Exercise 1

- A PWR operates at a nominal electric power of Pe = 1200 MWe, with a thermal efficiency of 33%, a generator efficiency of 99% and turbine efficiency of 90%. Knowing that the water enters the core at 275 deg. a nd leaves at 305 deg., compute the necessary massflow rate to extract all the power (@150 bar, Cp = 8160 kJ/kgK)

Exercise 1 - Solution

1. Compute the thermal power

$$Q_{th} = \frac{P_e}{\eta_t \eta_g \eta_{th}} \approx 4080\ MW_{th}$$

2. Compute the mass flow rate

$$\dot{m} = \frac{Q_{th}}{c_p \Delta T} = 16670\,\frac{kg}{s}$$

Exercise 2

- Assume now the same reactor is a BWR. If the total core flow is the same, what would be the necessary feedwater flow to obtain steam with 15% quality at the core outlet? Where does the remaining water go? What would be the total thermal power?

- @ 70 bar
  - h (70 bar, 275 deg) = 1210.4 kJ/kg
- @ saturation (70 bar, 285 deg)
  - h_vap = 2772.6 kJ/kg
  - h_liq = 1267.7 kJ/kg

Exercise 2 - Solution

1. Write the mass balance. If only the steam exits the core, then the outlet flow rate is given by

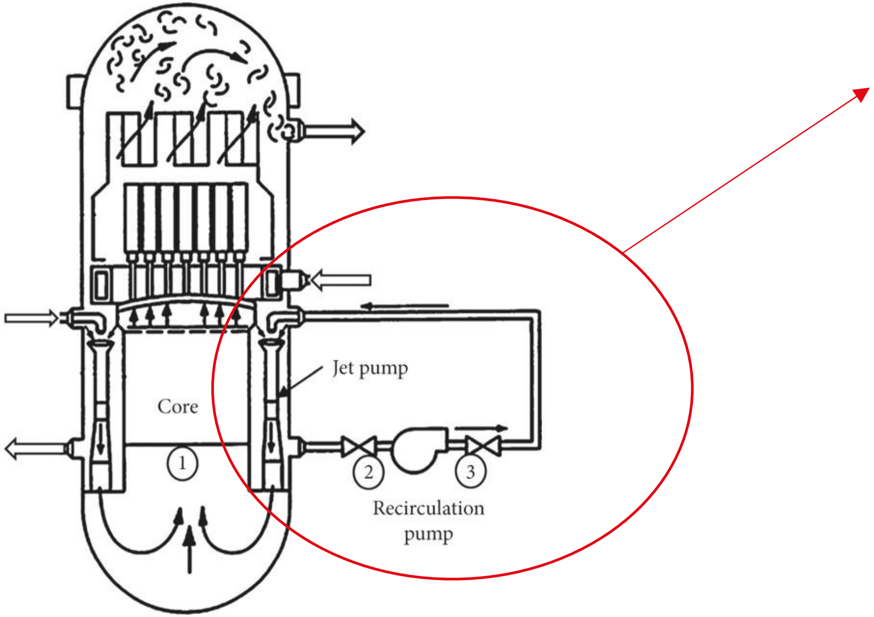
$$\dot{m}_{out} = x \cdot \dot{m}_{core}$$

In steady state conditions

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} = 0 \rightarrow \dot{m}_{in} = \dot{m}_{feed} = \dot{m}_{out} = x\dot{m}_{core} \approx 2500 \frac{kg}{s}$$

Exercise 2 - Solution

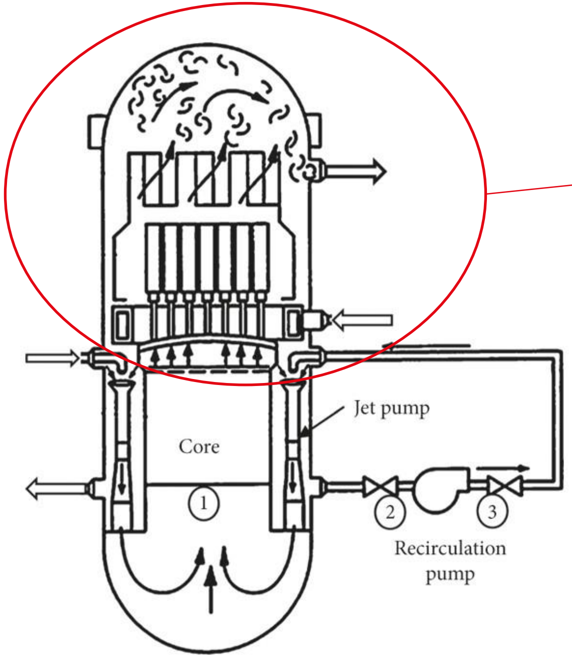
2. Where does the remaining water go?



The non-evaporated water is **recirculated** by an external circuit and is re-injected in the vessel by **jet pumps** which create extra suction → this decreases the necessary pumping power

Exercise 2 - Solution

2. Where does the remaining water go?



The steam is purified by water separators to obtain a very high steam quality in the turbine (>99.75%)

Exercise 2 - Solution

3. What is the total thermal power

Let’s write and enthalpy balance:

$$Q_{th} = \dot{m}_{feed} \cdot (h_{sat} - h_{in}) + x \cdot \dot{m}_{core} \cdot \Delta h_{boil} \approx 3910\ MW_{th}$$

Exercise 2 - Solution

4. What happens if the amount of recirculated water increases?

$$Q_{th} = \dot{m}_{feed} \cdot (h_{sat} - h_{in}) + x \cdot \dot{m}_{core} \cdot \Delta h_{boil}$$

If the recirculated mass flow increases, if the other parameters are constant, the steam quality x decreases. This leads to having more water in the core, hence more **moderation**. An increase in moderation creates an increase in reactivity which increases the power. This increases the title again, stabilizing the reactor. This mechanism is used in BWR to control the reactor power!

Exercise 3

3. Assume now the reactor is a sodium-cooled fast reactor (SFR). Because of the higher operating temperatures, the thermal efficiency is much higher (42%). If the core-flow is the same and the sodium inlet temperature is 400 degrees, compute the outlet temperature (@ 1 bar, Cp = 1300 J/kg/K).

Exercise 3 - Solution

1. Same as exercise 1:

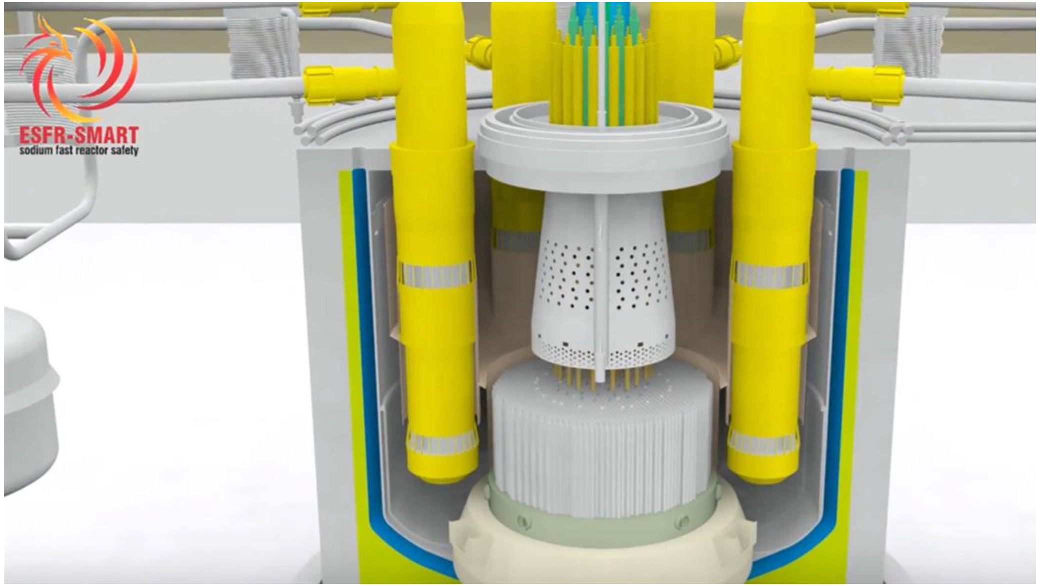
$$\Delta T = \frac{Q_{th}}{\dot{m}c_p} = \frac{P_e}{\eta_t \eta_g \eta_{th} \dot{m} c_p} \approx 150\ K\ \rightarrow T_{out} \approx 550^o C$$

An SFR can operate at much higher temperatures, as no boiling occurs. This also allows to operate at ambient pressure, w/o need to pressurize the vessel

On the other hand, as sodium solidifies at 100 degrees, it needs to be constantly heated up above the fusion point!

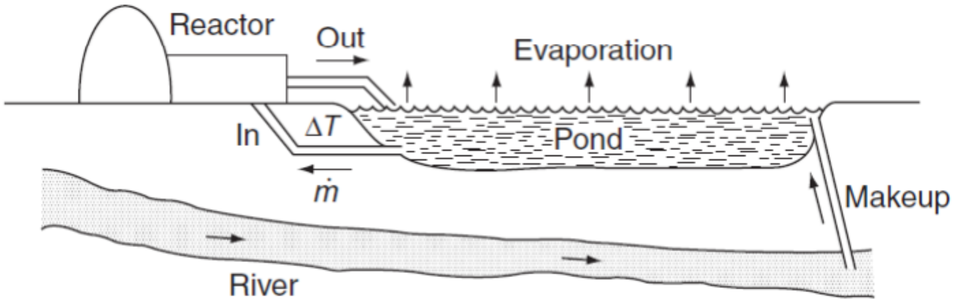
Exercise 3 - Solution

As the vessel is not pressurized, it is much larger and contains all the other circuit components, e.g. the pumps and the heat exchangers. This is called a **pool-type** reactor



Exercise 4

1. In the PWR, the waste heat is removed by a cooling pond like that shown in the figure below



[Murray and Holbert, Nuclear Energy, Elsevier 2015]

Water is drawn from the cooling pond at 20 degrees and returns at 35. What is the necessary flow rate? As part of it boils, the pond is kept at constant level by a makeup flow. What is the makeup flow if the water has a vaporization heat of 2260 kJ/kg?

EPFL

Exercise 4 - Solution

1. Compute the waste heat and flow rate

$$Q_{waste} = Q_{th} - \frac{P_e}{\eta_t \eta_g} = 2733.2\ MW$$

$$\dot{m}_{flow} = \frac{Q_{waste}}{C_p \cdot \Delta T} \approx 43530 \frac{kg}{s}$$

2. Compute the evaporated water / make up flow

$$\frac{dm}{dt} = 0 \ \rightarrow \dot{m}_{boil} = \dot{m}_{makeup} \rightarrow \dot{m}_{boil} = \frac{Q_{waste}}{\Delta h_{vap}} \approx 1200 \frac{kg}{s}$$