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AREVA evaluation of SCO2 cycle for Sodium Fast Reactor

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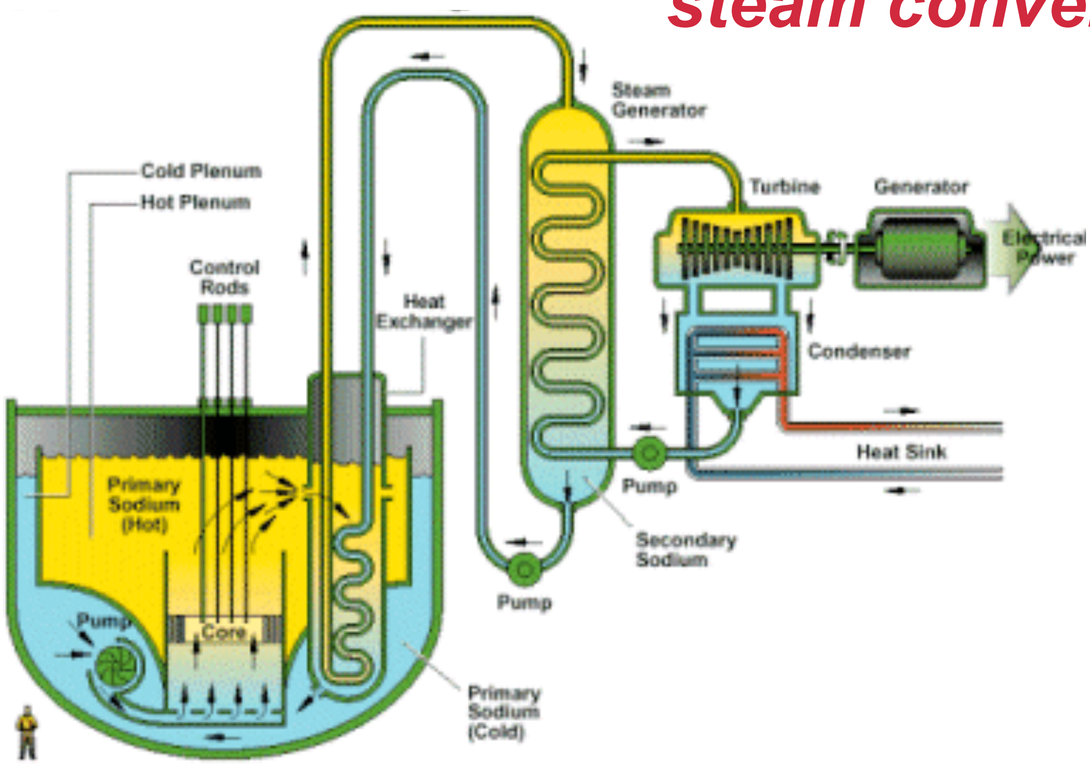
- R&D activities for advanced Sodium cooled Fast Reactors (SFR) in progress in AREVA NP
  - Objective: development of an indutrial product by 2040, with the respect of Generation IV criteria
- Investigation of different power conversion cycles with the objective of plant efficiency optimisation
  - Increase of plant efficiency with acceptable constraints on plant design
  - Or simplification of plant design
- SCO2 cycle appears as a possible candidate

Presentation of main advantages, drawbacks and uncertainties associated with the application of SCO2 cycle to a SFR

SFR possible design with a « classical » water steam conversion cycle



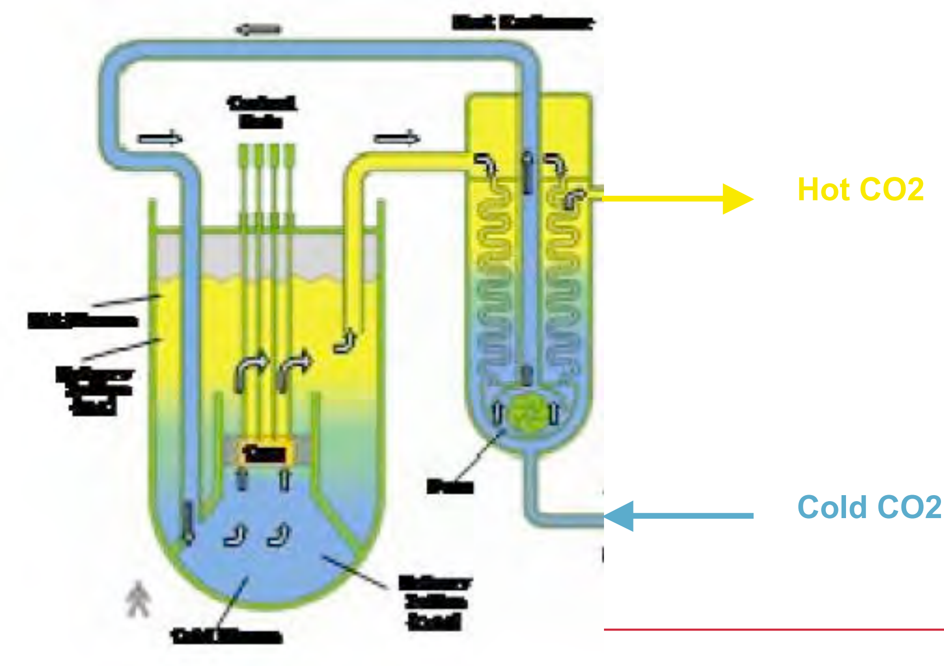
- **Rankine water steam conversion cycle**
- **Risk for sodium – water reaction in case of leak on the steam generator**
  - **Rapid and exothermic reaction**
  - **→ Safety issues for the core, necessity of an intermediate sodium loop between water and primary sodium**
- **Plant efficiency: 40.8 % (EFR project)**
  - **Temperatures: 545°C for sodium at core outlet and 490°C for steam at turbine inlet**
  - **Turbine efficiency (dry steam): 89 %**

Possible design with SCO2 cycle

- No risk for water – sodium reaction

⇒ If the SCO2 option allowed removing the intermediate sodium loop → Major simplifcation of plant design

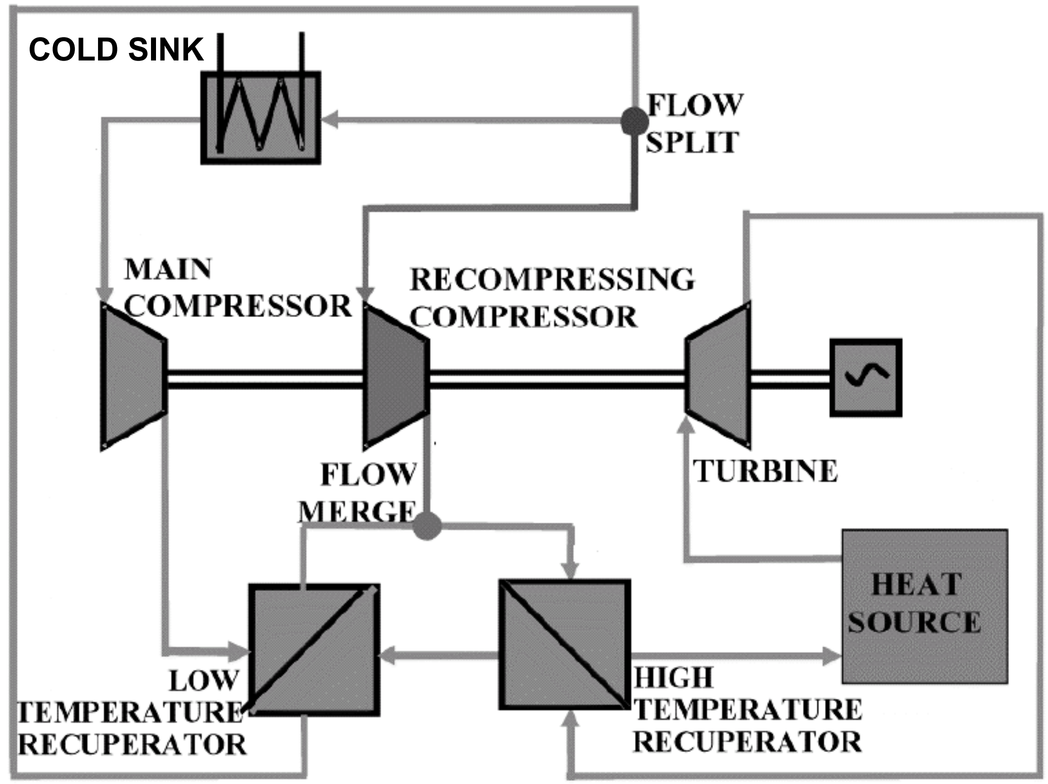
- High gas pressure in contact with the primary sodium loop
  - Risk for leaks on Na / CO_2 exchanger → Risk for gas passage in the core
  - Core sodium void effect: in case of gas flow in the core, large reactivity insertion → the prompt criticality can be reached (= nuclear power excursion)
  - ⇒ Major safety issue
  - Na / CO_2 exchanger has to be out of the core vessel
  - In addition, preventive and mitigative measures have to be taken
    - Detection (exchanger leak, gas flow in primary sodium), robust exchanger design, sodium loop design (gas / sodium separator) …



SCO2 power conversion cycle

- **SCO2 cycle design:**

  Heat regeneration and gas flow split (from MIT studies)



- **Plant efficiency**
  - **SCO_2 pressures: 74 – 210 bar**
  - **SCO_2 temperatures: 32 – 510°C**
  - **Efficiencies: turbine 93%, compressor 89%**
  - **⇒ Plant efficiency: 43.4 %**
    - **To be compared to 40.8 % with a classical Rankine cycle**

Main advantages associated with SCO2 cycle

- **No risk for water / sodium reaction**
  - **No intermediate loop in sodium → major simplification of the plant design**
- **Efficiency increase**
  - **+ 2.5 % compared to a Rankine cycle for a sodium hot temperature of 545°C**
  - **Potentially higher for higher sodium temperatures (but limitations due to available materials)**

Main drawbacks associated with SCO2 cycle

- Risk for gas flow in the core → Major safety issue
  - Requires preventive and mitigative measures, still to be developed
    - Detection devices
    - Gas / sodium separators …

- Size of heat exchangers (case of a 1500 MWe SFR)
  - Na / CO2 exchangers (tubular exchangers)
    - 3600 MWth on exchangers: 17 modules of 7.5 m height and 2.4 m diameter
    - For classical cycle (Na/Na exchanger): 6 modules with the same dimensions
  - CO2 / CO2 recuperators (plate exchangers, Heatric type)
    - High temperature recuperator (4530 MWth): 14 modules 0.65 * 5.0 * 2.5 m^3
    - Low temperature recuperator (2540 MWth): 9 modules 1.5 * 3.0 * 1.6 m^3

Main uncertainties associated with SCO2 cycle

- **Compatibility with sodium**
  - **CO_2 reacts with sodium, exothermic reaction**
  - **However, the reaction kinetics seem to be slower than that of the reaction with water**
  - **A work program is planed by CEA to investigate the characteristics of the reaction**
    - **Kinetics, wastage effect on the exchanger tubes …**

- **Industrial development of the SCO2 technology**
  - **R&D needs for the turbomachinery design**
    - **A special design is required for large power energy conversion system**
    - **The design of the compressor has to deal with the CO_2 properties variations**

  ⇒ **SCO2 technology seems to be incompatible with a short or medium term industrial development**

Main uncertainties associated with SCO2 cycle

- **Cold sink**
  - **Low CO2 temperature in the cycle: 32°C**
  - **Corresponding cold sink temperature: around 27°C max**

  ⇒ **Which impact of a higher temperature on plant operation ?**

  Decrease of plant efficiency …

- **Load following**
  - **Preliminary study of partial load conditions**
  - **Differents means to reduce the electric power**
    - **By-pass of Na / CO2 exchanger**
    - **By-pass of Na / CO2 exchanger + turbine**
    - **Decrease of CO2 mass inventory in the conversion cycle → decrease of the pressure**
  - **Solution 3 seems to bring the higher efficiency:**
    - **35 % efficiency for 50 % P_N**
    - **To be compared to 39 % for 50 % P_N with a Rankine cycle**

  ⇒ **Significant decrease of plant efficiency for partial load conditions**
  The strategy of plant control for load following should be further optimized

Conclusions on SCO2 cycle for SFR

- **Needs for developments for non nuclear technology**
  - Turbomachinery (compressor and turbine)
  - Technology for high power levels is required
  - Heat Recuperator technology
  - Cold sink temperature

- **Application of SCO2 cycle to nuclear technology requires additional developments**
  - It is necessary to manage a gas leak into primary sodium
  - The reactivity with sodium has to be assessed
  - Sodium / gas exchanger technology
  - Load variations
  - …

- **But potential interest**
  - Efficiency increase
  - Simplification of plant design (if no intermediate loop)
  - Compact turbomachinery
  - …

AREVA NP viewpoint
The industrial application of SCO2 cycle to nuclear plants appears as a long term, potentially attractive, perspective