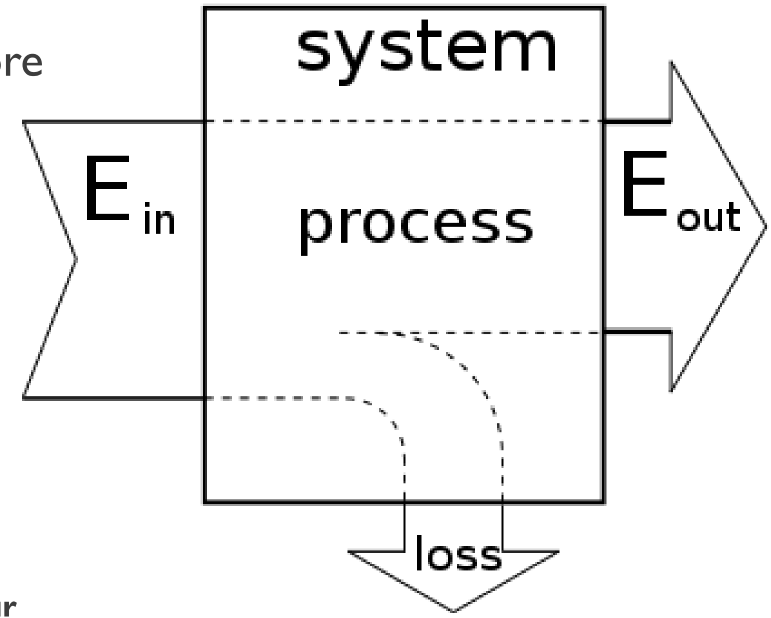
TOMSK POLYTECHNIC UNIVERSITY

NUCLEAR POWER PLANT EFFICIENCY

NPP ENERGY BALANCE

- Ein – heat/energy released in the reactor core
- Eout - electrical power output
- Heat Losses:
  - In the main (first) coolant circuit $\Delta \mathbf{q}_{1c}$
  - In the condenser $\Delta \mathbf{q}_{c}$
  - In pipelines $\Delta \mathbf{q}_{pipes}$
  - Mechanical (friction) loss in the turbine $\Delta \mathbf{q}_{tur}$
  - In the electrical generating set $\Delta \mathbf{q}_{eg}$



NPP THERMAL EFFICIENCY

- Elements:
  - Efficiency factor
  - Heat rate
  - Fuel-consumption rate

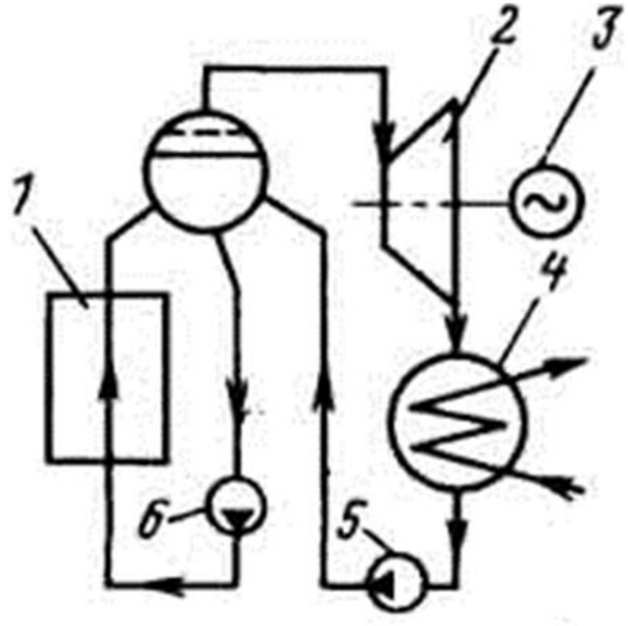
NPP EFFICIENCY

$$\eta_{npp} = \frac{N_{el.}}{Q_{total}}$$

- The efficiency factor of a power plant is the percentage of the total amount of energy produced in the reactor that is converted into electricity
- The remaining energy is usually lost to the environment:
  - Steam generating facilities loss (reactor, steam generator)
  - Pipes loss
  - Turbine loss

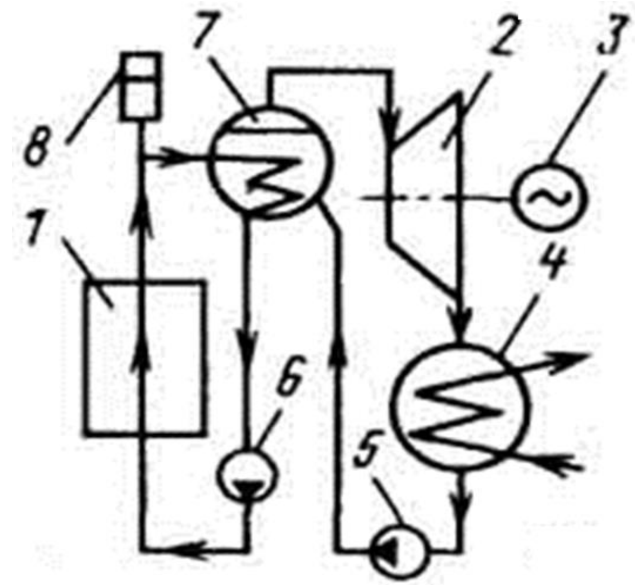
ONE-CIRCUIT NPP EFFICIENCY

$$\eta_{npp} = \eta_{el} \cdot \eta_{pipes} \cdot \eta_{rs}$$



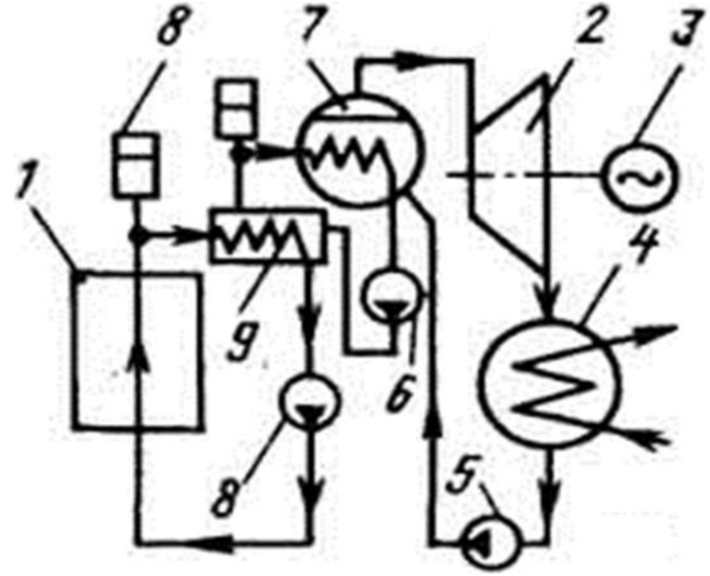
TWO-CIRCUITS NPP EFFICIENCY

$$\eta_{npp} = \eta_{el}\eta^{II}_{pipes}\eta_{sg}\eta^{I}_{pipes}\eta_{rs}$$



THREE-LOOP NPP EFFICIENCY

$$\eta_{npp} = \eta_{el}\eta_{pipes}^{III}\eta_{sg}\eta_{pipes}^{II}\eta_{ihe}\eta_{pipes}^{I}\eta_{rs}$$



REACTOR SYSTEM EFFICIENCY

$$\eta_{rs} = \frac{Q_{rs}}{Q_{total}}$$

PIPES EFFICIENCY

$$\eta_{pipes} = \frac{Q_{\mathrm{rs'}}}{Q_{rs}}$$

EFFICIENCY OF FIRST LOOP PIPES

$$\eta^{1}_{pipe} \geq 0,99$$

EFFICIENCY OF II AND III LOOP PIPES

$$\eta_{pipe}^{\mathrm{II}} = 0,97 \div 0,98$$

$$\eta_{pipe}^{\mathrm{III}} = 0,97 \div 0,98$$

STEAM GENERATOR EFFICIENCY

$$\eta_{sg} = \frac{Q_{sg}}{Q_{rs'}}$$

- Includes
  - Environmental heat loss (<1 %)
  - Steam generator blowdown water loss

$$Q_{bd} = G_{bd}(h_s' - h_{fw})$$

INTERMEDIATE HEAT EXCHANGER EFFICIENCY

$$\eta_{ihe} = \frac{Q_{ihe}}{Q_{rs'}}$$

- Environmental heat loss

NPP EFFICIENCY

η_{npp}- Gross Efficiency

- Does not include consumption of electricity for own needs (service power)

SERVICE POWER

N_{sp}- Service Power

- Consists of:
  - Pump drives
  - Common plant systems
  - Electric heaters
  - Instrumentation and controls
  - Valve drives
  - etc.

SERVICE POWER COEFFICIENT

$$\beta_{sp} = \frac{N_{sp}}{N_{el}}$$

$$\beta_{sp} = 0,05 - 0,07$$

- Values can be found in a reference book
- 5 - 7% of NPP generated electricity is consumed for NPP own needs (Service power)

NPP NET EFFICIENCY

$$\eta_{npp}^{net} = \frac{N_{el} - N_{sp}}{Q_{total}}$$

$$\eta_{npp}^{net} = \eta_{npp}(1 - \beta_{sp})$$

NUCLEAR POWER UNIT EFFICIENCY (TURBINE INSTALLATION K-500-60/3000)

- NPP gross efficiency

$$\eta_{npp} = \frac{N_{el.}}{Q_{total}} = \frac{1000}{3200} = 0,313$$

- NPP net efficiency

$$\eta_{npp}^{net} = \frac{N_{el} - N_{sp}}{Q_{npp}} = \frac{1000 - 70}{3200} = 0,291$$

$$\eta_{npp}^{net} = \eta_{npp}(1 - \beta_{sp}) = 0,313(1\text{- }0,07) = 0,291$$

NPP HEAT RATE

$$q_{npp} = \frac{Q_{total}}{N_{el}} = \frac{1}{\eta_{npp}}$$

$$q_{npp} = \frac{1}{\eta_{npp}} = \frac{1}{0,312} = 3,21$$

$$q_{npp} = \frac{3600}{\eta_{npp}} = \frac{3600}{0,312} = 11,5 \cdot 10^{3} \frac{\mathrm{kJ}}{\mathrm{kW} \cdot hr}$$

SPECIFIC CONSUMPTION OF BURNUP NUCLEAR FUEL

$$b_{nf} = \frac{B_{nf}}{E} = \frac{B_{nf}}{Q_{total} \cdot \eta_{npp}} = \frac{B_{nf}}{Q_{nf} B_{nf} \eta_{npp}} = \frac{1}{Q_{nf} \eta_{npp}}, kg / kJ$$

- B_{nf} – rate of consumption of burnup fuel
- E – electrical power output

SPECIFIC CONSUMPTION OF BURNUP NUCLEAR FUEL IN KW·HR

$$b_{nf} = \frac{3600}{Q_{nf}\,\eta_{npp}},\ \frac{kg}{kW \cdot hr}$$

HEAT GENERATED FROM BURNUP FUEL

- Fission of 1 kg U-235 generates $7,9 \cdot 10^{10}$ kJ
- During operation 10-20 % of nuclear fuel is converted into non-fissionable isotope U-236, Pu-240

$$Q_{nf} = 6,7 \cdot 10^{10} \text{ kJ/kg}$$

SPECIFIC CONSUMPTION OF BURNUP NUCLEAR FUEL

$$b_{nf} = \frac{3600}{Q_{nf}\eta_{npp}} = \frac{3600}{6,7\cdot 10^{10}\eta_{npp}} = \frac{0,0537\cdot 10^{-6}}{\eta_{npp}} kg/(kW\cdot hr)$$

- To consider service power, should change gross efficiency to net

NHPP HEAT EFFICIENCY

- Elements:
  - Electricity production
  - Heat production for customers

NHPP ELECTRIC EFFICIENCY

$$\eta_{npp}^{\mathrm{el}} = \frac{N_{el}}{Q_{total} - Q_{hc} / \left(\eta_{hc} \cdot \eta_{losses}\right)}$$

- Qhc – supplied heat to consumers, kW
- η_{losses} - efficiency which includes losses in heat exchangers and pipes from turbine to heat consumers

HEAT USED FOR ELECTRICITY GENERATION

$$Q_{total}^{el} = Q_{total} - \frac{Q_{hc}}{\eta_{hc} \cdot \eta_{losses}}$$

$$Q_{total} = Q_{nf} B_{nf}$$

SPECIFIC HEAT RATE FOR ELECTRICITY GENERATION

$$q_{npp}^{el} = \frac{Q_{total}^{el}}{N_{el}}$$

SPECIFIC NUCLEAR FUEL CONSUMPTION FOR ELECTRICITY GENERATION

$$b_{nf}^{el} = \frac{0,0537 \cdot 10^{-6}}{\eta_{npp}^{\mathrm{el}}} kg/(kW \cdot hr)$$

- To consider service power, should change gross efficiency to net

NHPP HEAT EFFICIENCY

$$\eta_{npp}^{heat} = \eta_{hc} \cdot \eta_{losses}$$

SPECIFIC CONSUMPTION OF BURNUP NUCLEAR FUEL FOR HEAT PRODUCTION

$$b_{nf}^{\text{heat}} = \frac{1}{6,7 \cdot 10^{10} \eta_{NHPP}^{heat}} = \frac{0,01}{\eta_{NHPP}^{heat}}, \quad g/\text{GJ}$$

- To consider service power, should change gross efficiency to net

THANK YOU FOR YOUR ATTENTION