Energy Conversion Systems

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Introduction

Energy Conversion:

The energy produced by chain reaction has to be converted into electricity

Reactor specific solutions needed

Main priorities for SFR

- **1- Rankine cycle – Water Sodium Reaction in Steam Generators**
  - Modeling and validation of sodium leak propagation in a SG tubes bundle (reaction jet, thermal and mechanical effects). Comparison with existing experimental database.
  - Modeling of the leak self-evolution.

- **2- Brayton cycle – System loop**
  - Analysis of the scale effects, test facility specification for the ASTRID Gas PCS operation,
  - Test facility development and tests,
  - Analysis and validation of the CATHARE code.

Focus on SWR in SFR Steam generators

- **SWR modeling and validation**

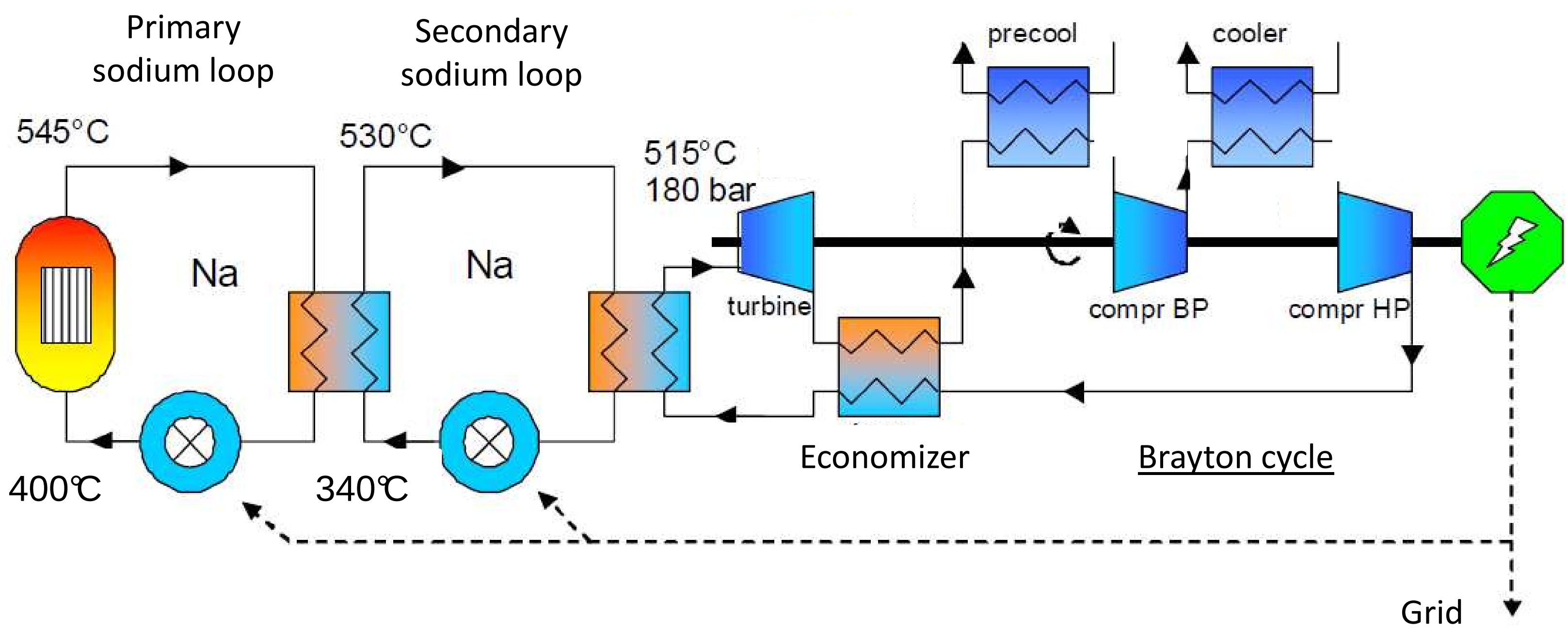
  – Wastage and overheating models correlated with the SG tubes material (ferritic or ferritic-martensitic steels)
  - Distance between the leaking tube and the target wall, penetration time
  - Influence of the leak evolution and on the wastage rate and kinetics, behavior towards the overheating and bursting effects in the field of the high temperatures (up to 1200°C)

  – Modeling of the leak self-evolution
  - Thermal and CFD coupling, multi-phase flow
  - Meshing deformation and evolution (solid cells to liquid cells depending on the wastage rate)

  – Experimental data base analysis
  - Wastage tests
  - Bursting tests

Focus on Brayton system loop in SFR

Gas power conversion system for SFR



Focus on Brayton system loop in SFR

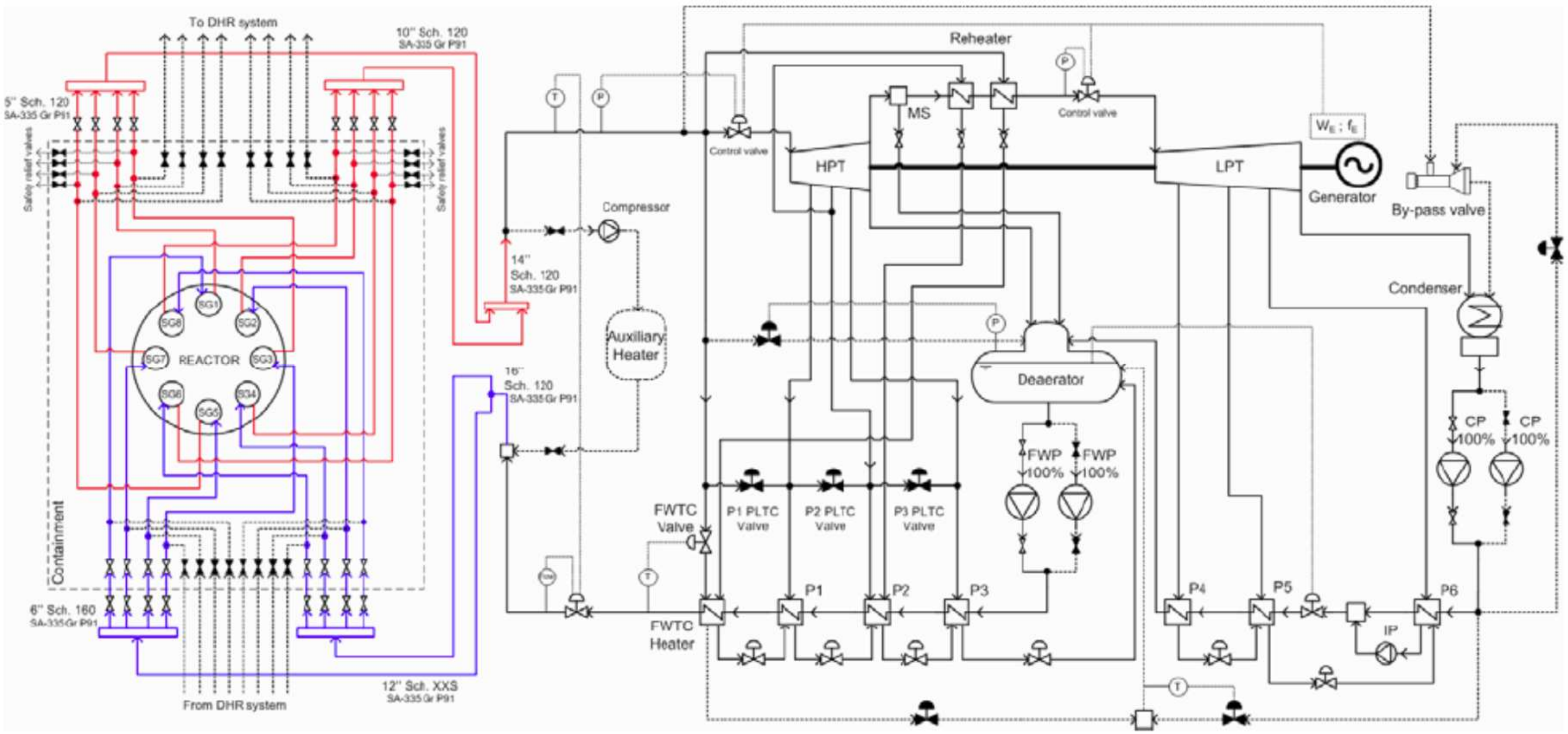
CATHARE validation needs for ASTRID gas PCS

- Definition of similarity laws and representative scales for the phenomena to be simulated
- Test facility specification for the validation of the ASTRID Gas PCS operation,
- Construction and test program,
- Experimental data base analysis and Cathare Gas code validation
  - Transient incidental situations
  - Turbomachinery model and control system, general operating procedures (start-up/normal shut down, turbine bypass,...)

ALFRED - Secondary System

Power conversion system based on superheated cycle with dual turbine configuration, three extractions in the HP and in the LP with an axial outlet

Plant net output, MWe	125
Cycle Net Efficiency, %	41
Mass Flow, kg/s	193
Pressure, MPa	18
Steam Temperature, °C	450

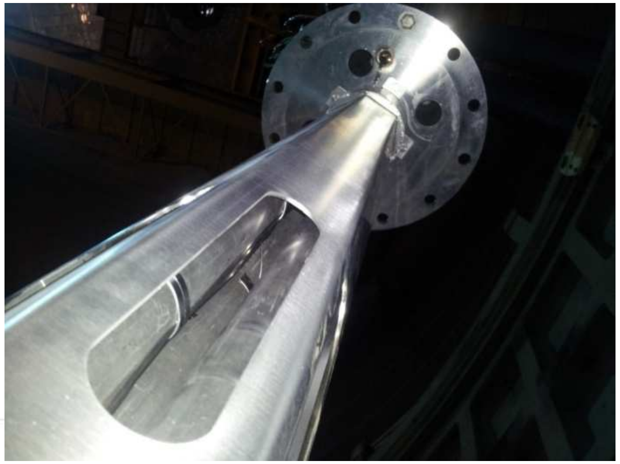


Open Issues   ALFRED

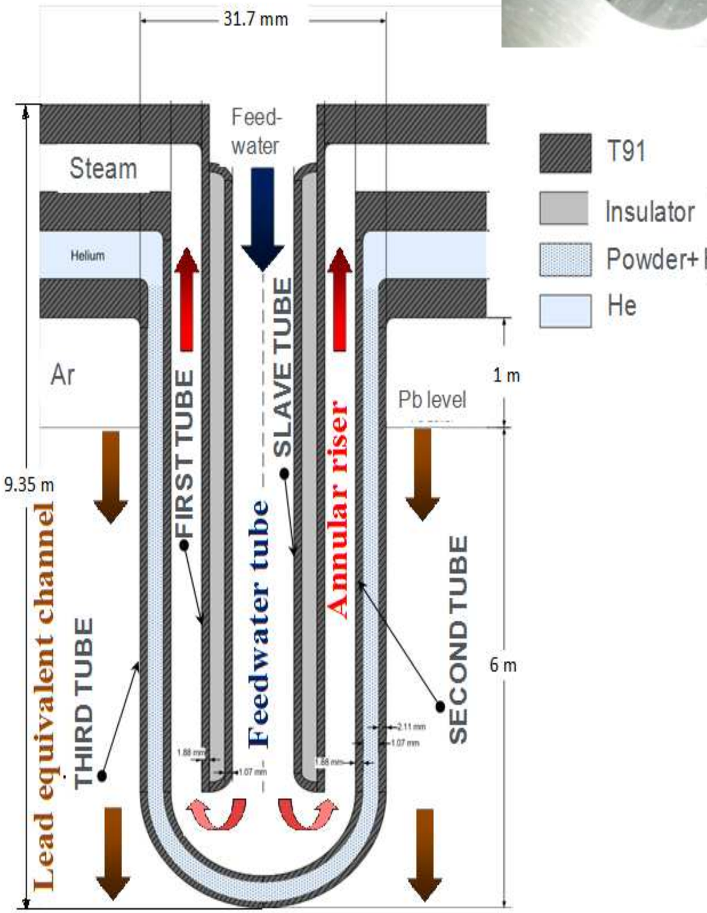
Steam Generator

- ▶Design validation
- ▶Material selection
- ▶Component behavior in forced and natural convection
- ▶Tube rupture/leakage detection
- ▶Tube rupture mitigation
- ▶Reliability and performance assessment
- ▶Replacement
- ▶SG type: spiral-tube, helical-tube, bayonet-tube

DWBT ALFRED



Assessment of the SGBT by RELAP-5



The maximum steam temperature is predicted in the range 438-456 °C depending on the diamond conductivity.

Superheated steam is always predicted, a void fraction close to 1.0 is reached within the first 3 m of the annular riser.

The lead temperature drop is about 80 °C.

REMARKS ALFRED

- ☑ Innovative design solutions have to be adopted to exploit favorable properties of lead and overcome most of the unfavorable properties (i.e. SG in the primary system)

- ☑ Simple internals have to be used (to be all removable)

GFR-2400

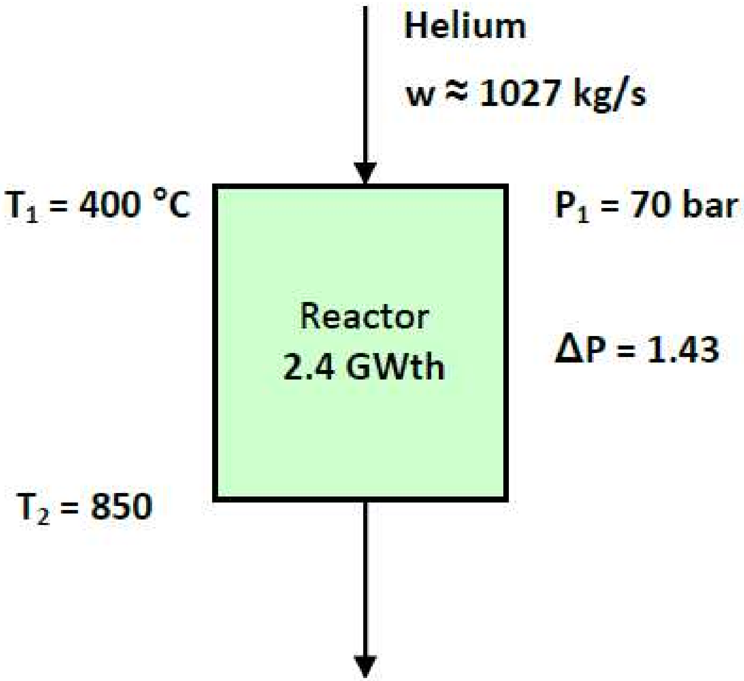
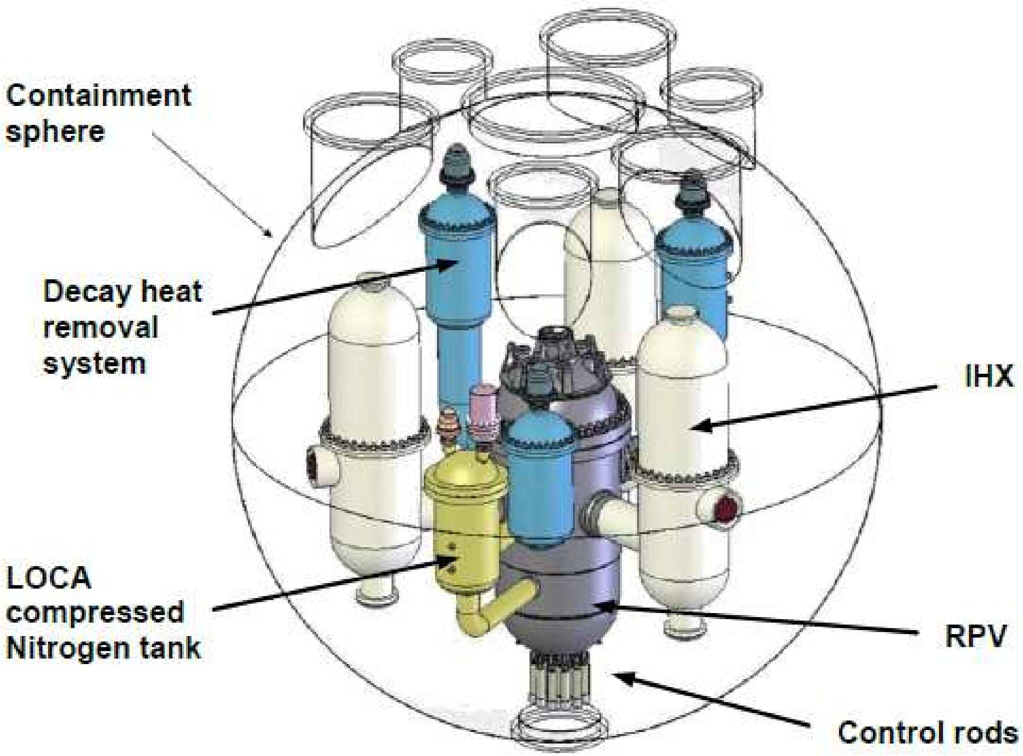
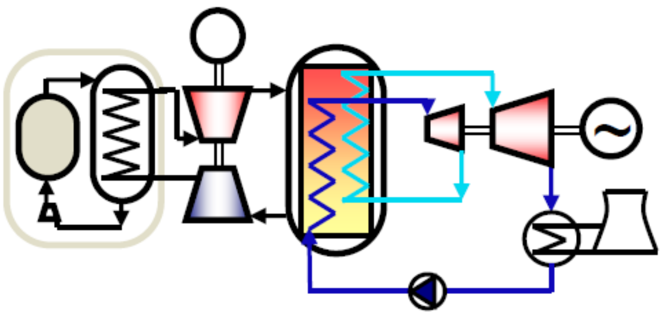


Figure 1 – Simplified representation of reactor conditions as the basis for any power conversion system study.





Indirect Combined Cycle Gas Turbine

Source: GoFastR-DEL-1.1-8

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Challenges:

1)high operating temperature (structural materials, e.g. Alloy 617) 850 ℃ / 390 ℃

2) both working fluids are gases (large size compared to liquid-liquid heat exchangers) He / 80%N+20%He

3) part of the pressure boundary of the primary circuit (physical barrier)

Source: GoFastR-DEL-1.1-9

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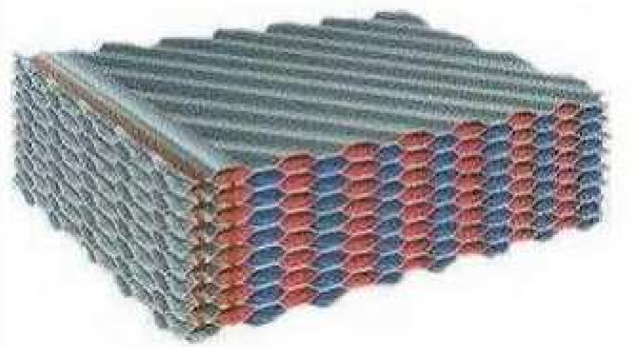
Helical Coil Heat Exchangers (HCHE):

- not feasible

Printed Circuit Heat Exchanger (PCHE):

- compact solution (800 MW 10 m^3), but low maturity



Source: GoFastR-DEL-1.1-9

Conclusions GFR

Need for new heat exchanger desings

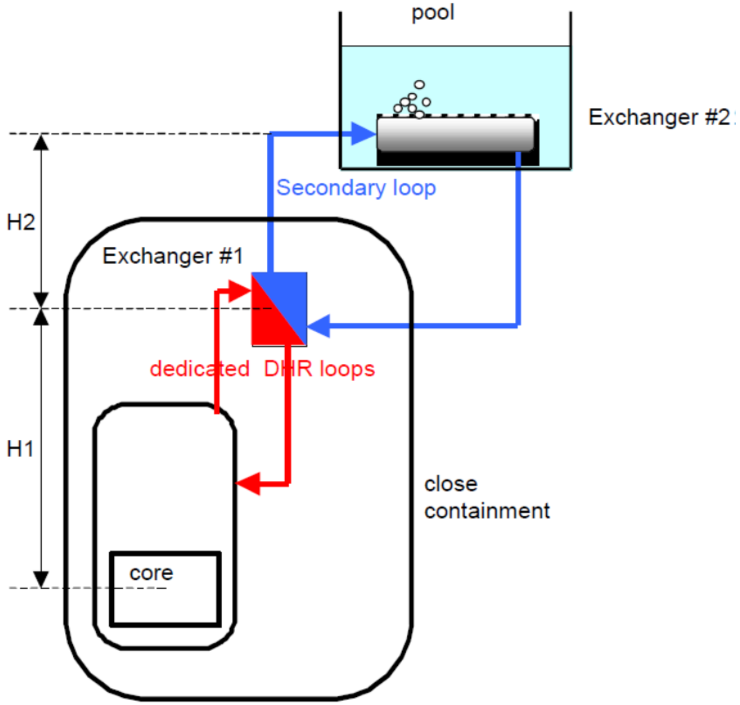
- detailed modelling
- test facilities

Material selection

- mechanical strength
- interaction with gases

Special designs:

- DHR
- steamgenerators



Conclusions SFR LFR GFR

Innovative systems need innovative designs

New solutions

- different coolants
- gas coolant; large heat transfer area;
- selection of materials
- chemical interactions
- primary system interface
- new components, systems

Synergy

- high temperatures
- validition of numerical tools for component design and safety assessment
- compact and reliable designs

Research priorities

- SFR system loop for CATHARE code validation (operation and safety)
- LFR qualify double wall bayonet tube heat exchanger design
- GFR fix conceptual design