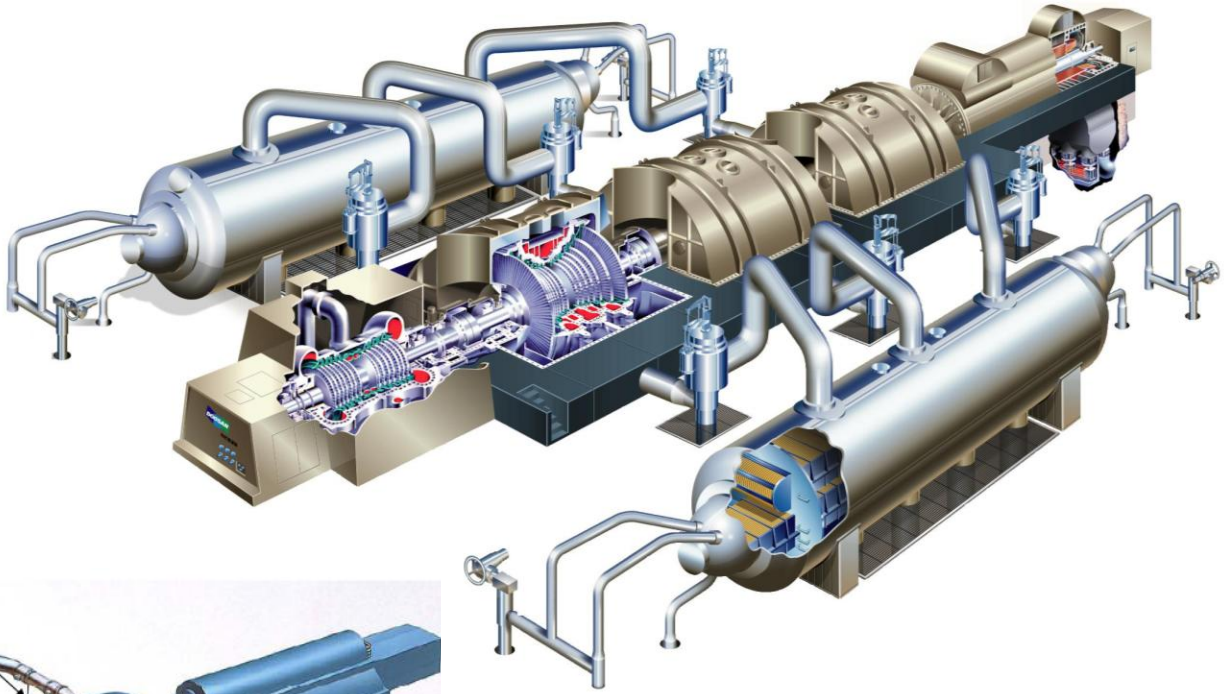


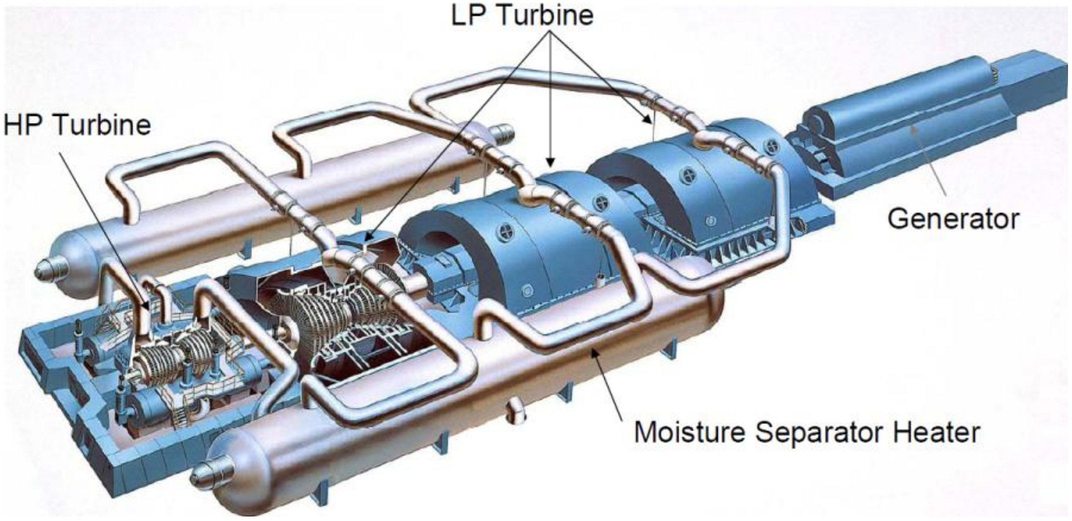
(Required) Quality	
①	around 25 %
②	around 96~98 %
③	should be higher than 99.75 %

Calculated Quality	
①	around 25 %
②	96 % (assumed)
③	99.95 %

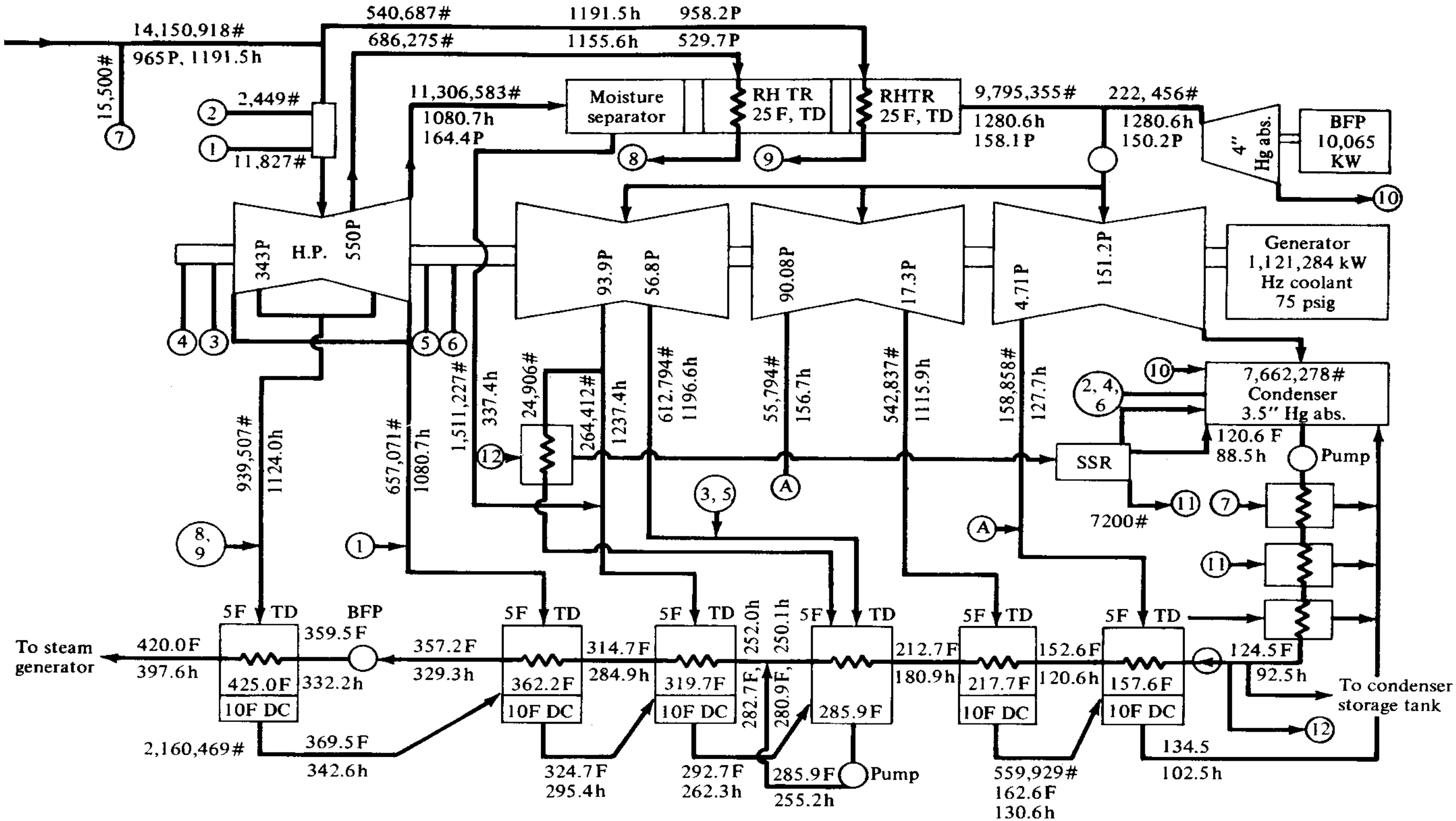
Steam Turbine Arrangement

Four-Casing, Six-Flow Steam Turbine [Nuclear-APR 1400]

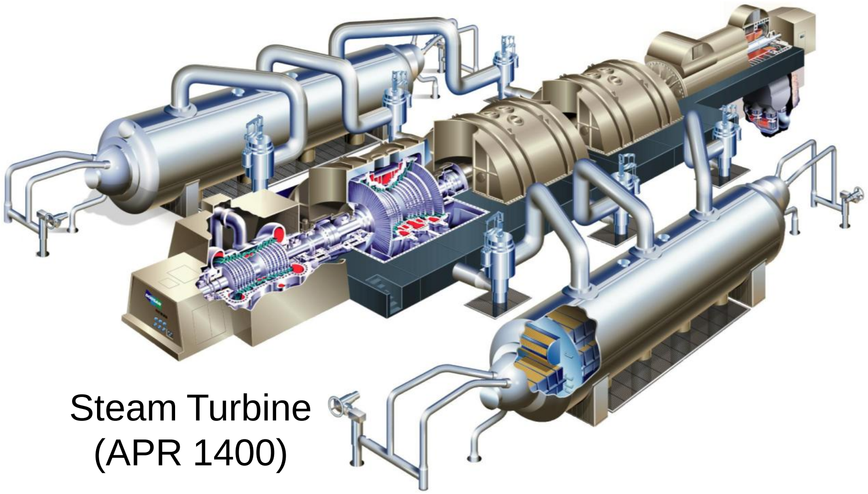




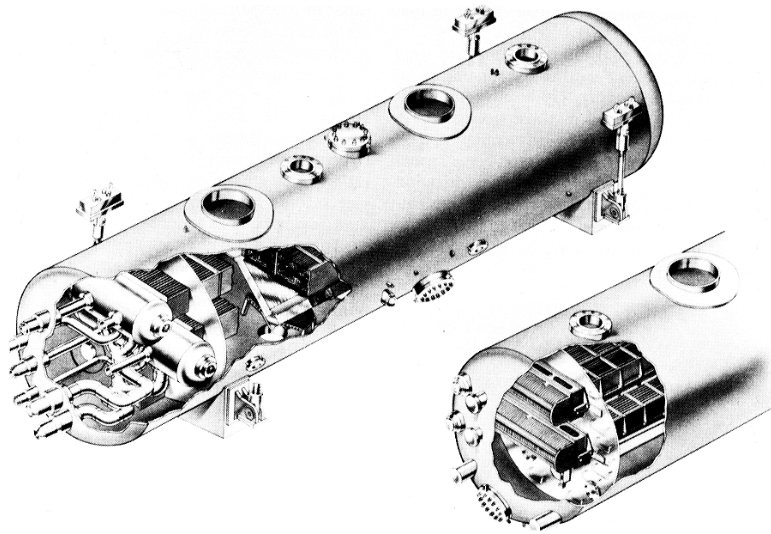
Heat Balance –1000MW Nuclear Unit

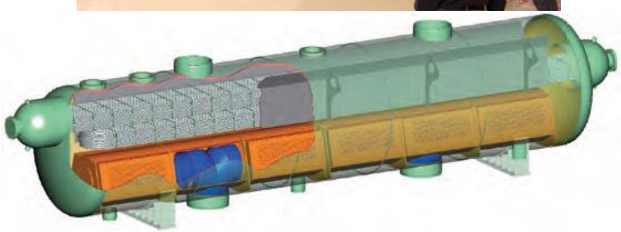


MSR – Horizontal

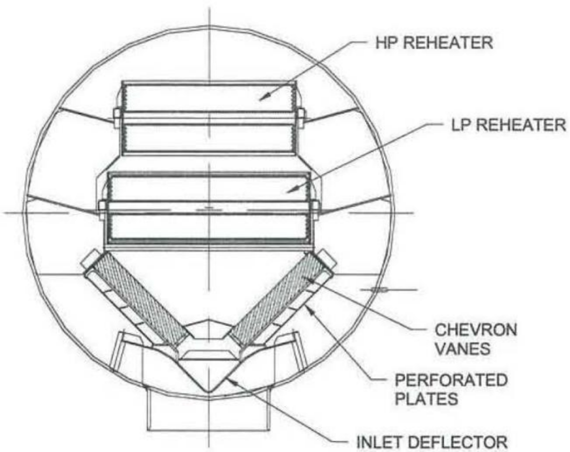


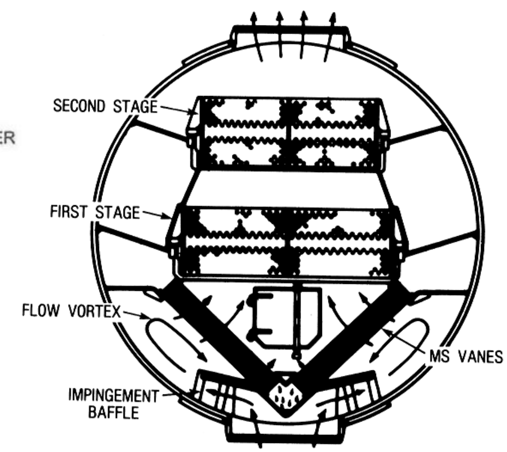
Steam Turbine
(APR 1400)





MSR (Horizontal)

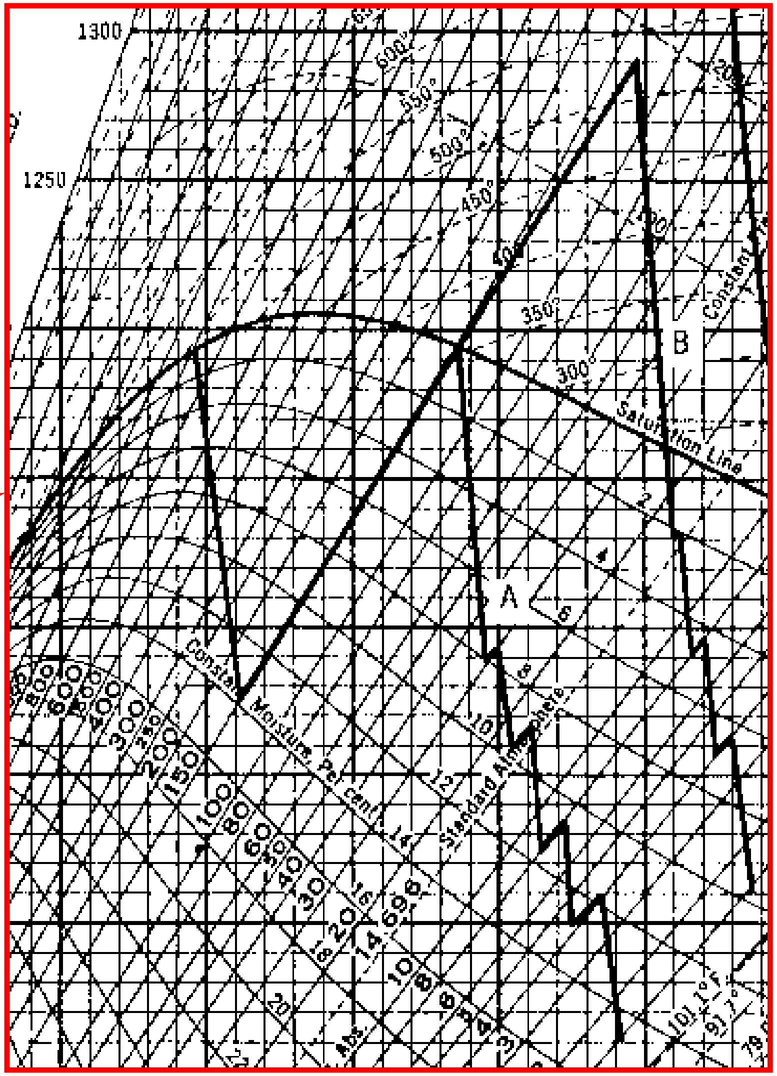




MSR (GE)

원자력발전

Mollier Chart



질의 및 응답

작성자: 이 병 은 (공학박사)
작성일: 2015.02.11 (Ver.5)
연락처: ebyeong@daum.net
Mobile: 010-3122-2262
저서: 실무 발전설비 열역학/증기터빈 열유체기술