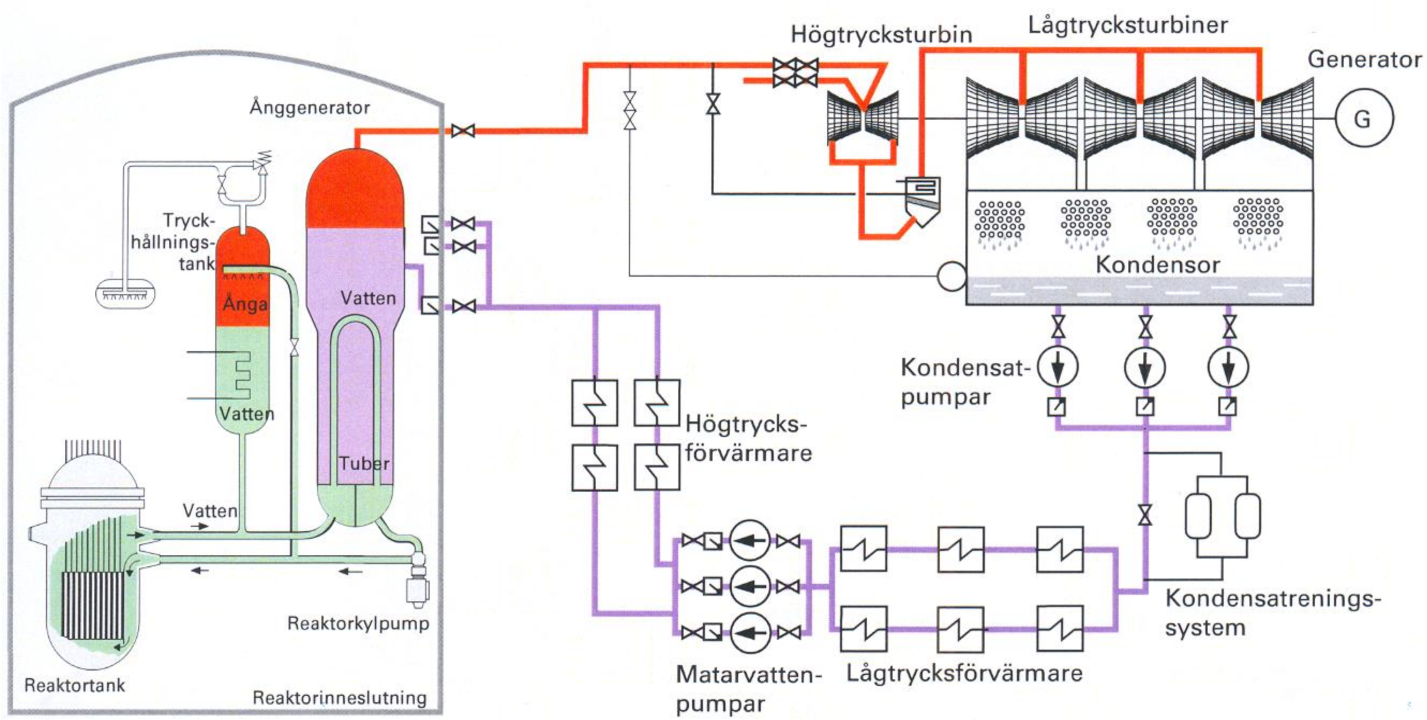
Nuclear Plant Components & Operation.
Steam Cycles for nuclear plants.
(a quick overview)

SPG course MJ2405

Miro Petrov

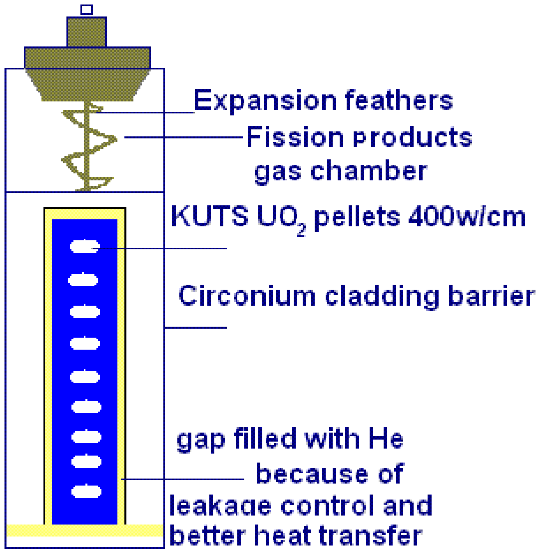
KTH Industrial Engineering and Management

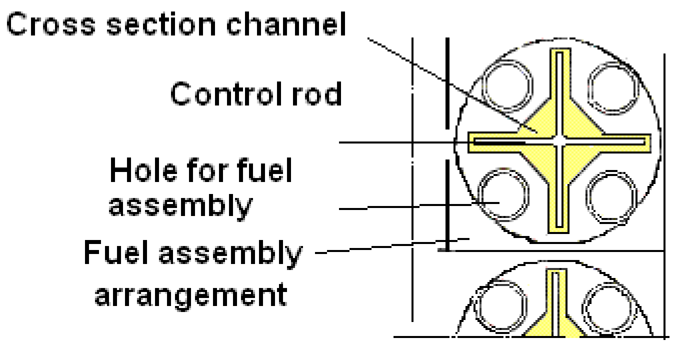
Most figures by courtesy of KSU AB (Kärnkraftsäkerhet och Utbildning), unless otherwise stated

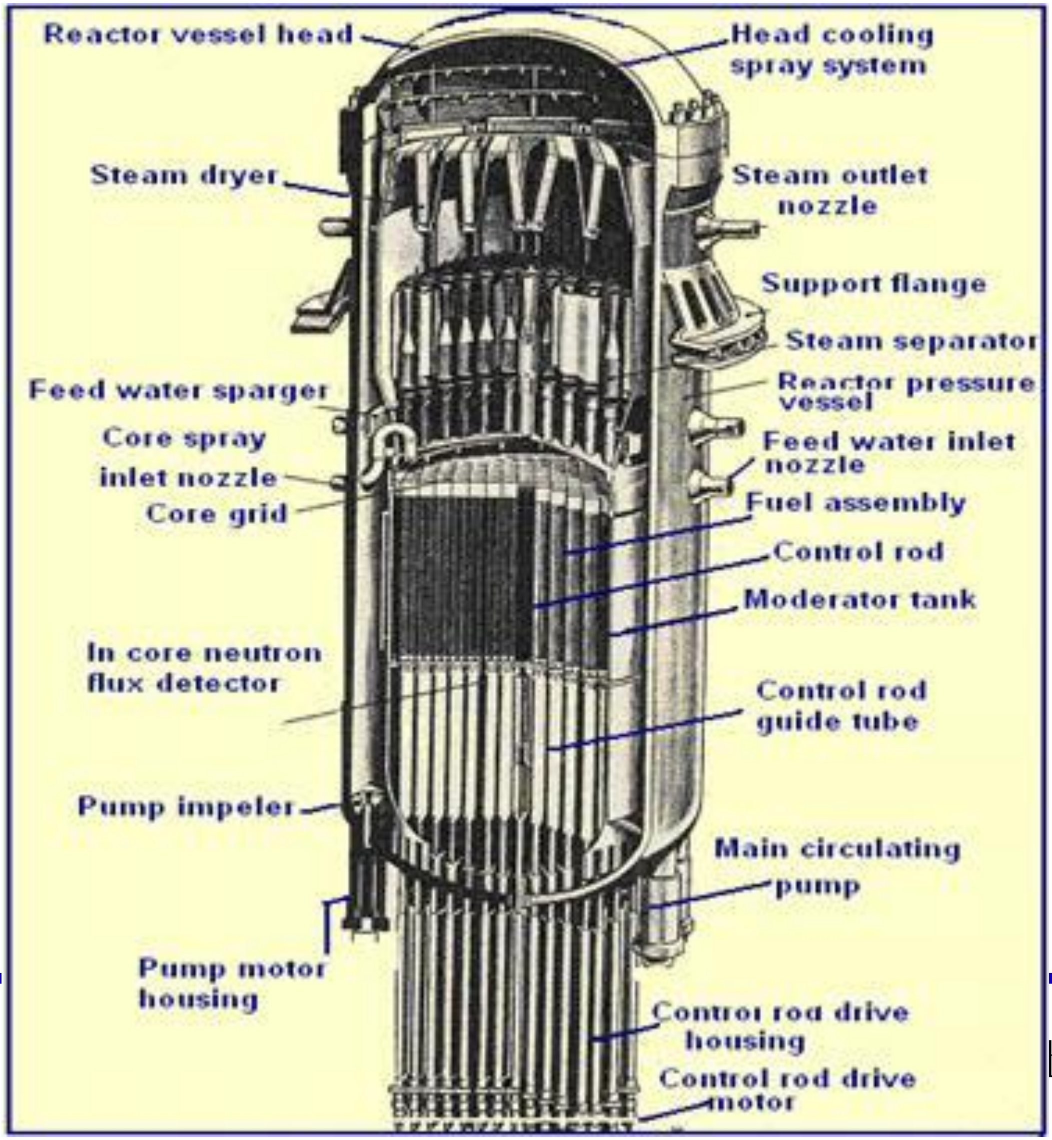


BWR vessel and core assembly

Figures from CompEdu







The BWR Steam Cycle

Figure by courtesy of KSU AB
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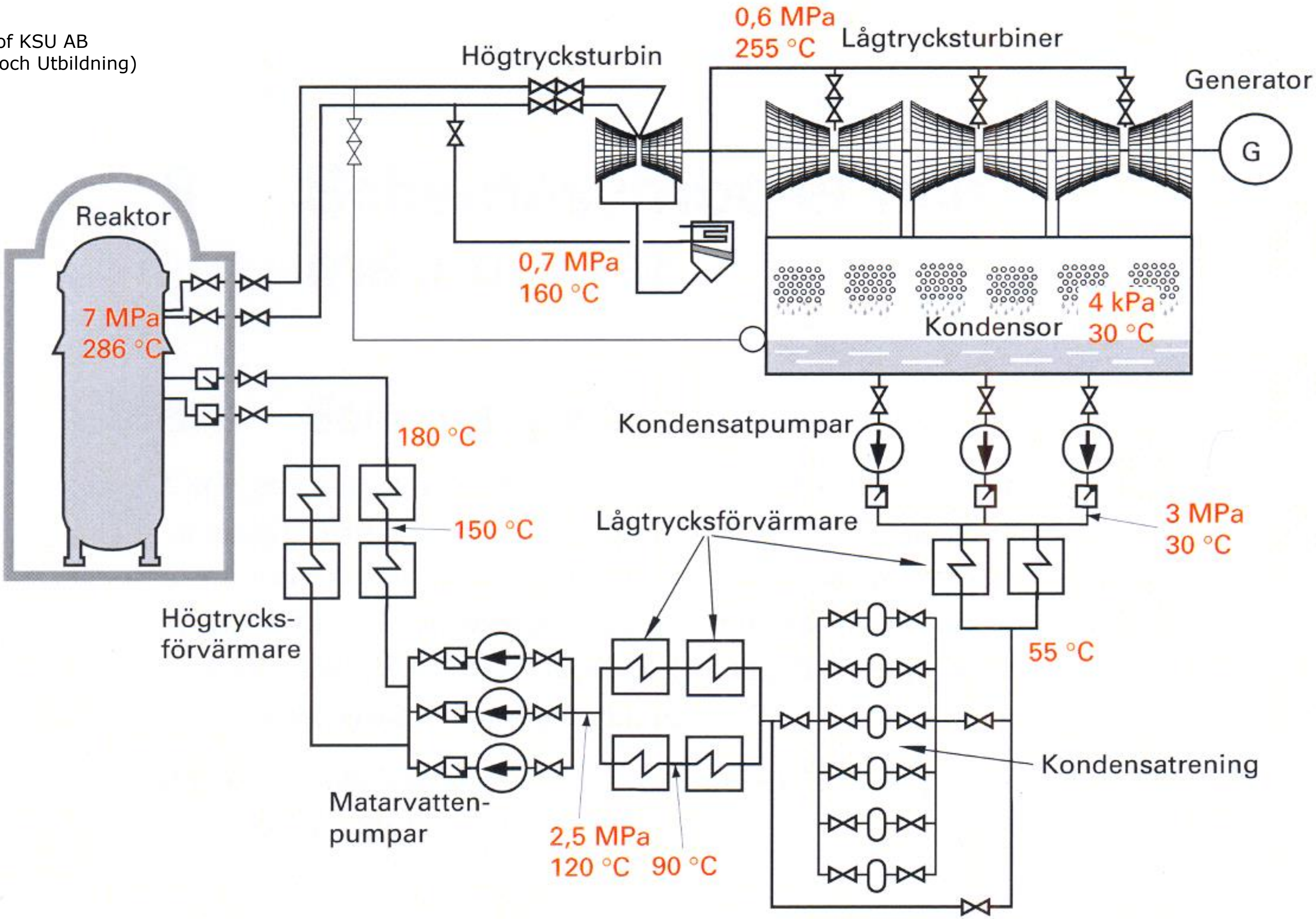

BWR steam pipe connections

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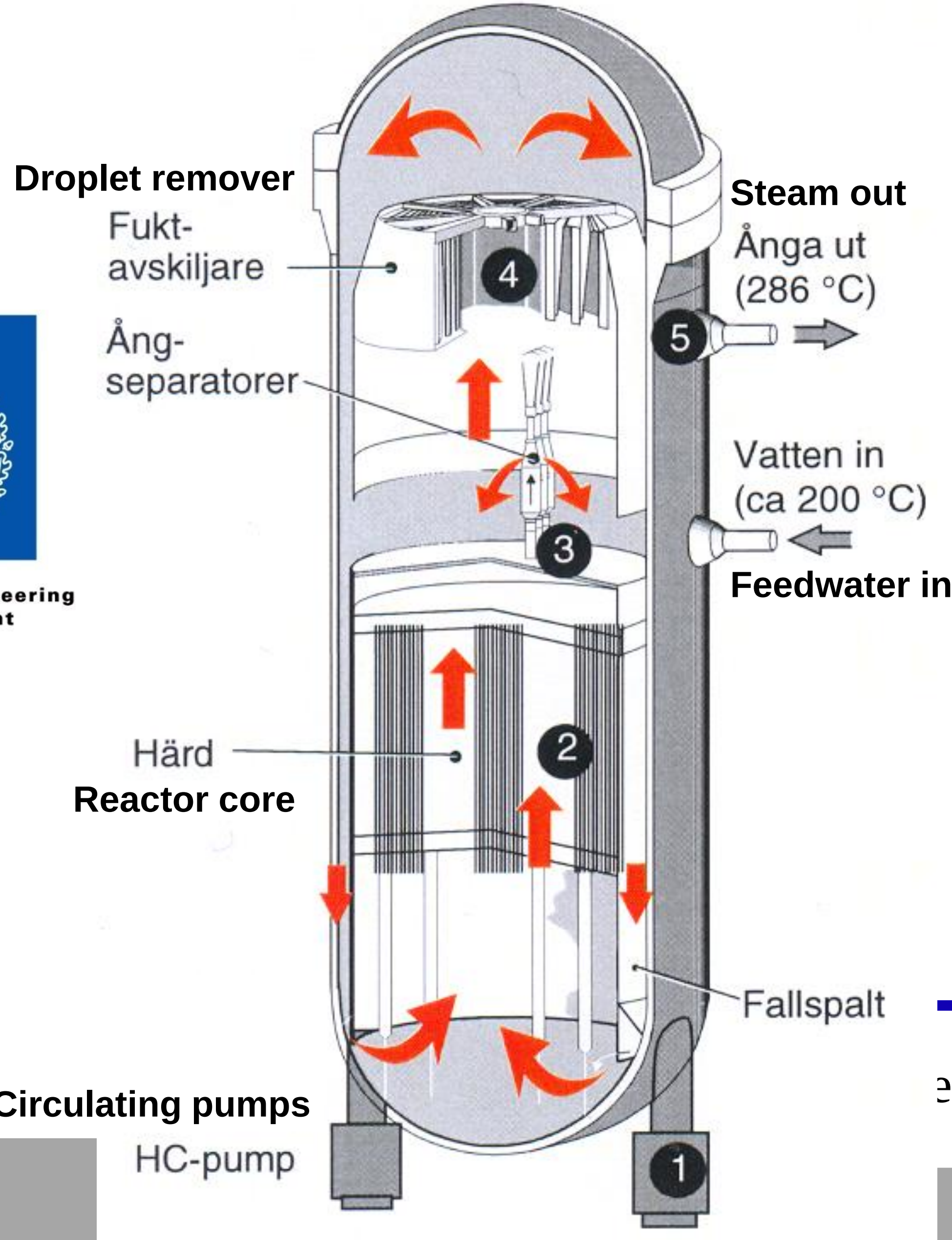
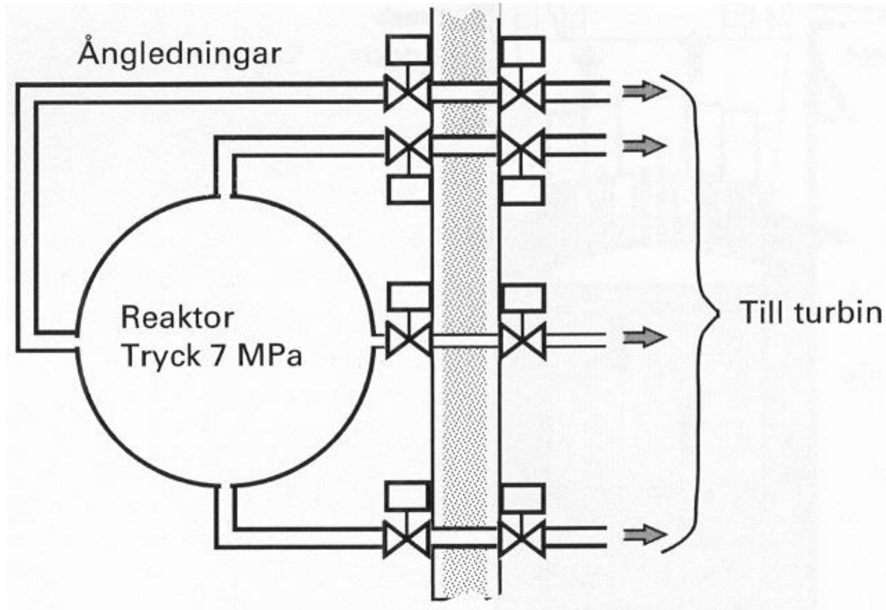


Critical steam piping penetrates the reactor containment wall



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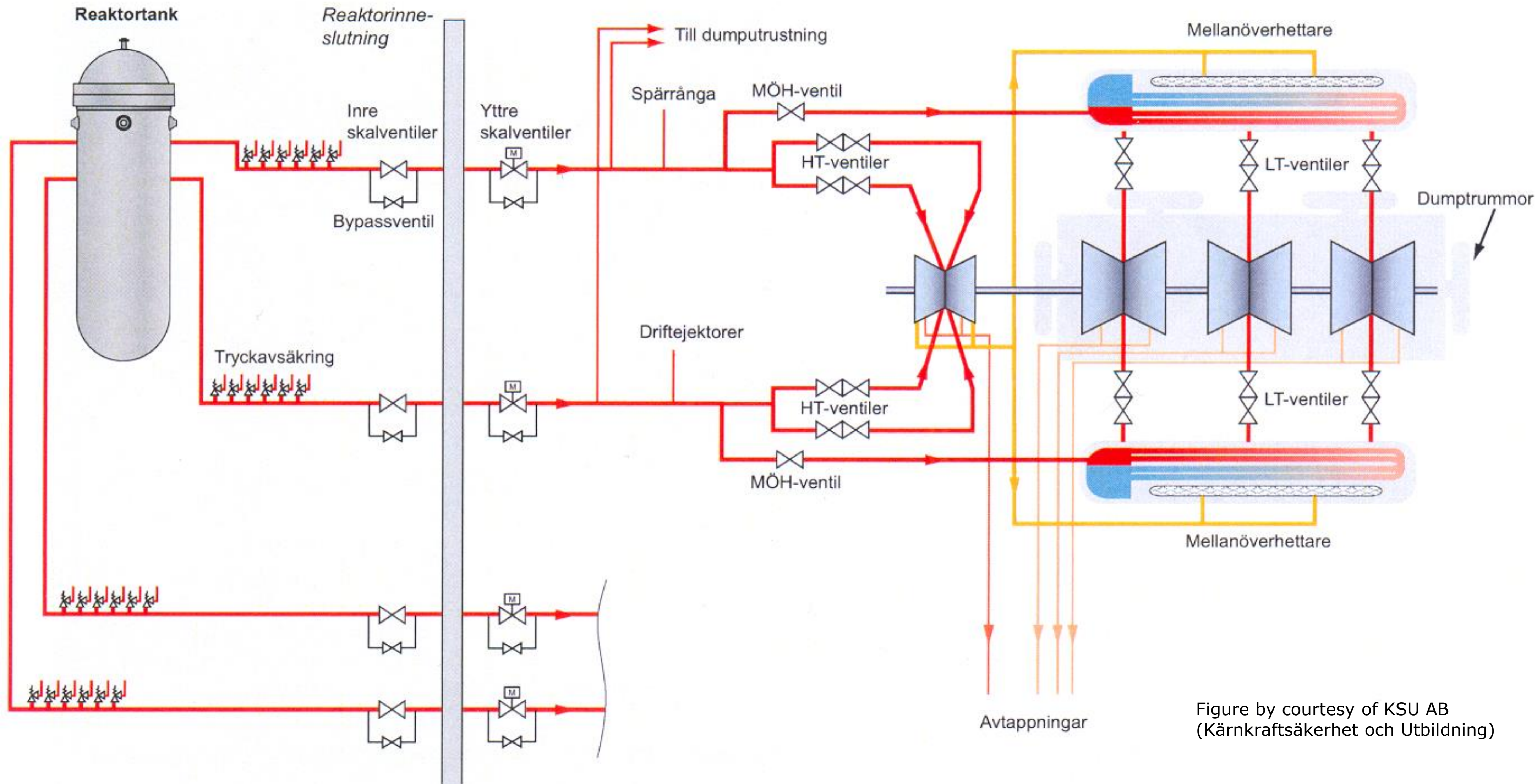
BWR Steam Headers



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PWR vessel and core assembly

Figures from CompEdu

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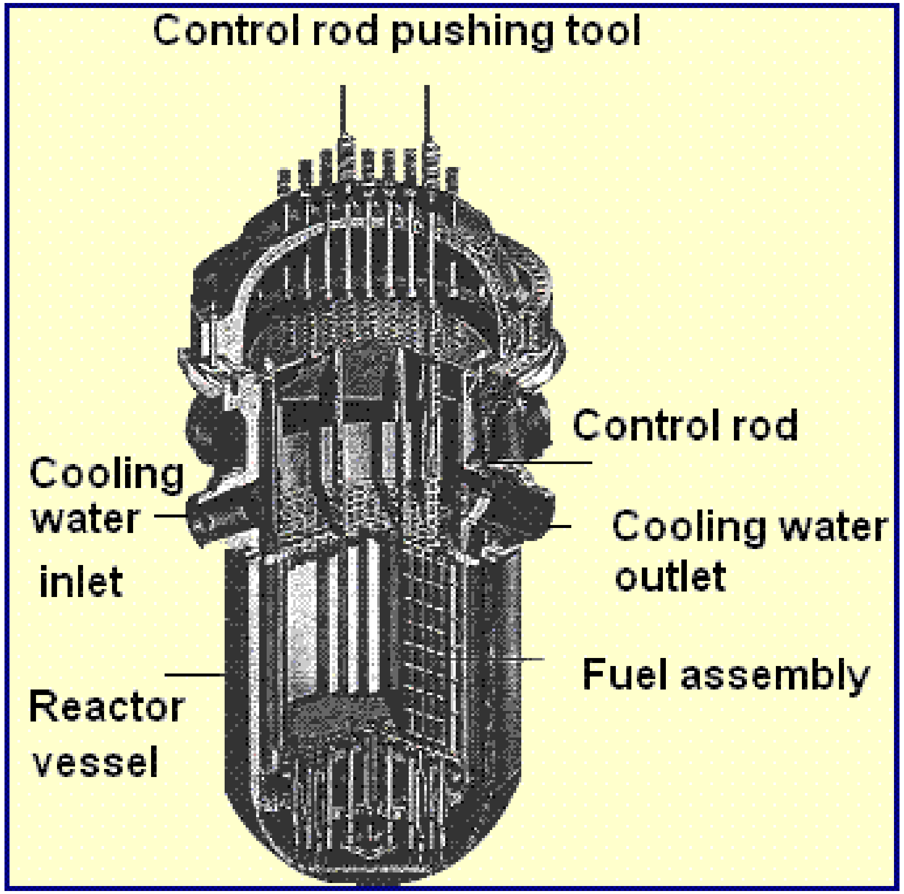

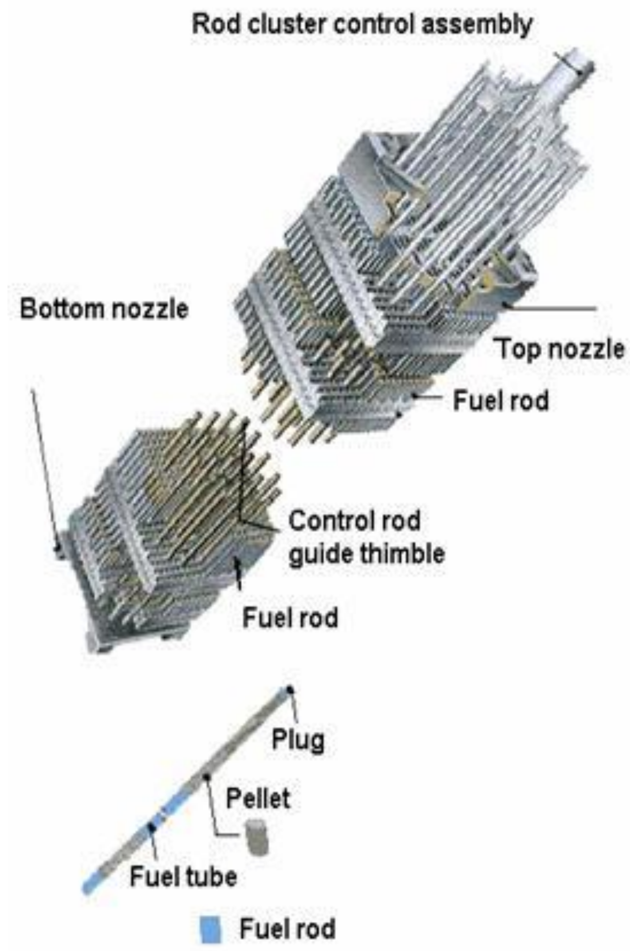

The PWR (WWR) Steam Cycle

Figure by courtesy of KSU AB
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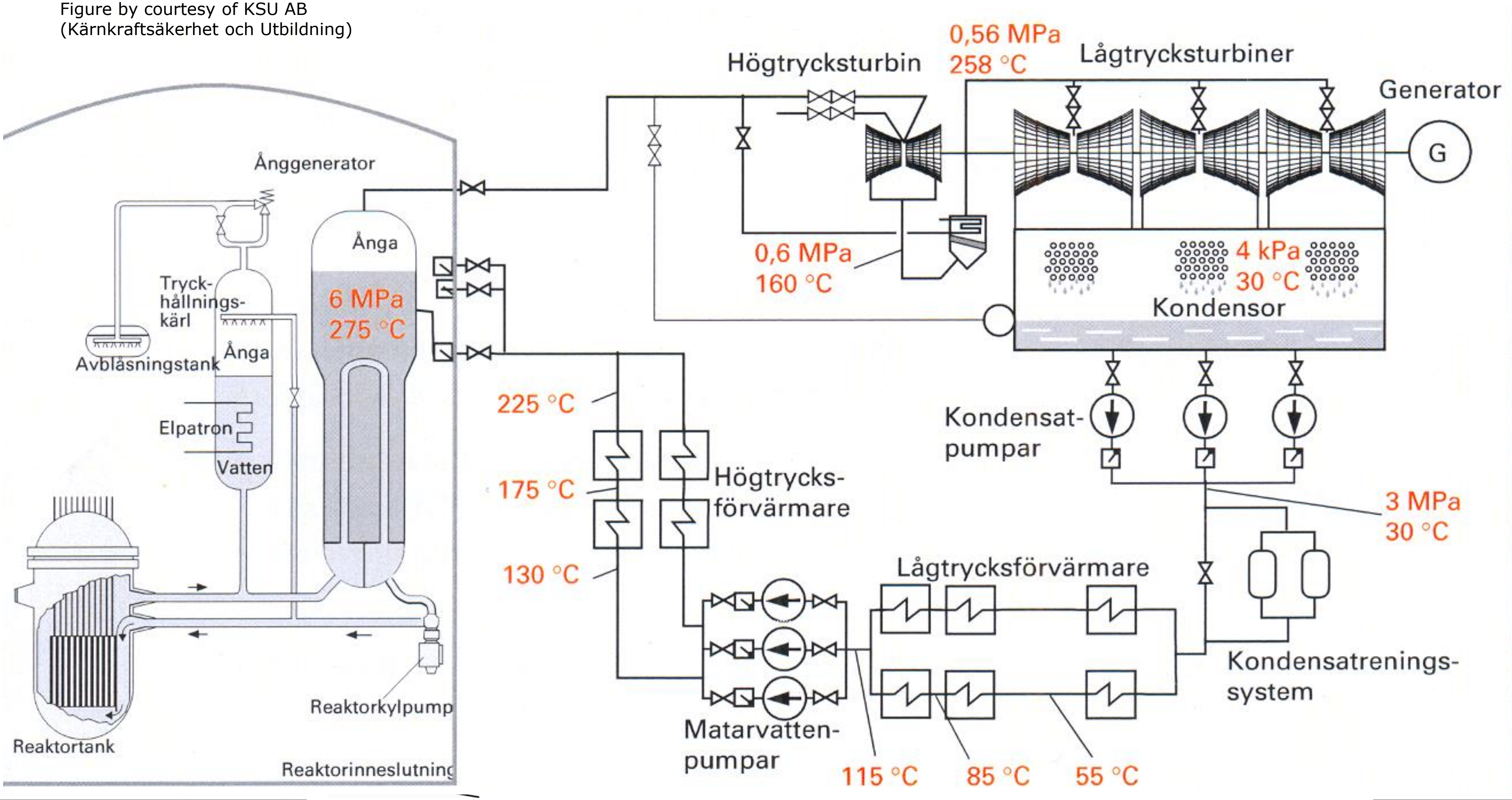
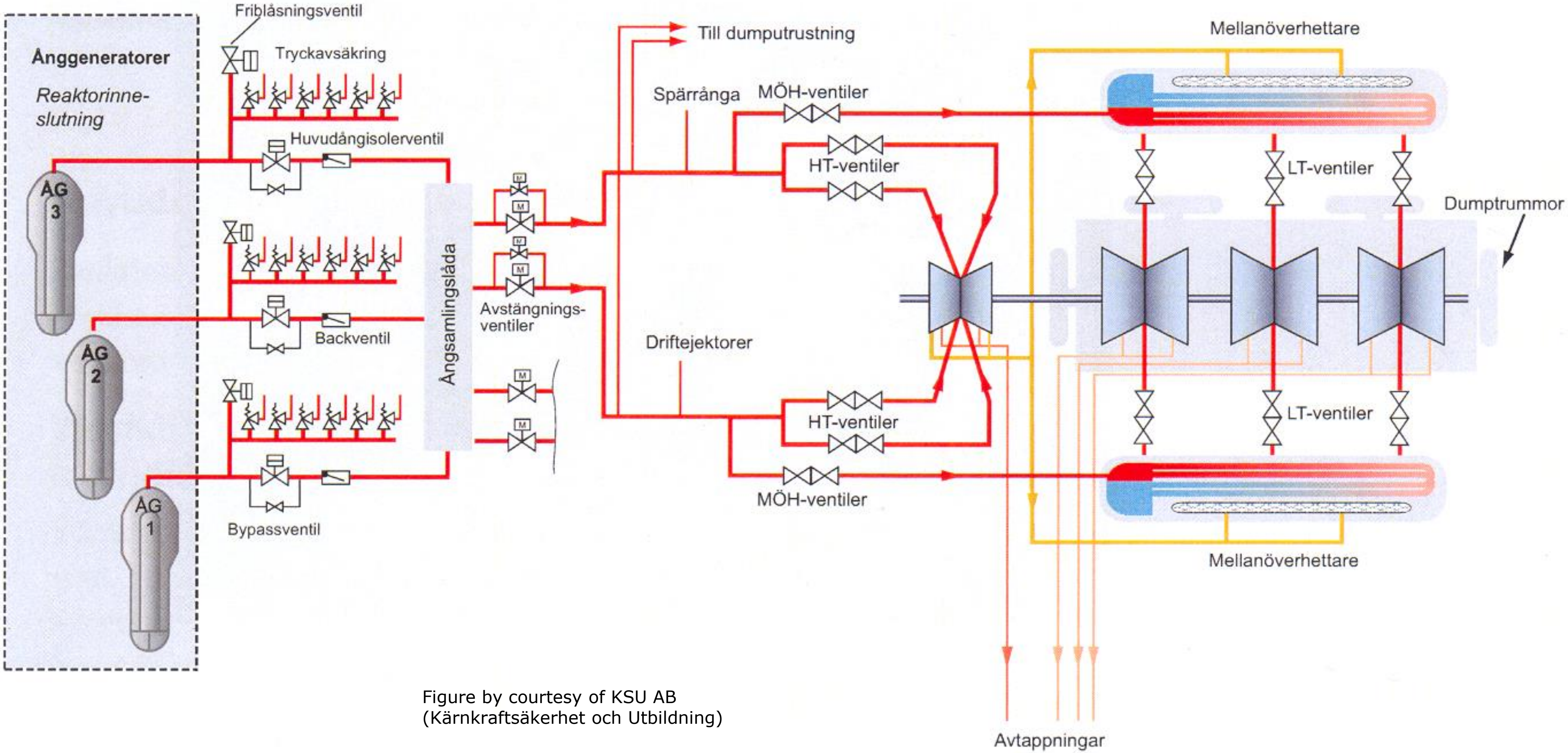


PWR Steam Headers



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PWR Steam Generators

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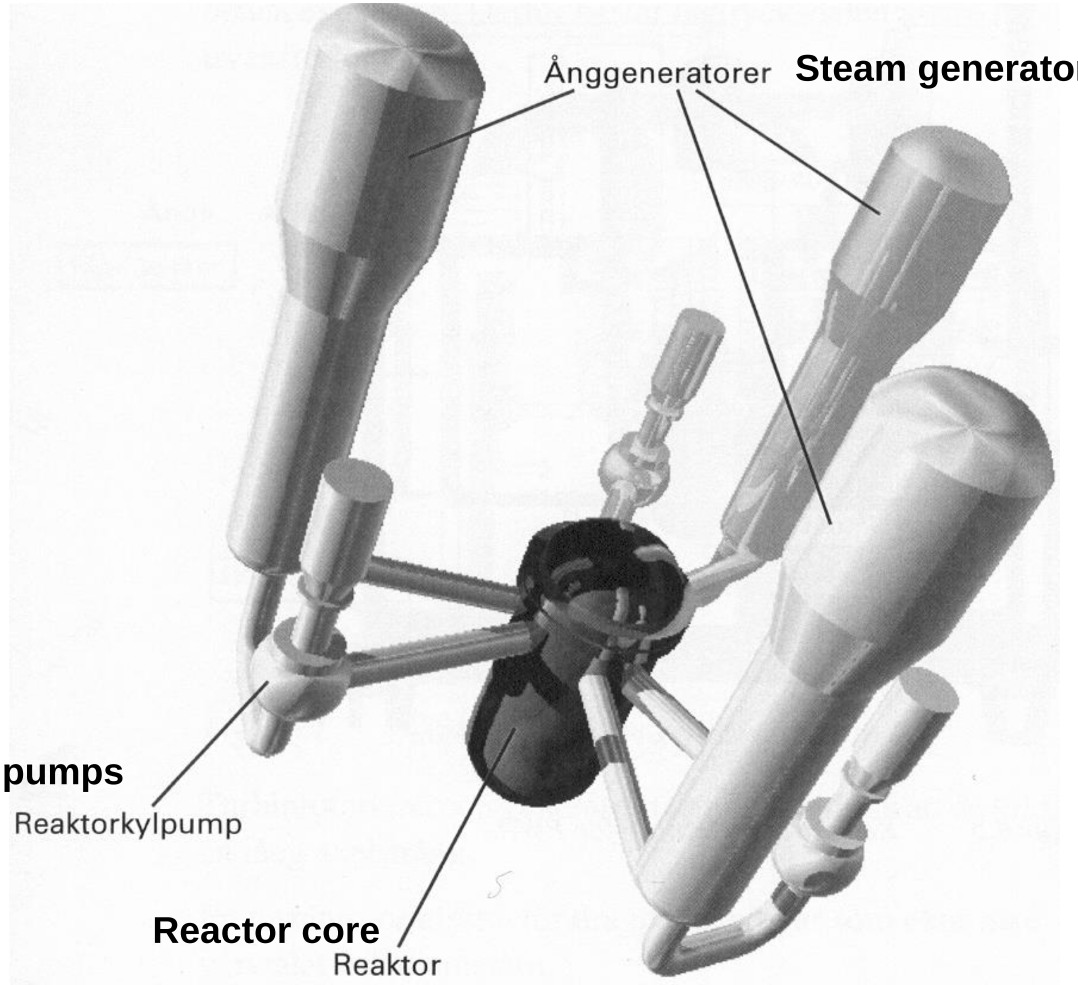

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BWR vs. PWR
similarities and differences

Operational peculiarities of BWR and PWR reactors – a review of fundamental features:

Similar in the overall concept, types of components and operational strategy. Light-water moderated and light-water cooled.
The reactor core should always be covered with water and kept at max.300 ^oC.
Similar fuel pellets and fuel rods, sealed in a zirconium alloy cladding resistant to corrosion and to radioactivity.

BWR:

Boiling in the reactor core = less complex and lower cost equipment.

Steam needs to be free from impurities and perfectly contained because it is in contact with the nuclear fuel.

The volume ratio of evaporated water (steam bubbles) in the reactor is called ”void”. The void fraction is a poor moderator, which makes the reactor self-controlled – the more water boils off, the less moderator is present, so the power decreases. The more water is circulated and thus a lower fraction boils off, the better moderator it is and the fission process becomes more powerful.

The void could do much harm if another moderator is used (e.g. graphite in the RBMK boiling reactor concept), thus losing the cooling ability while still having very good moderation. RBMK is prone to self-acceleration, which was a major reason for the Chernobyl accident.

Water is prone to radiolysis (radioactivity-triggered electrolytic splitting of water to H_2 and O_2 gas). Hydrogen is dangerous because it can ignite, oxygen is bad because it can initiate corrosion. Zr cladding and other metal surfaces can be oxidized by water and also produce hydrogen gas.

PWR:

Non-boiling reactor (highly pressurized core) = difficult and costly.

The power cycle is a secondary circuit and has no contact with the nuclear fuel, but the steam generator is a bulky heat exchanger, operating at very low ΔT.

There is no void in the reactor and no chance for self-control, but here some inhibitor (Boron) can be directly dissolved in the primary circuit water and assist the control rods, thus providing a wider choice of power control options.

Less prone to radiolysis, but the Zr cladding and other metal surfaces in the primary circuit are similarly subjected to danger of oxidation by water, triggered by radioactive discharge.

Same is valid for CANDU reactor, basically a PWR with heavy water.

Start-up and shut-down process is similar for all reactor concepts. ”Criticality” is used to denote the ability of the fission to accelerate (when neutron economy is positive) or slow down (when neutron economy is negative or when the fissile material is not sufficient). A reactor needs to be ”critical” if it would be able to start up at all.

PWR Recirculating Pumps

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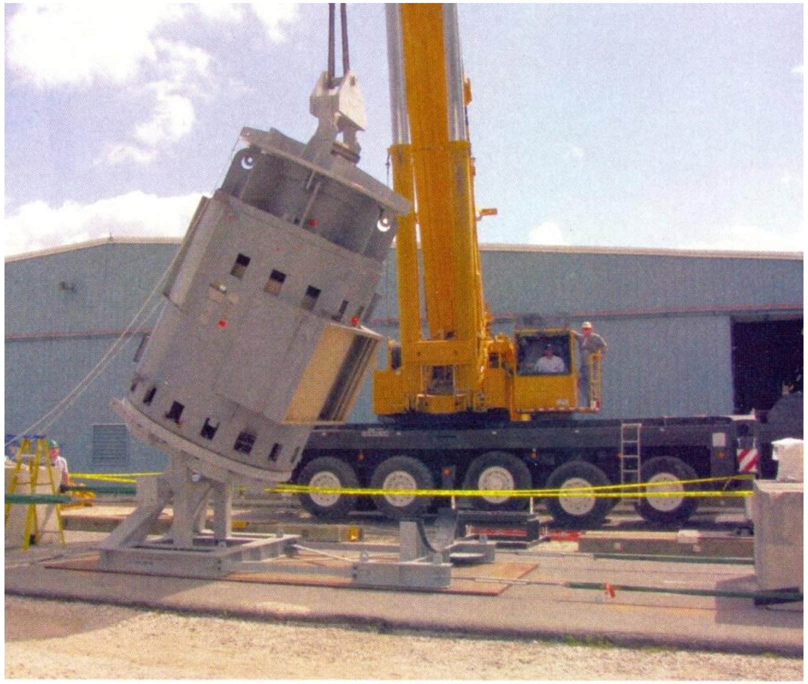
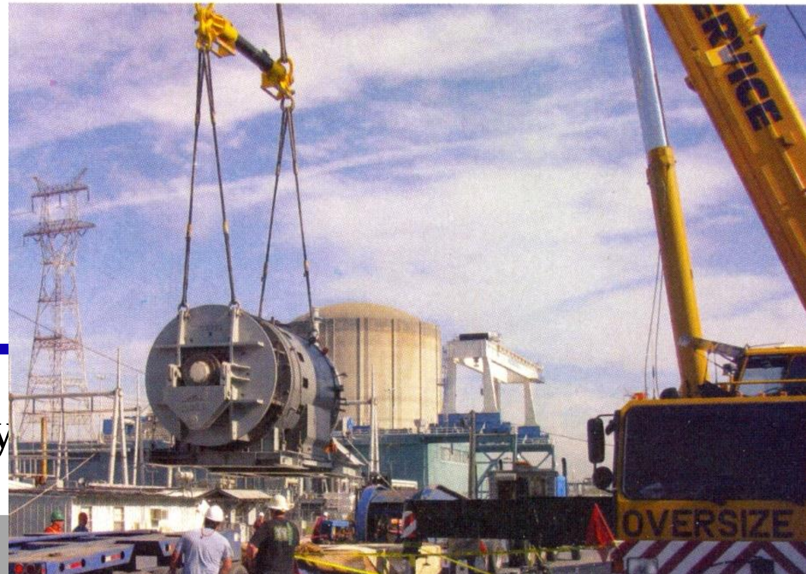
The circulating pump for a large PWR can be almost 60 tons heavy, with a power of 6 MW (just about the same parameters of a powerful freight train locomotive).

Fitting it in or out of the reactor for repair or replacement can take up to 25 days…

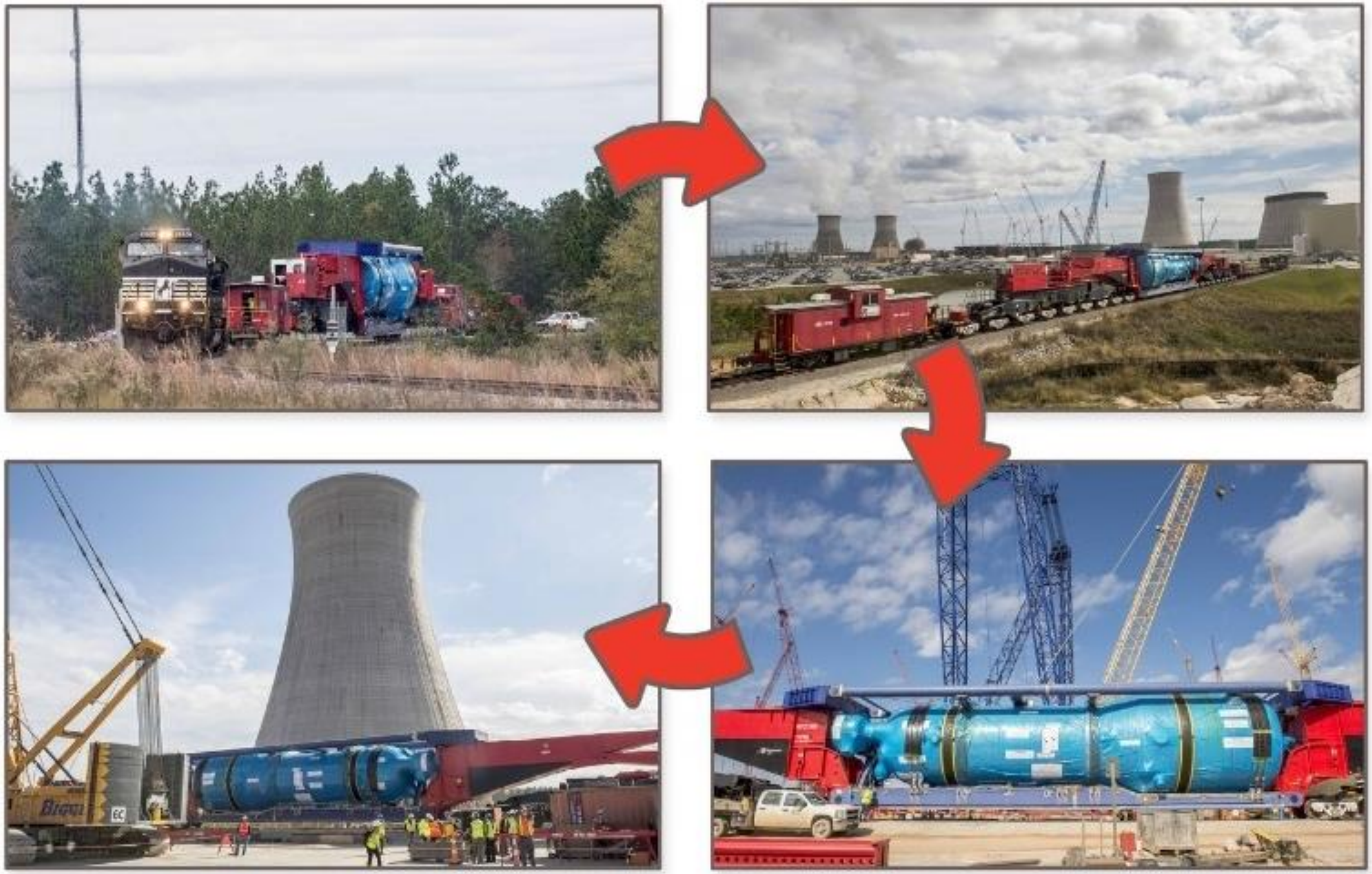




Pictures from the ASME magazine
”Mechanical Engineering”

Steam Generator for the PWR

**Delivery of the steam generator (600 ton)
for the new AP1000 reactor**



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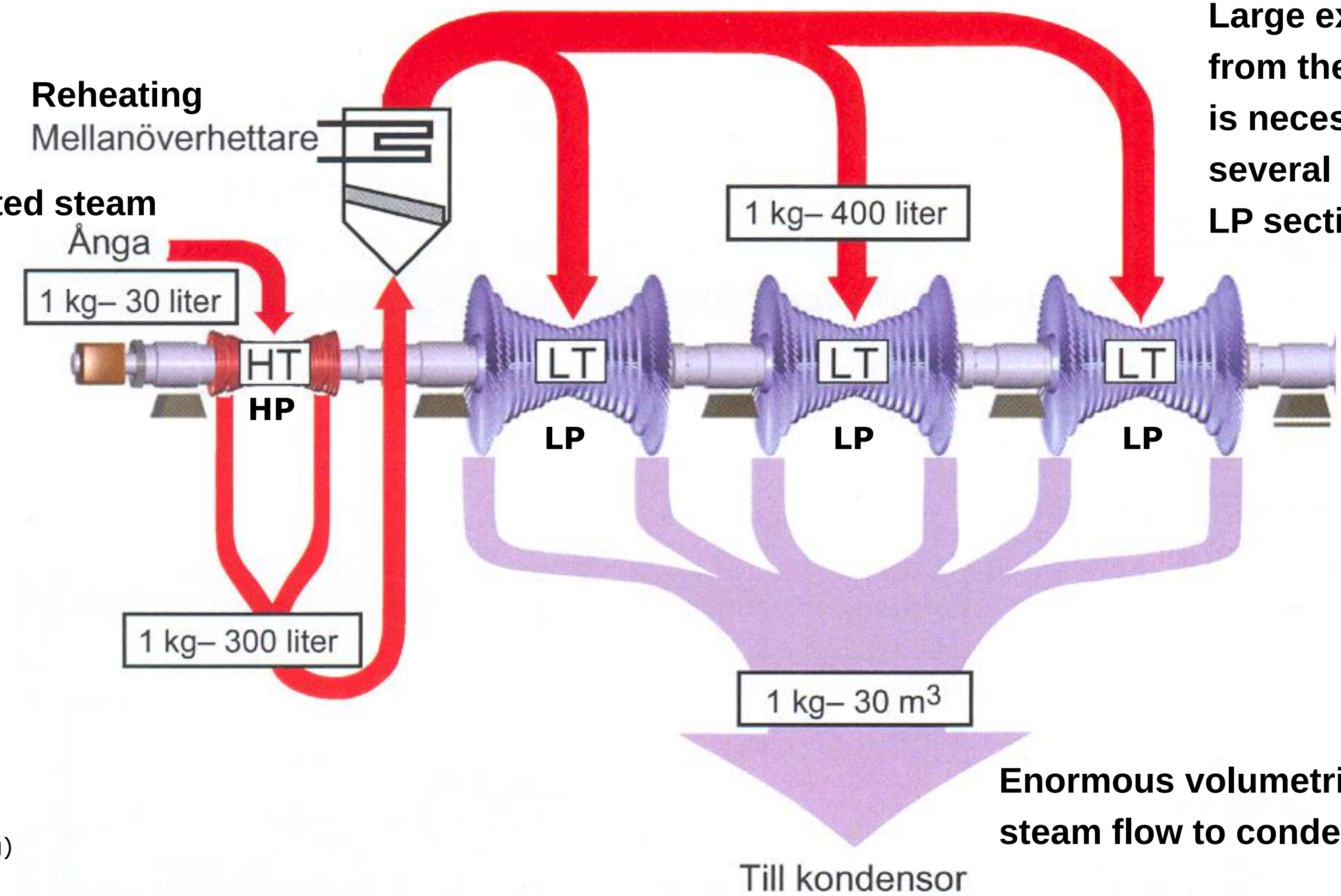
Pictures from the "Power Engineering" magazine.
This has also been documented in a nice video found on:
http://www.power-eng.com/articles/2015/03/video-one-nuclear-power-steam-generator-s-trip-to-the-summer-plant-site.html?cmpid=enl-poe-weekly-april-03-2015

Steam Turbine Sections



Large exit area from the turbine is necessary, thus several parallel LP sections

Enormous volumetric steam flow to condenser

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Steam Expansion

Carnot Efficiency potential:
$(T_H - T_C)/T_H = (553-303)/553 = 45\%$

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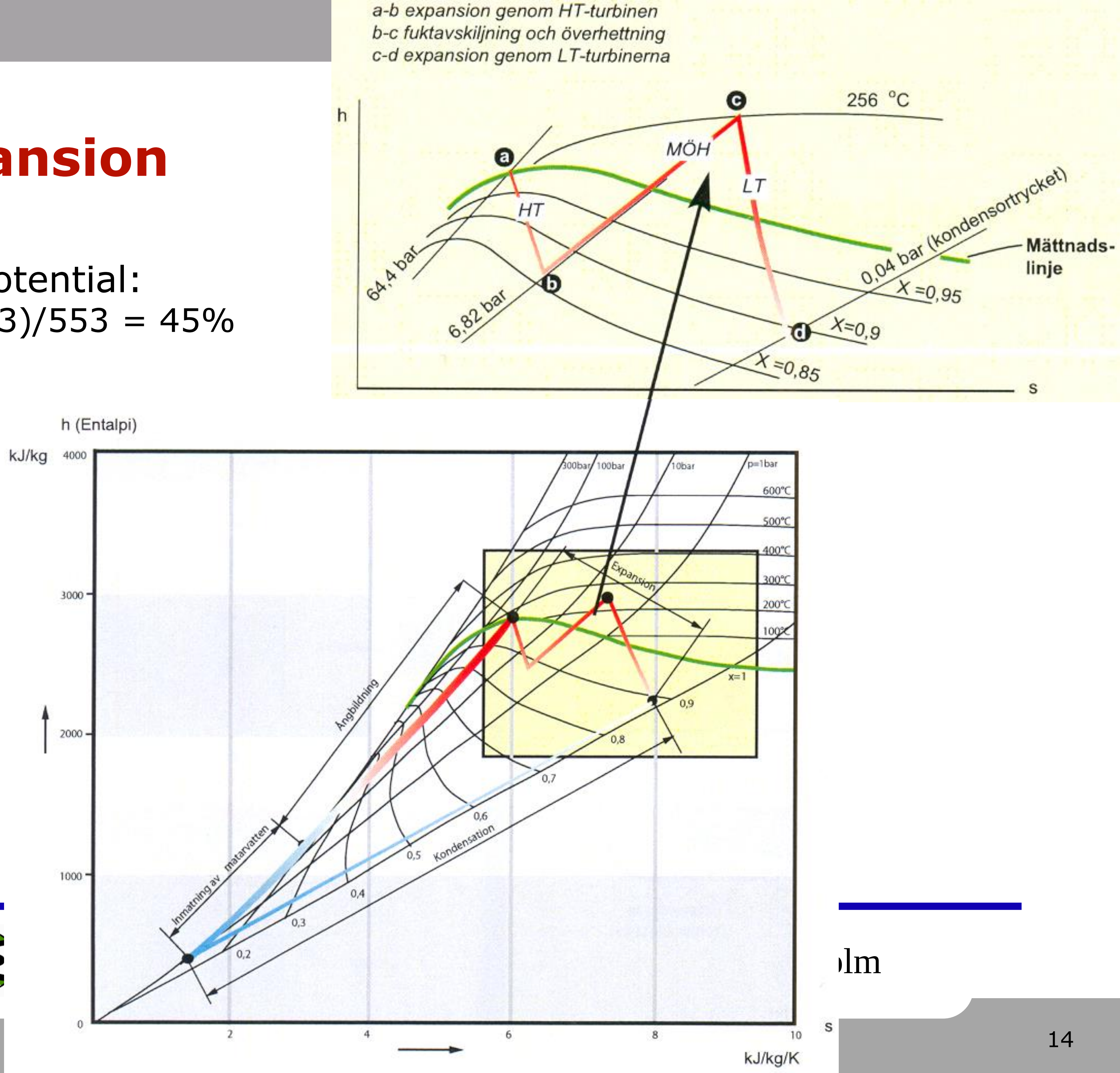

Aggregated expansion line

Full-load & part-load expansion lines with droplet extraction in the wet zone for the steam turbine at the Ascó nuclear power plant near Barcelona.

(Figure provided by Arnau Creus Vila)

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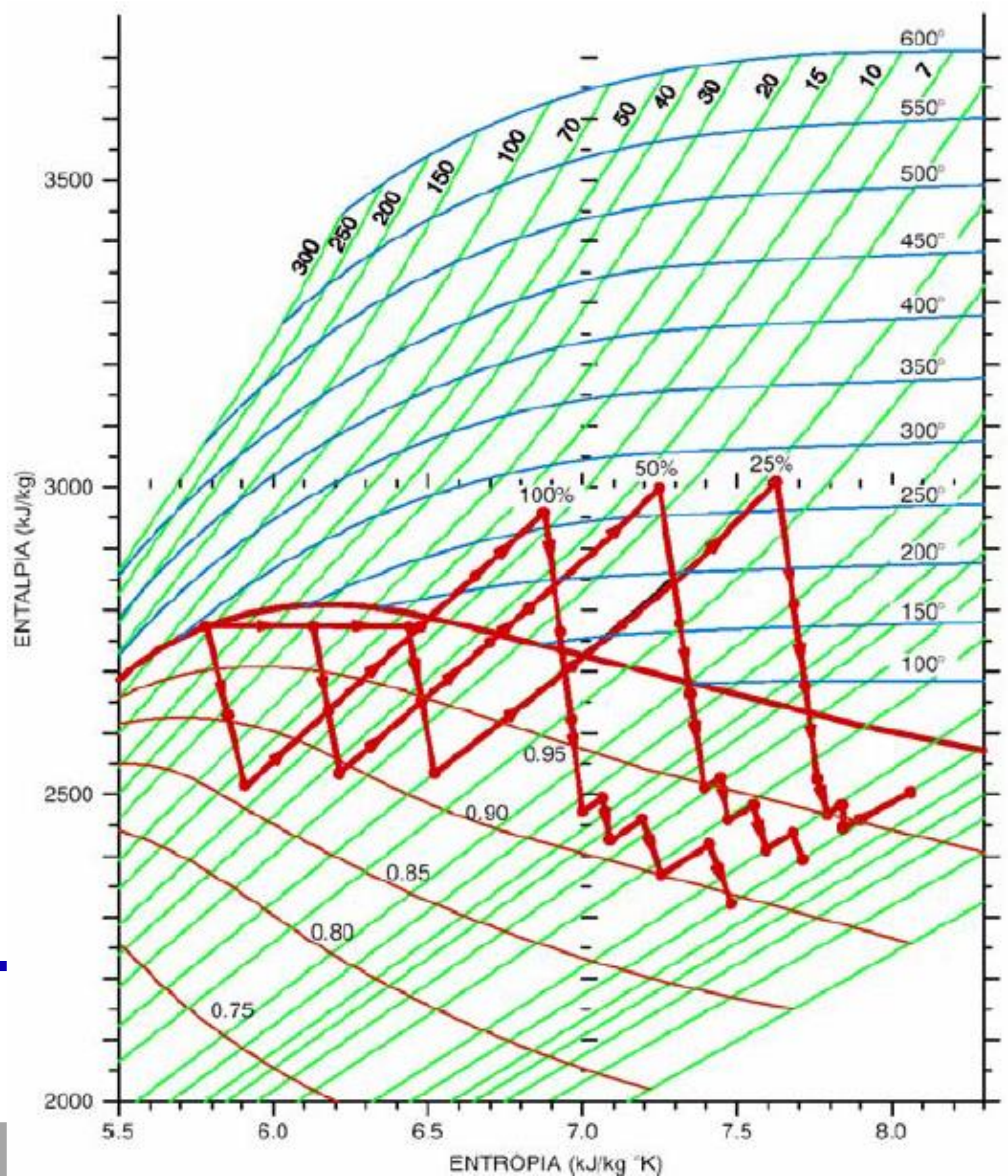

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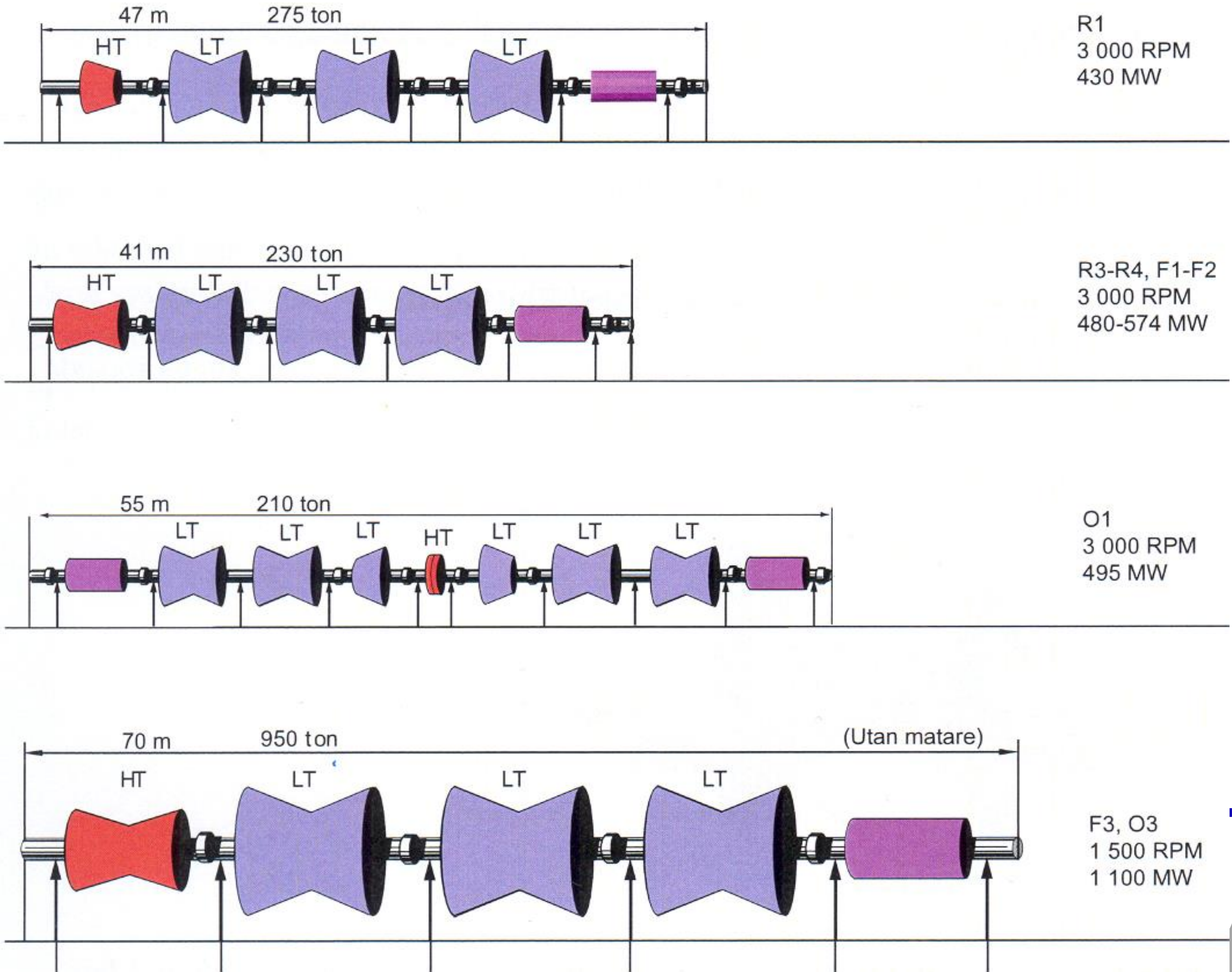
Turbine Drivetrain



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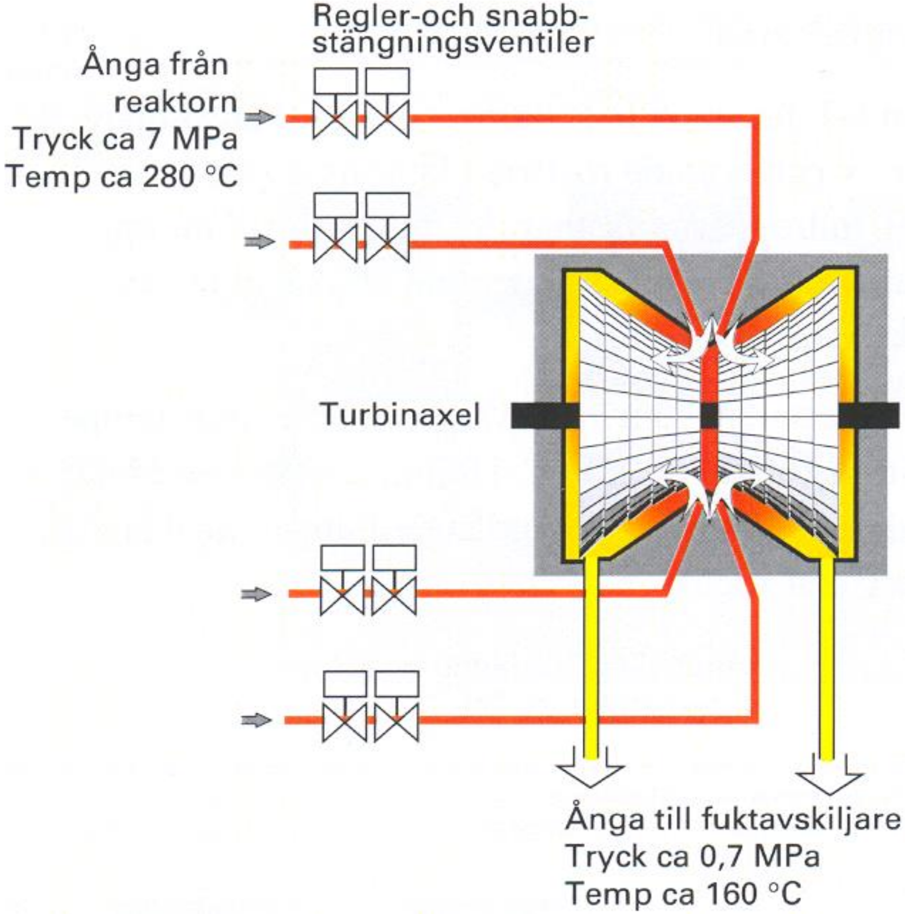
Many (and huge) turbine sections, coupled together on a very long shaft

HP Turbine



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Reheat

Figure by courtesy of KSU AB
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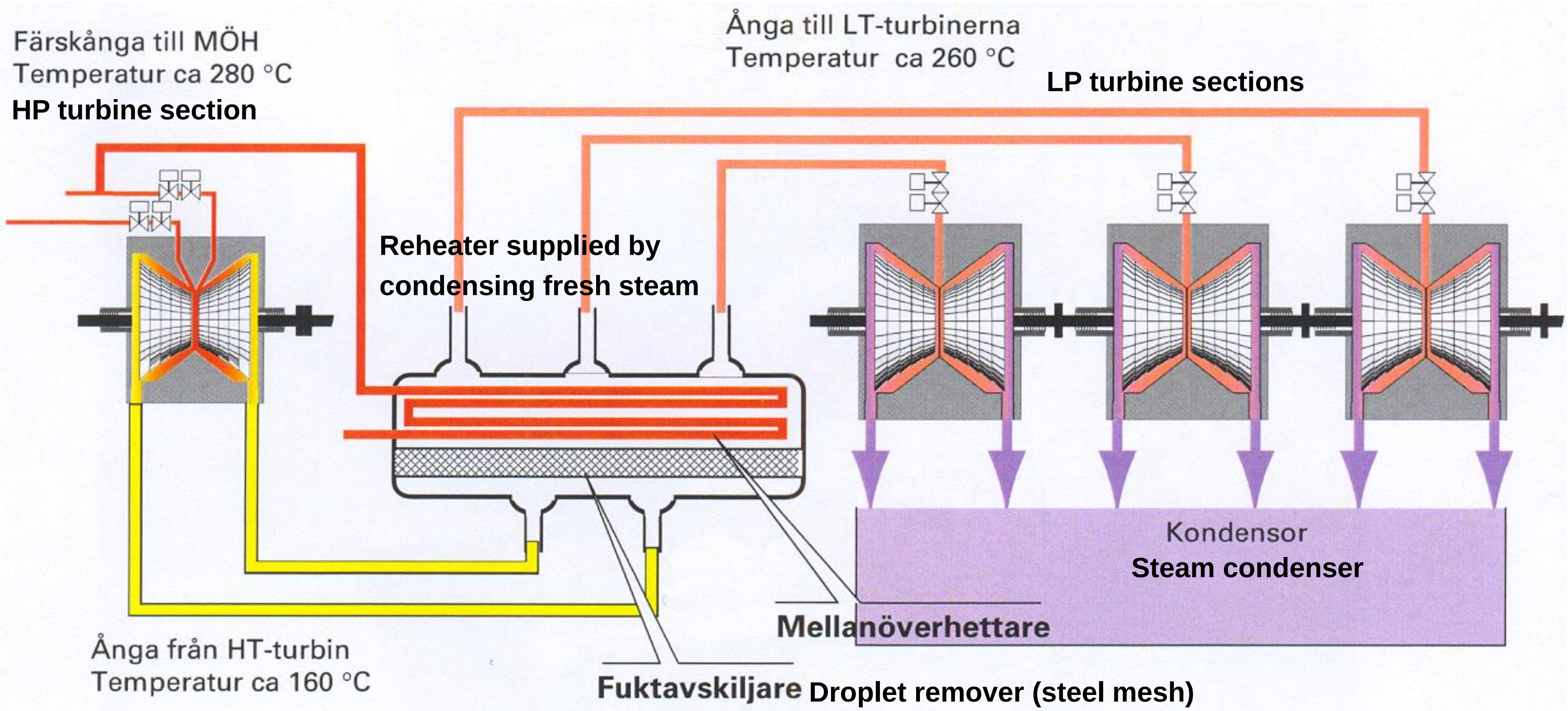
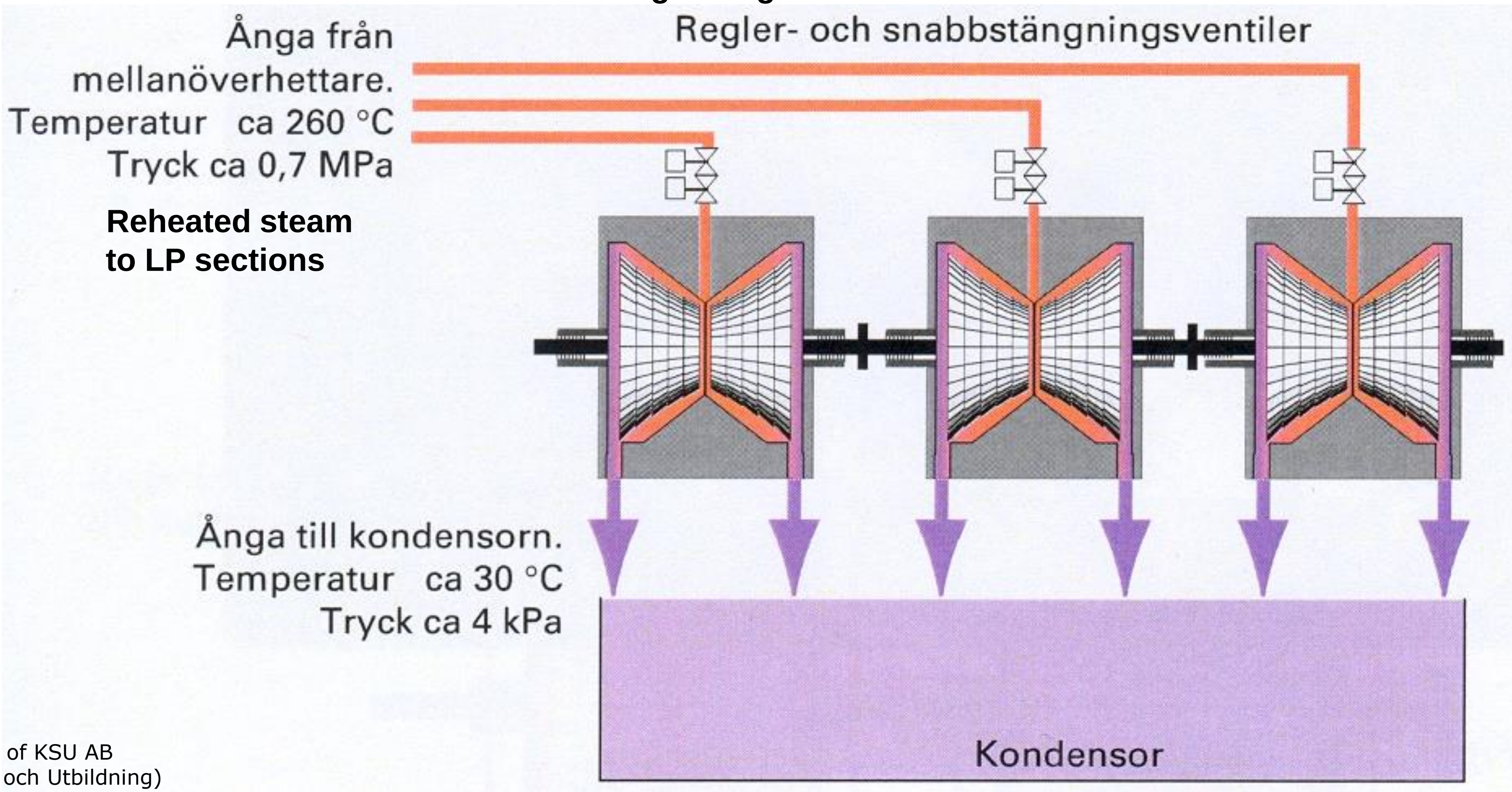


LP Turbine Sections

Regulating and shut-off valves on each steam line

Reheated steam to LP sections



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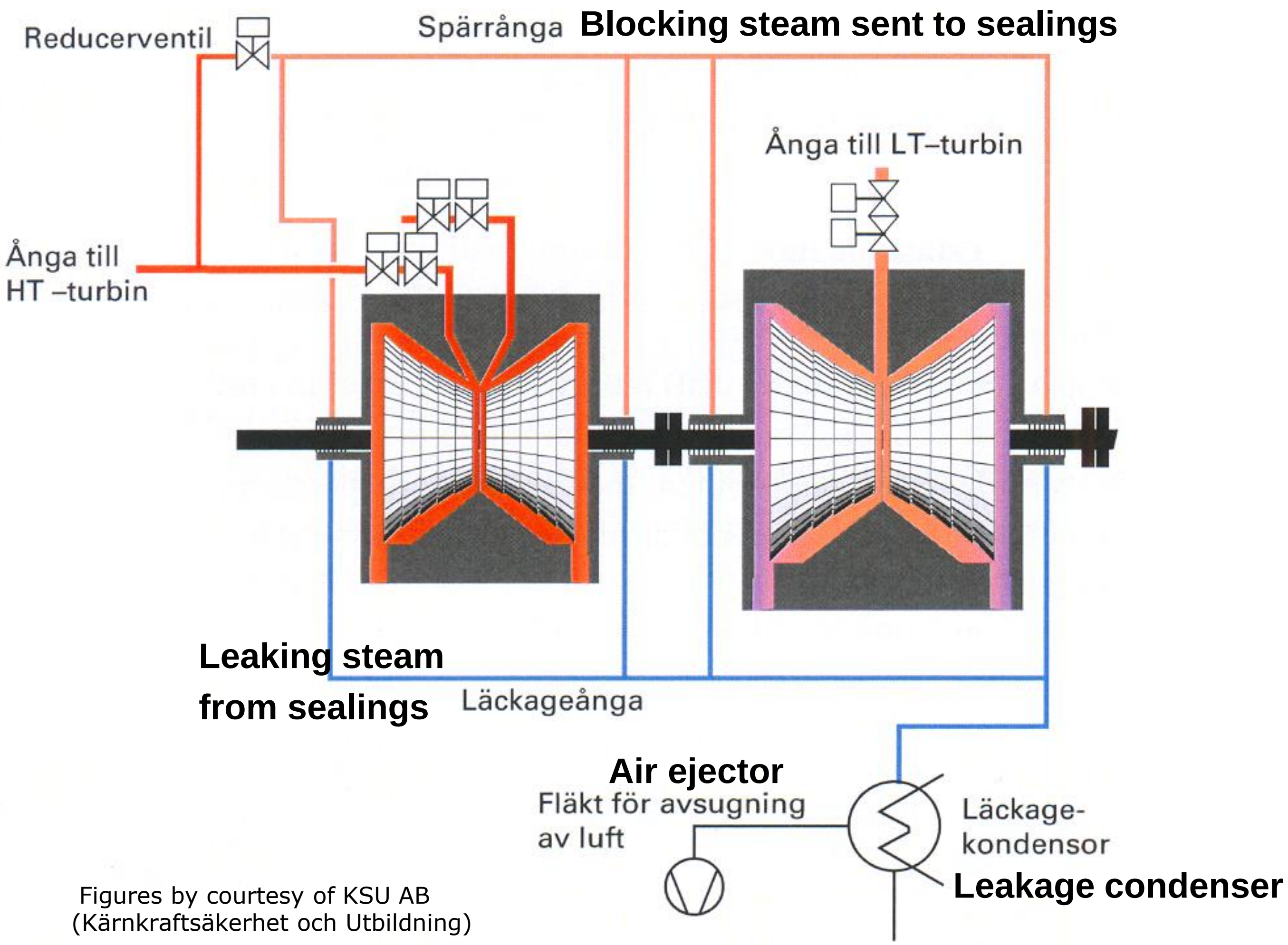
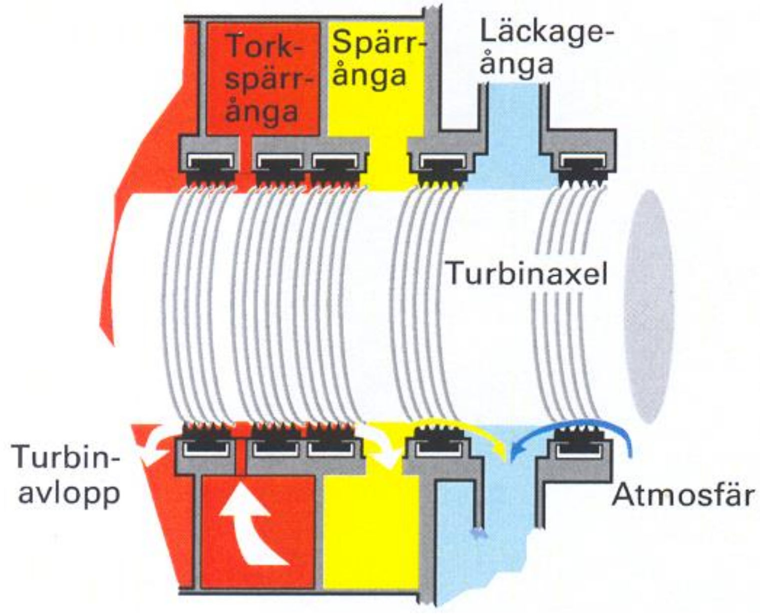
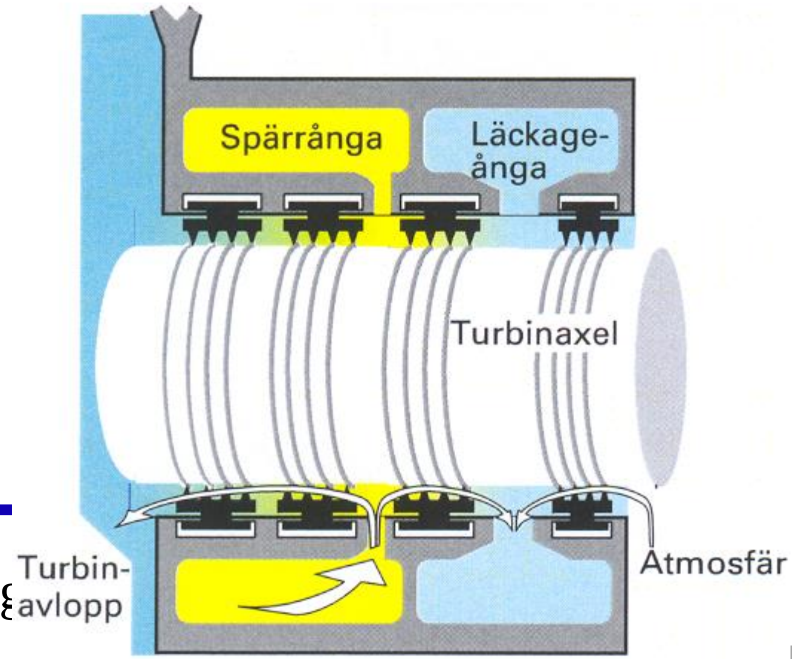
Turbine Shaft Sealings







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Feedwater Preheaters

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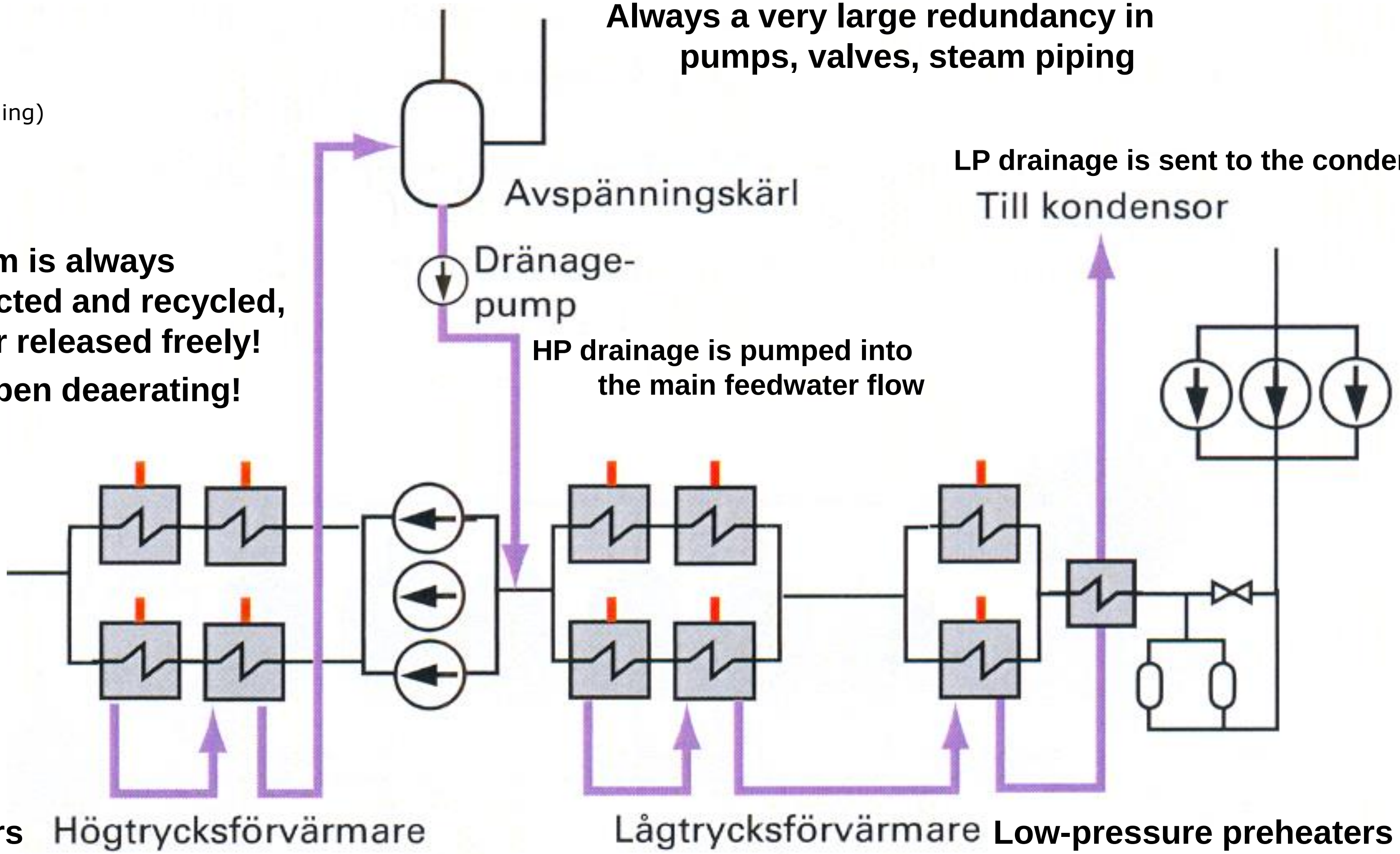
Steam is always collected and recycled, never released freely!

No open deaerating!

Always a very large redundancy in pumps, valves, steam piping

HP drainage is pumped into the main feedwater flow

LP drainage is sent to the condenser

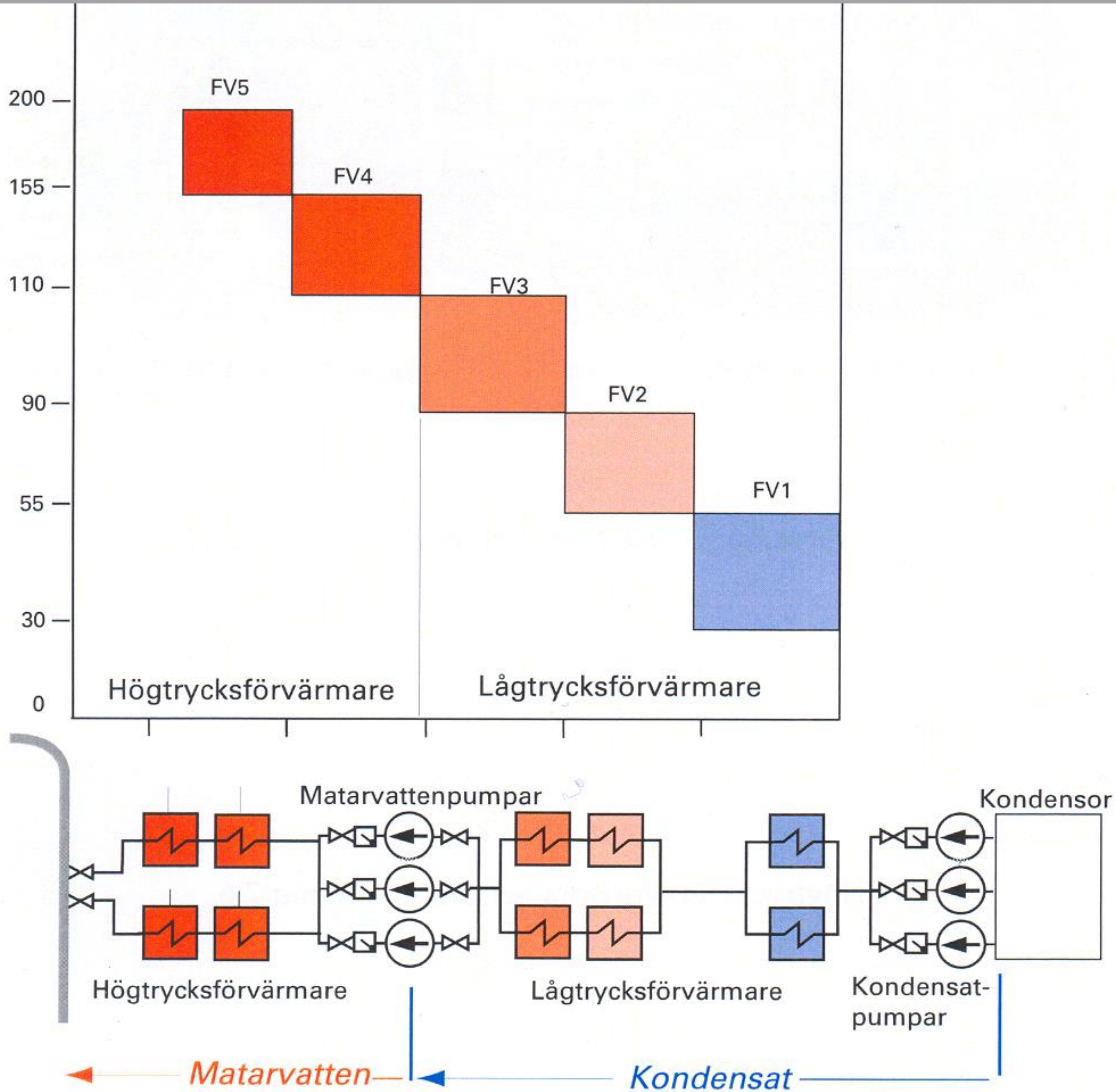


High-pressure preheaters

Low-pressure preheaters

Preheater Configuration

No deaerator/ feedwater tank, no release to atmosphere, only chemical treatment of feedwater, only closed preheaters



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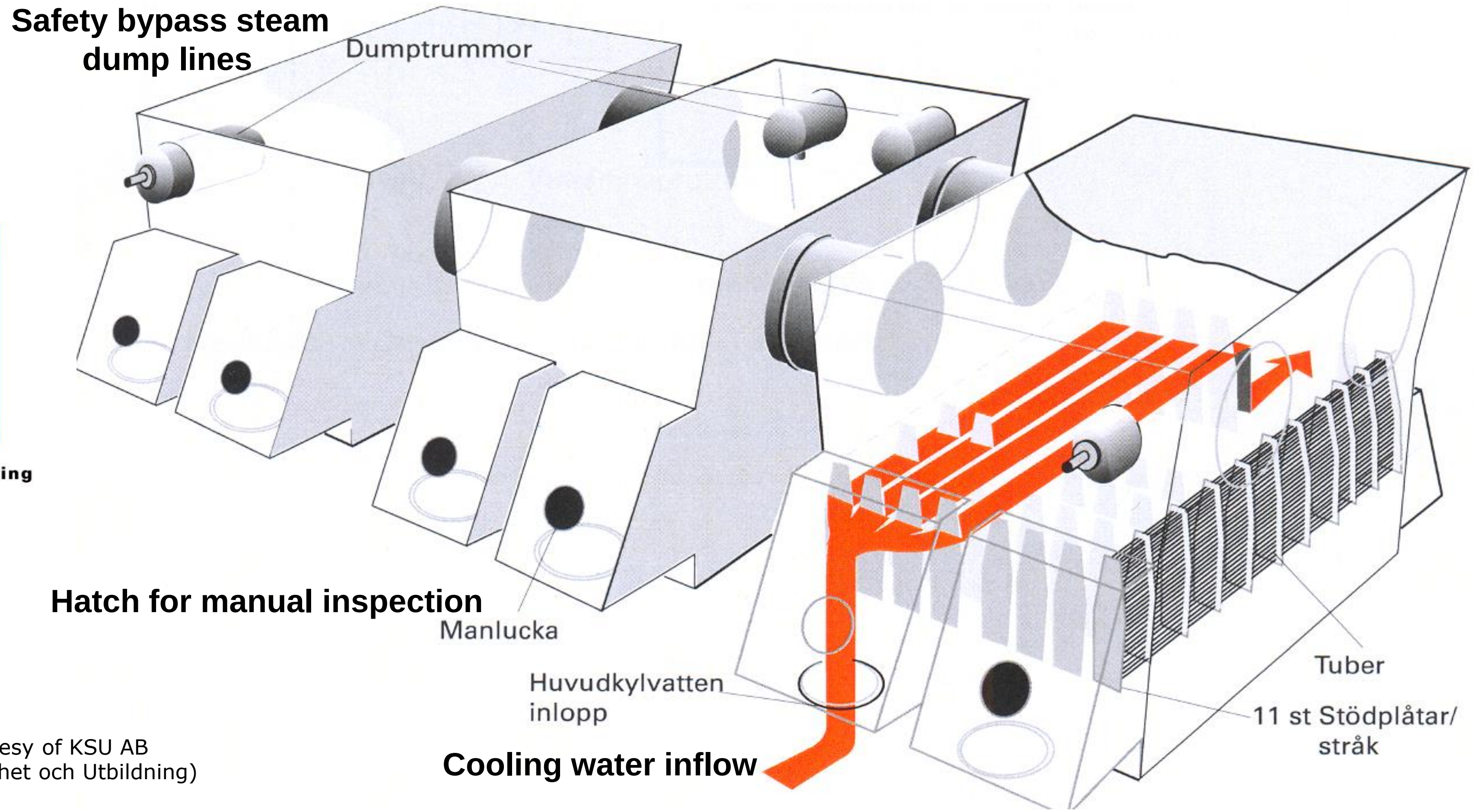
Steam Condenser



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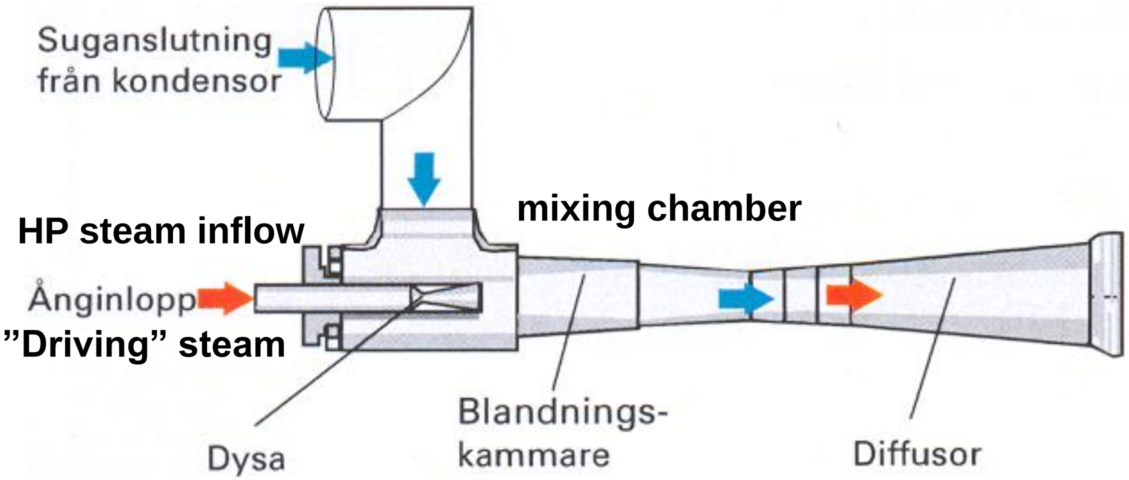
Condenser Ejectors

Suction inflow of non-condensable gases from condenser

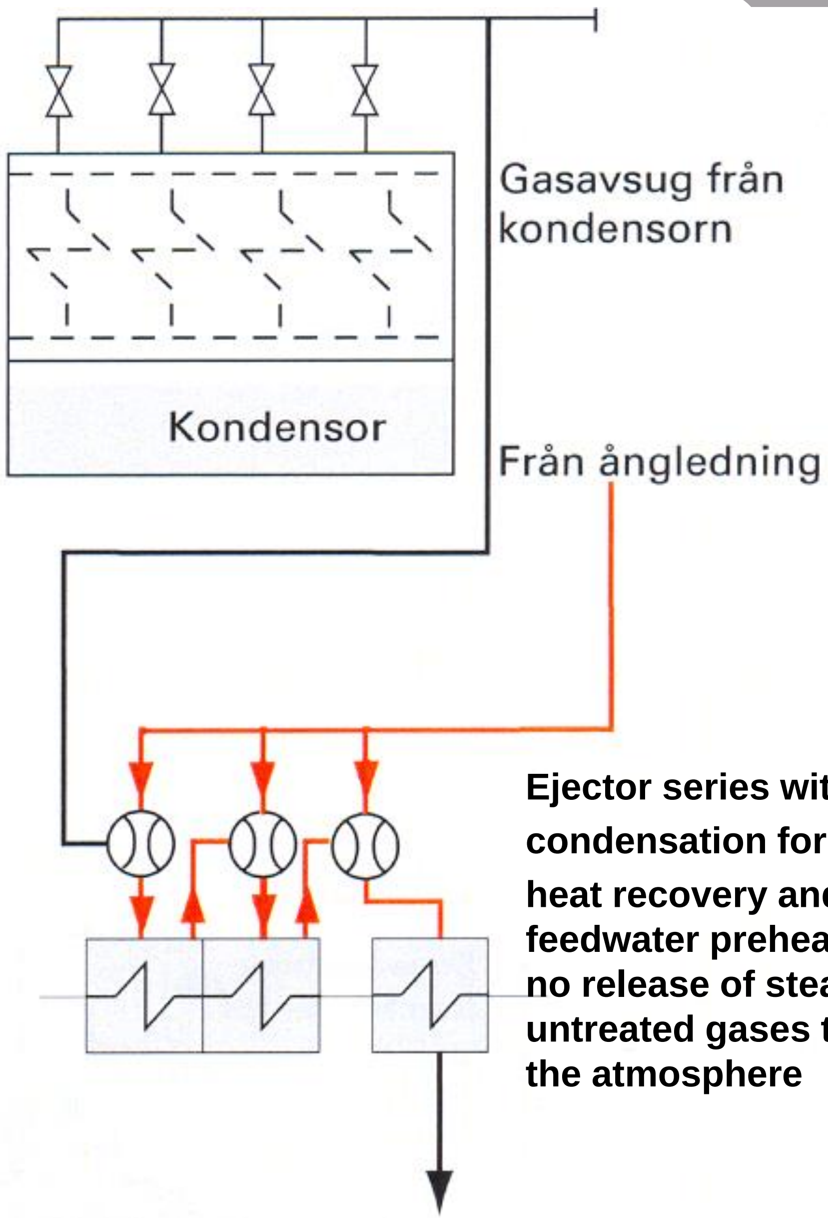


HP steam inflow

”Driving” steam

mixing chamber

Diffuser section:
decreases the speed,
increases the pressure



Ejector series with condensation for heat recovery and feedwater preheating, no release of steam or untreated gases to the atmosphere

Figures by courtesy of KSU AB
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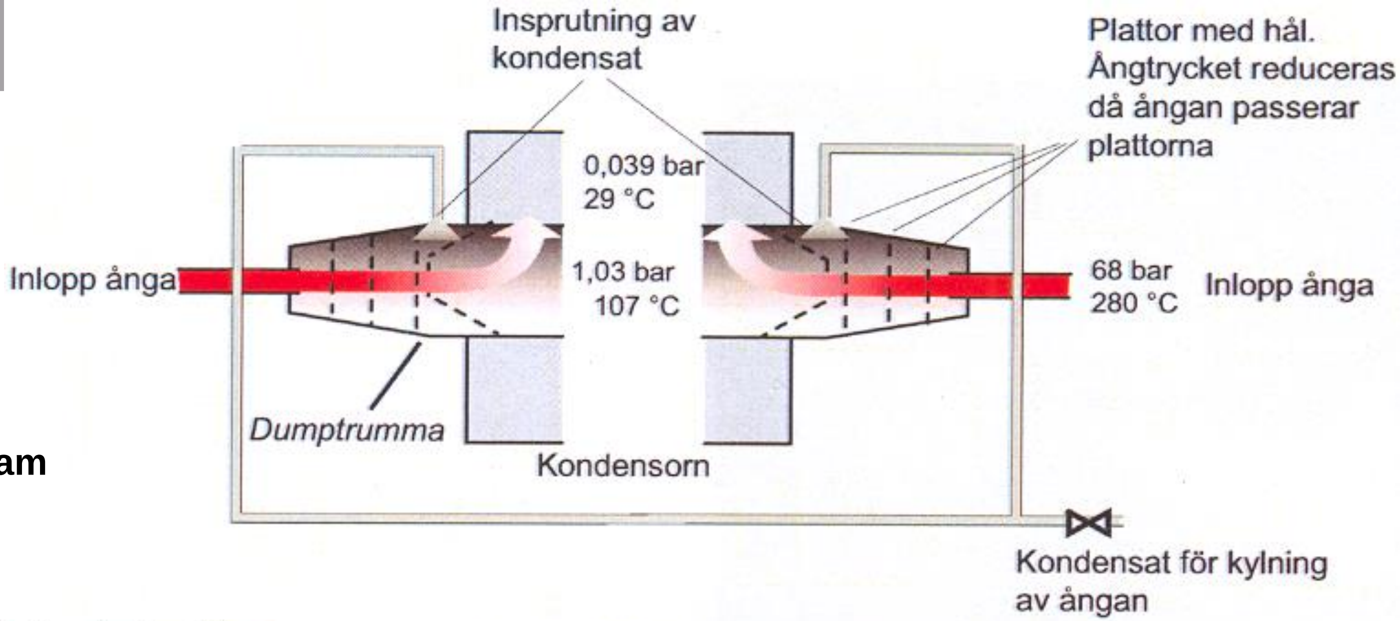
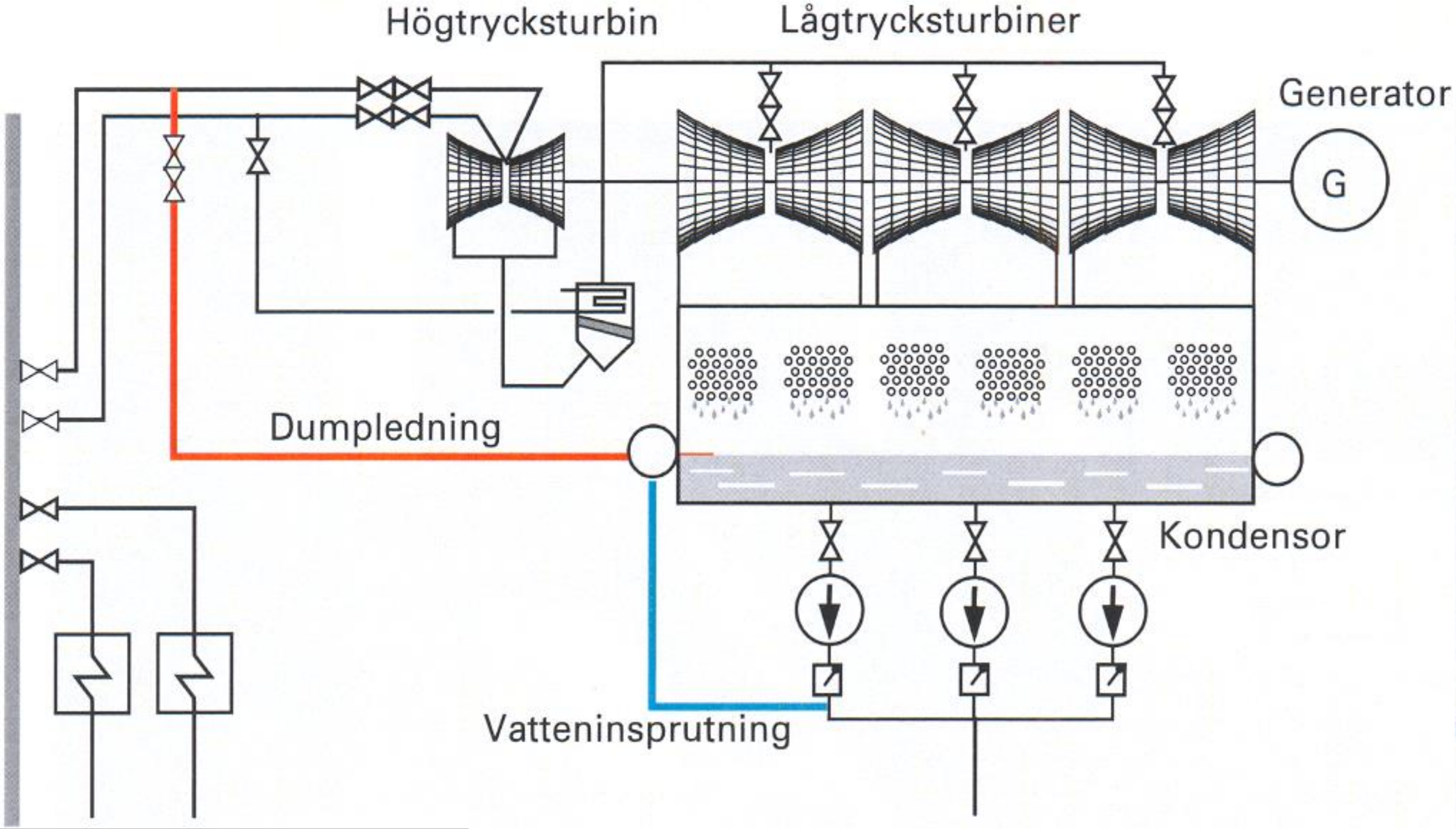
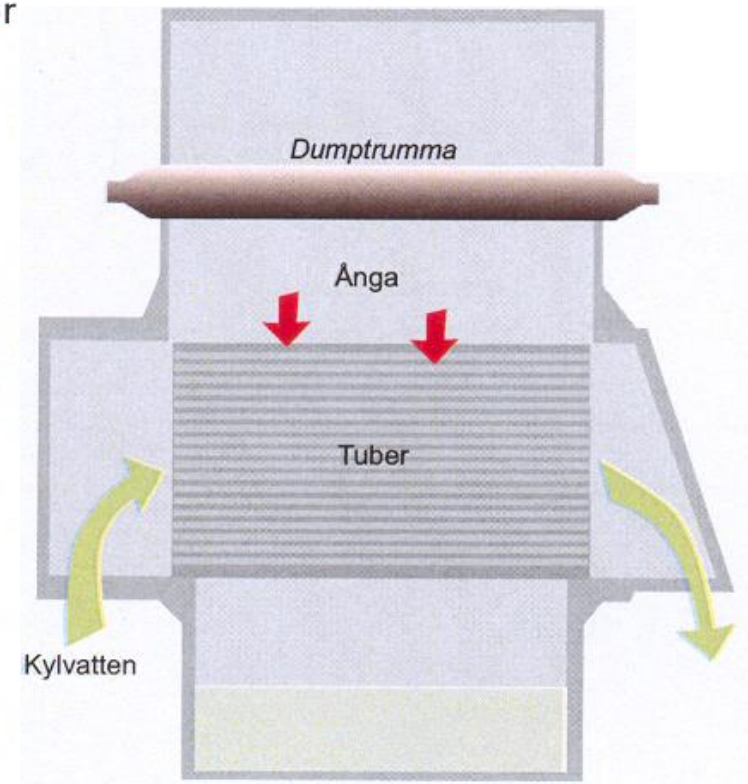
Steam Bypass (Dump Line)

Dumping drum for direct condensation of steam when the turbine is out of operation…







Turbine Bearings

The force on the axial bearing is minimized by the special turbine section arrangement, still it must exist and be able to dampen a sudden change in axial forces…

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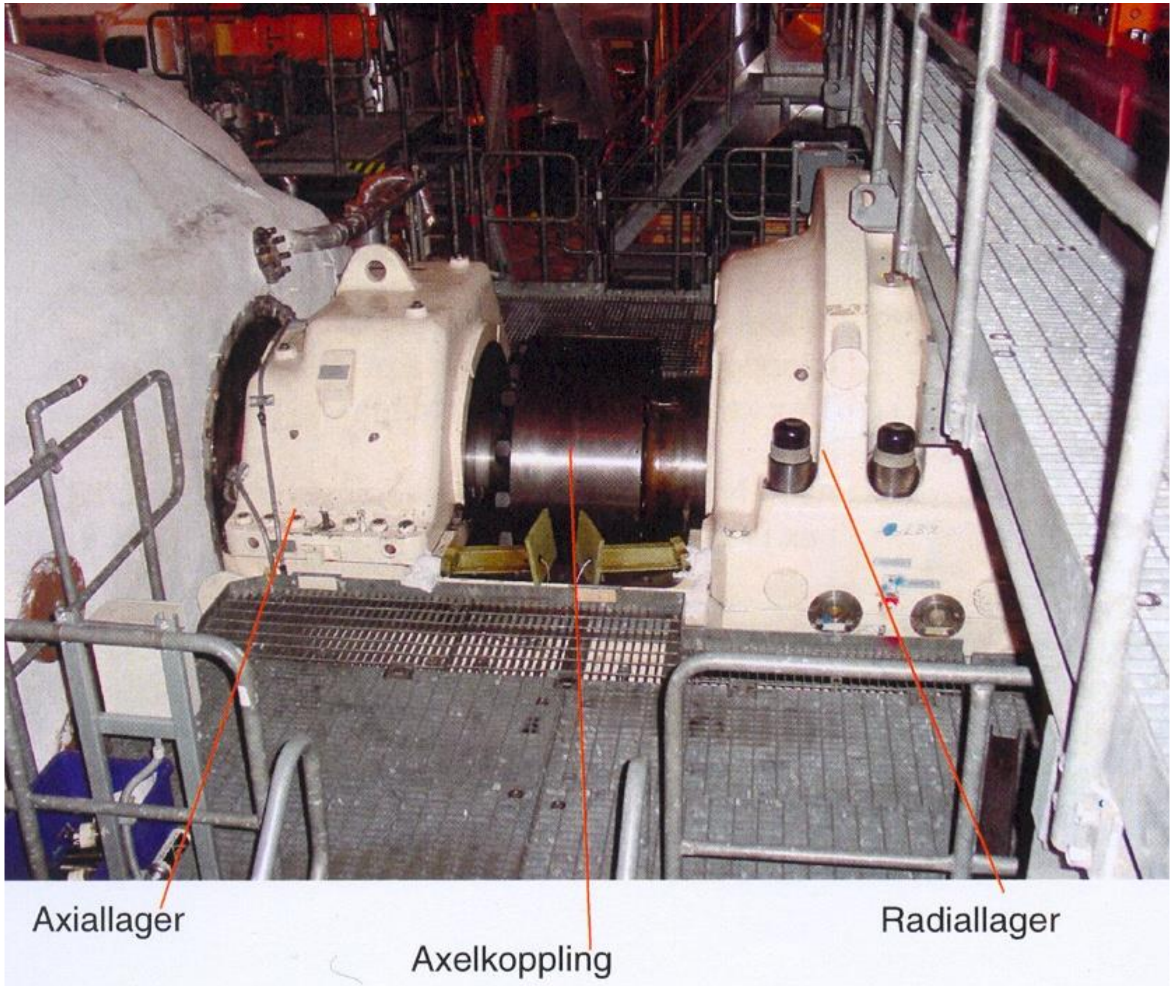

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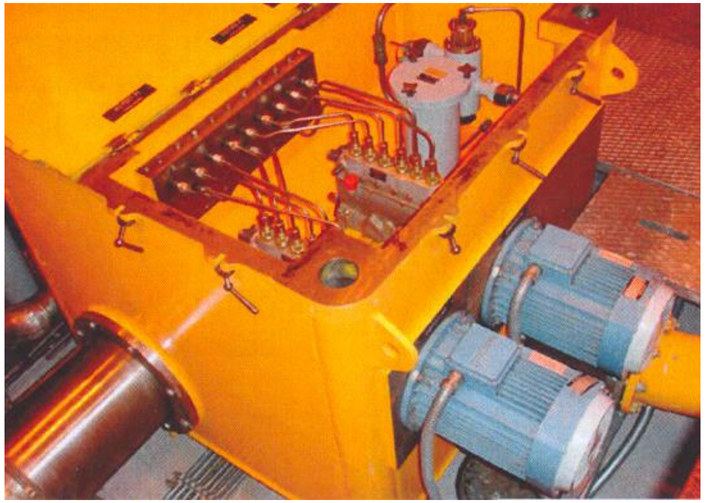
Slide-Bearing Technology

There are no roller- or ball-type bearings that can serve the heavy machinery. Always a sliding-type bearing is used for large turbines. A thin layer of lube oil between two plates supports the entire mass of the rotor.



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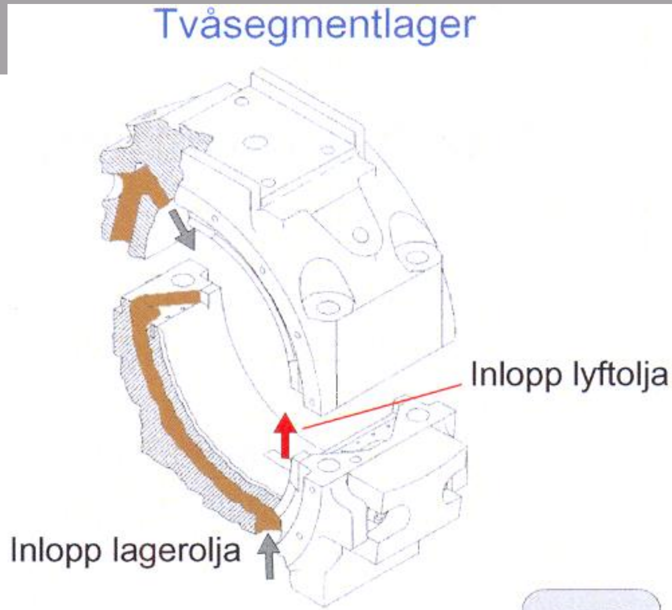

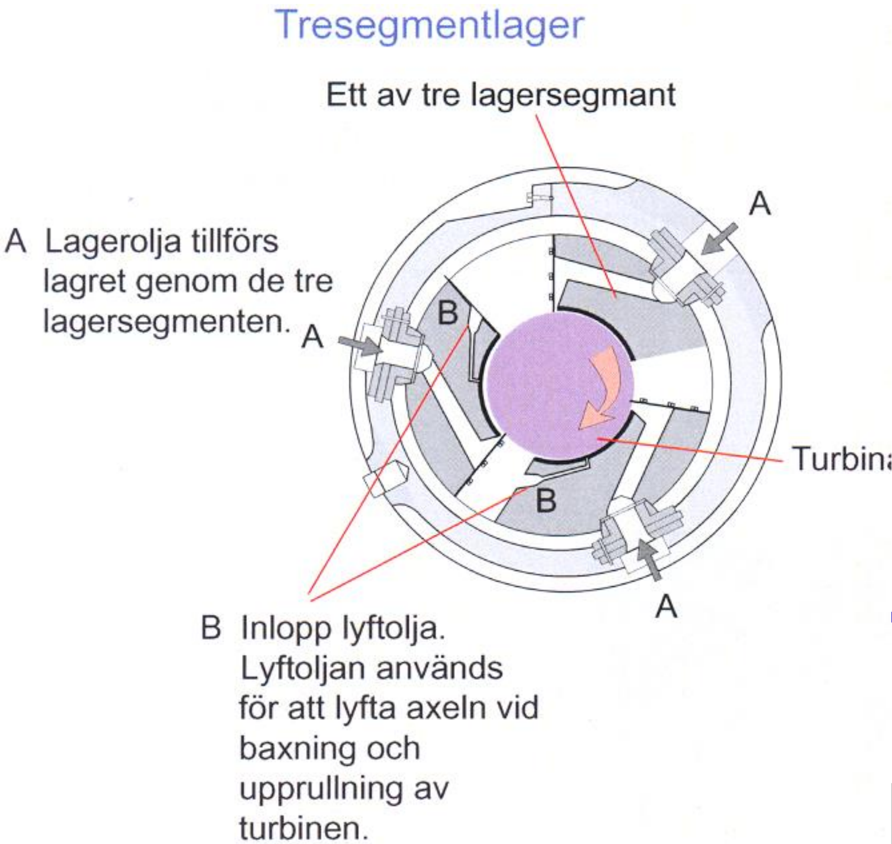

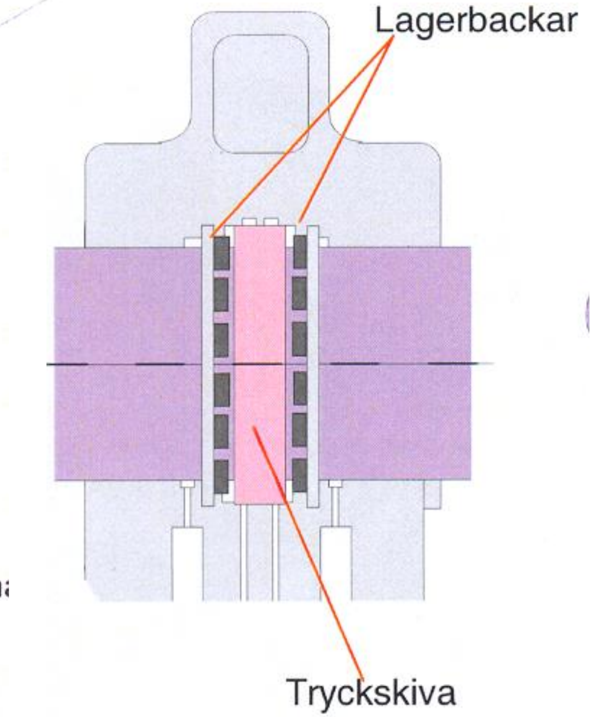

Steam Turbine Casing

Figure by courtesy of KSU AB
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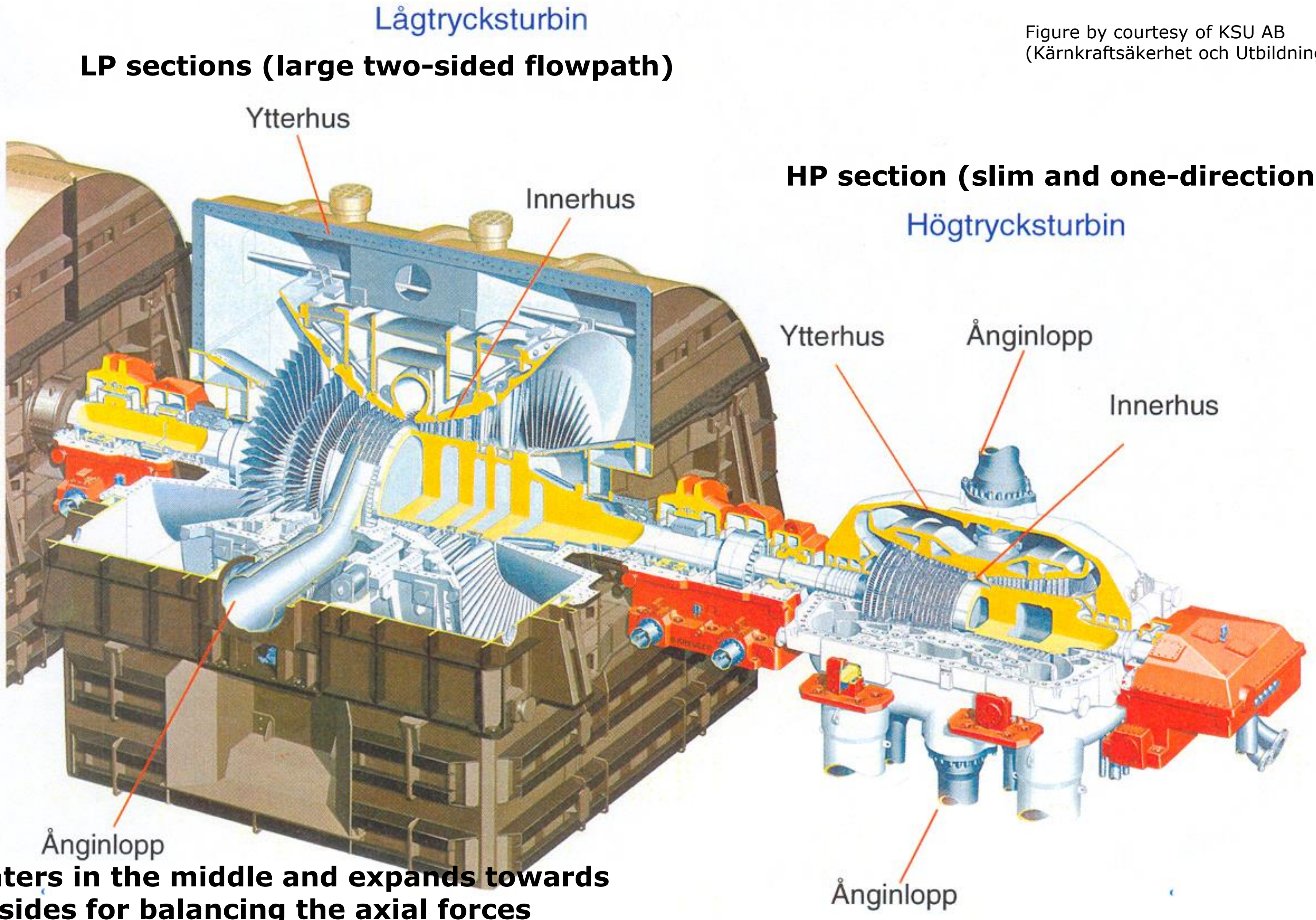
LP sections (large two-sided flowpath)

HP section (slim and one-directional)



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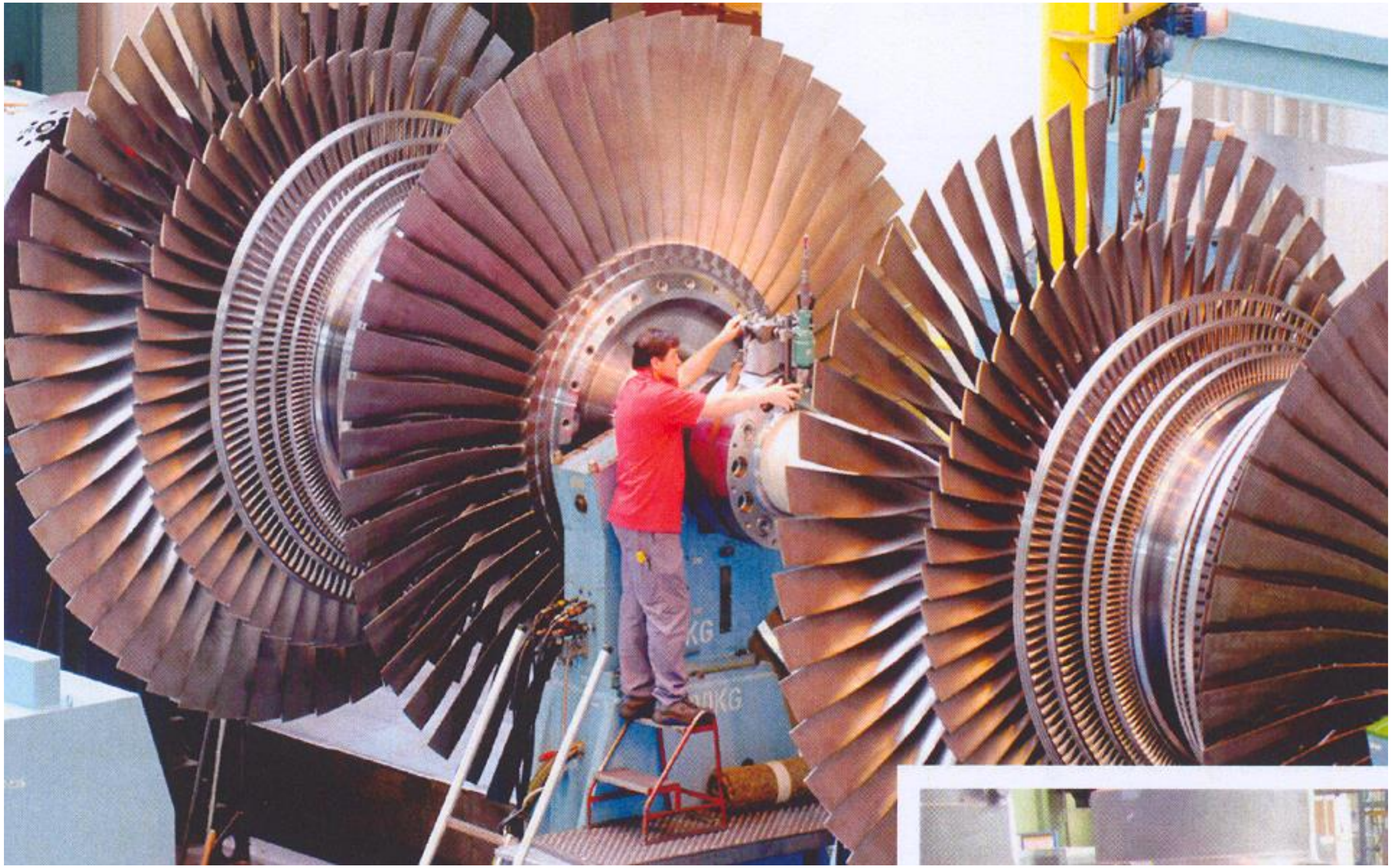
Steam enters in the middle and expands towards both sides for balancing the axial forces

Rotor Balancing

It's critical to keep the long and heavy rotor in perfect balance, without wobbling or bending from thermal or mechanical stress



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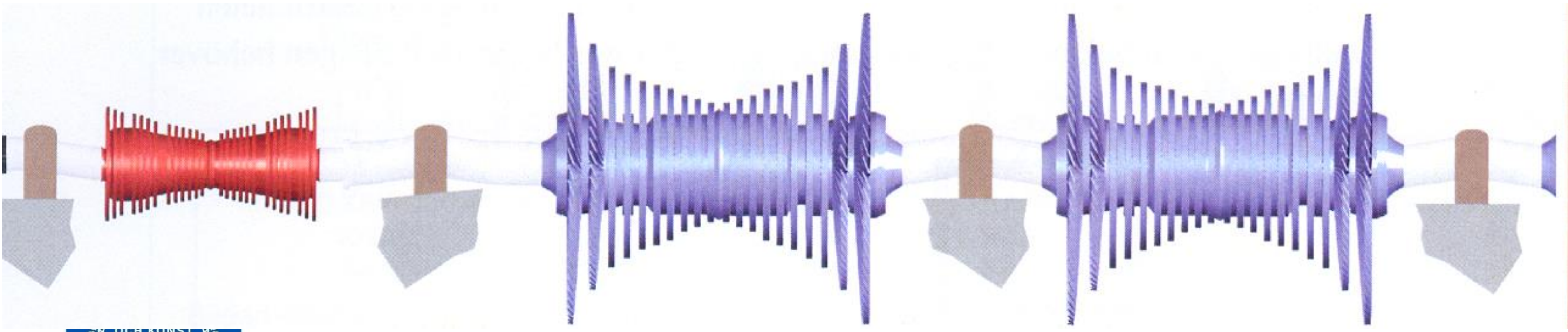
Shaft Bending/Disbalance



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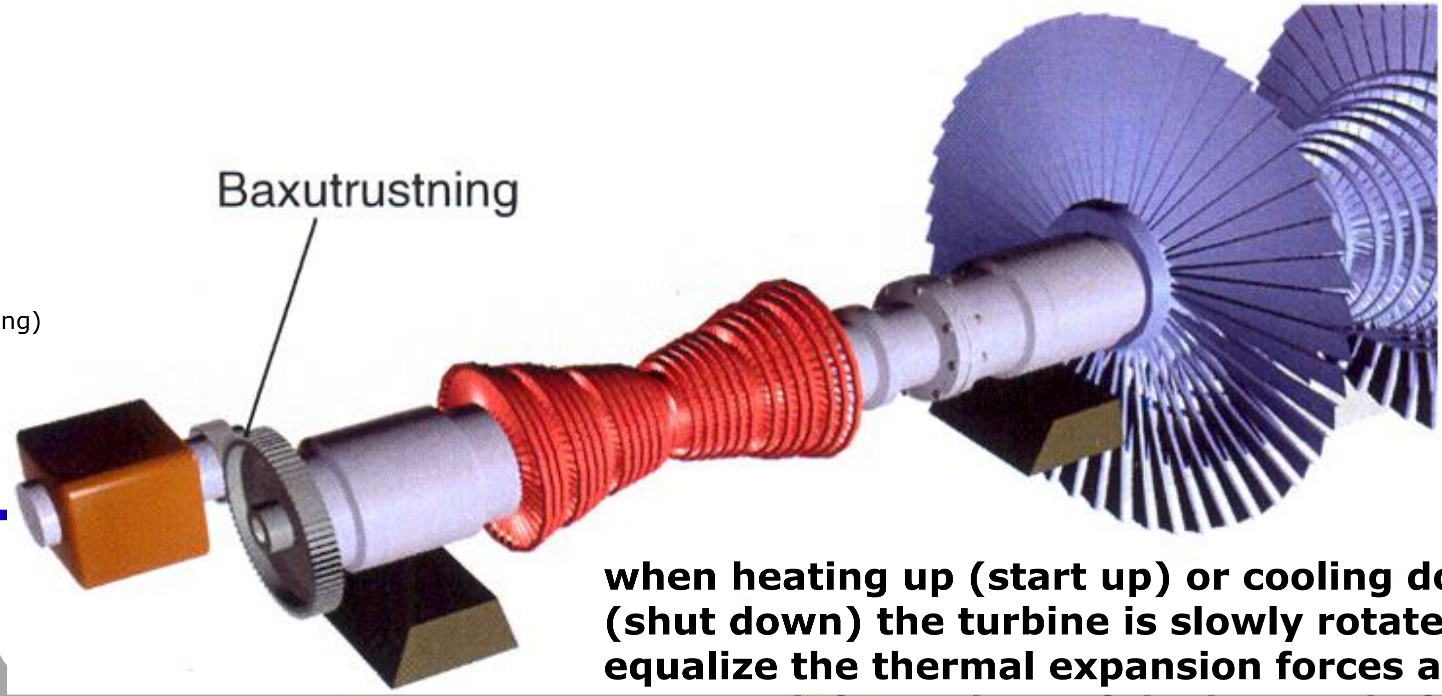

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when heating up (start up) or cooling down (shut down) the turbine is slowly rotated to equalize the thermal expansion forces and prevent deformations of the heavy shaft

Erosion Damage to LP Turbine Blades

Erosion by wet steam in the turbine is inevitable. Suction of condensed water droplets out of the turbine is employed in the several last stages.

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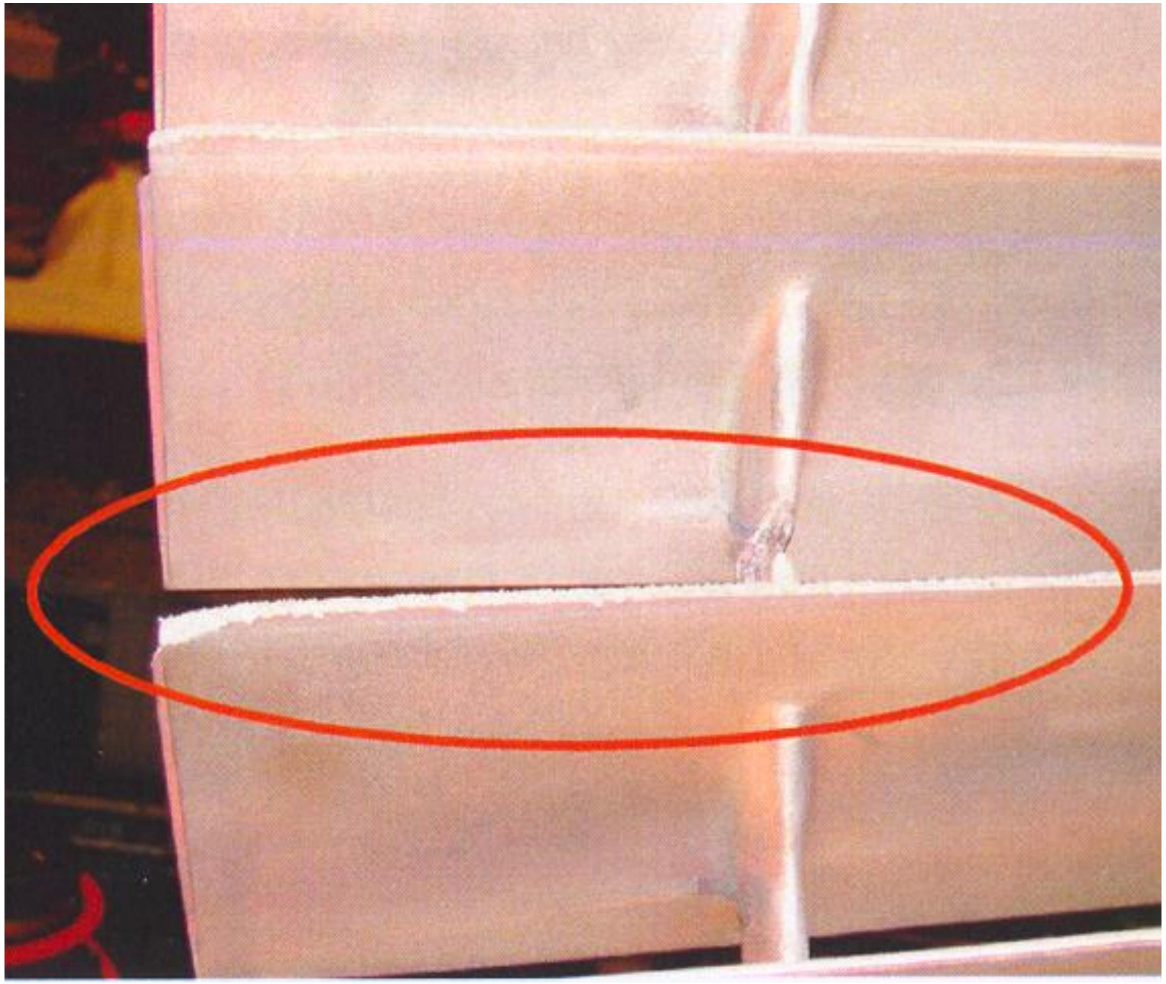

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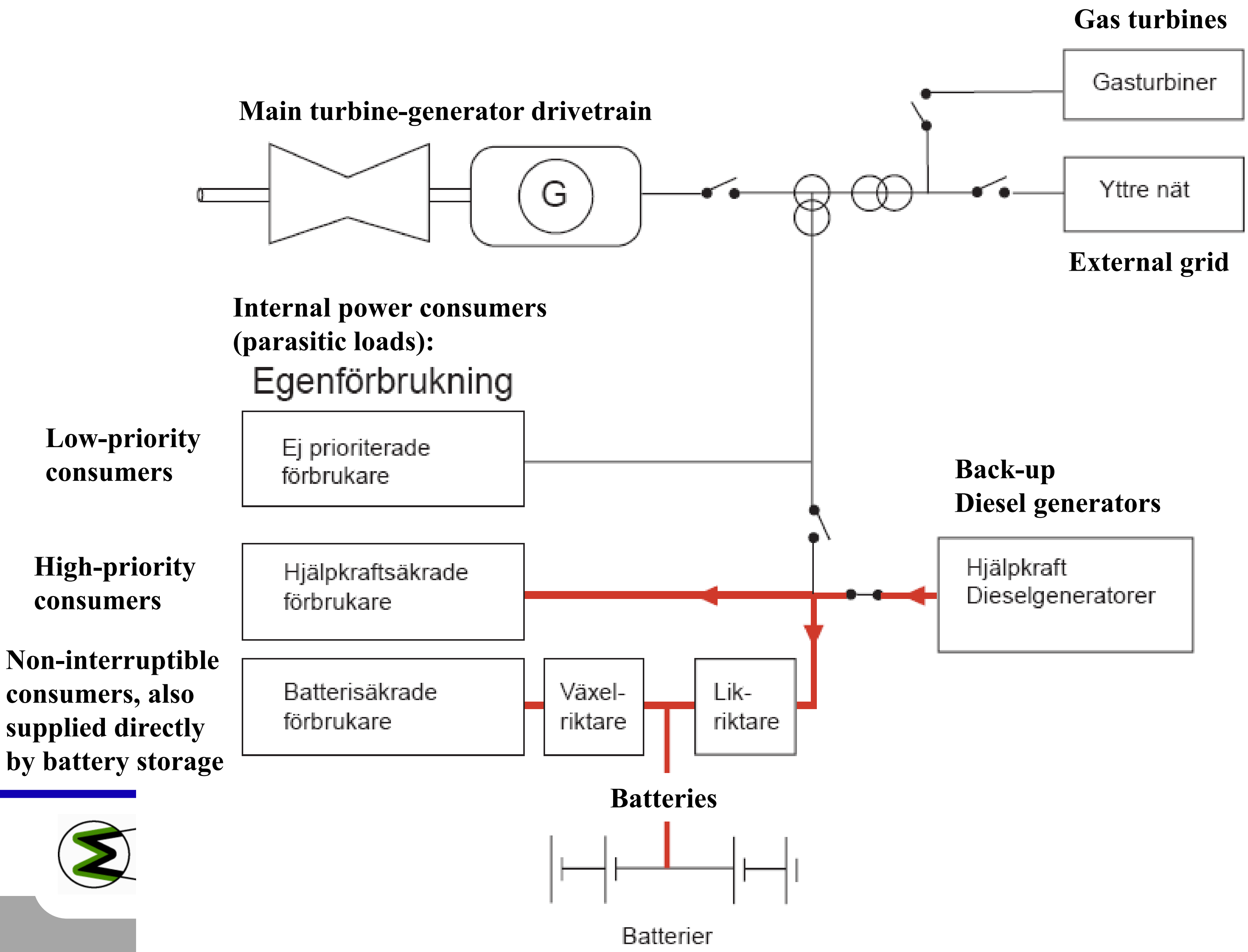
Back-up power supply



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Nuclear Plant Construction

A very long process, needs proper planning!
The new PWR unit (EPR) in Olkiluoto, Finland, is already 7 years delayed (as of 2017), and two times more expensive than planned !

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Source: http://weblog.greenpeace.org

Nuclear Plant Siting and Layout

natural draft cooling tower

the stackpipe is only for ventilation purposes or for the back-up generators

nuclear reactor containment building

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Source: www.lightandmatter.com

Proximity to cooling water, transport highways, high-voltage power lines, etc., is very essential… while the location should preferably be far away from large cities or densely populated areas.