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A S T R I D

Advanced Sodium Technological Reactor for Industrial Demonstration

ASTRID power conversion system : assessment on steam and gas options

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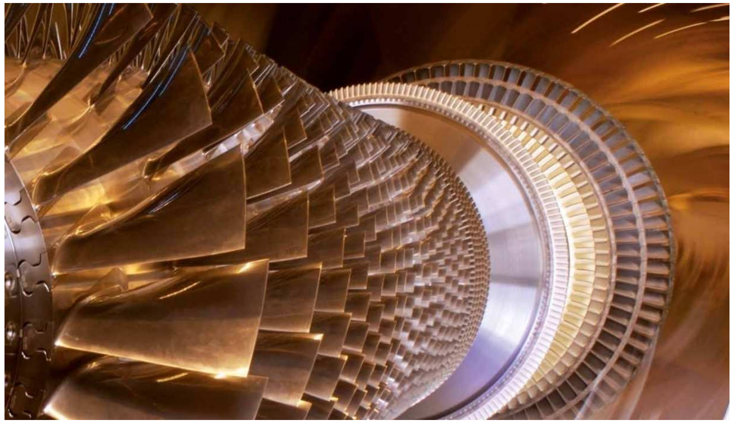
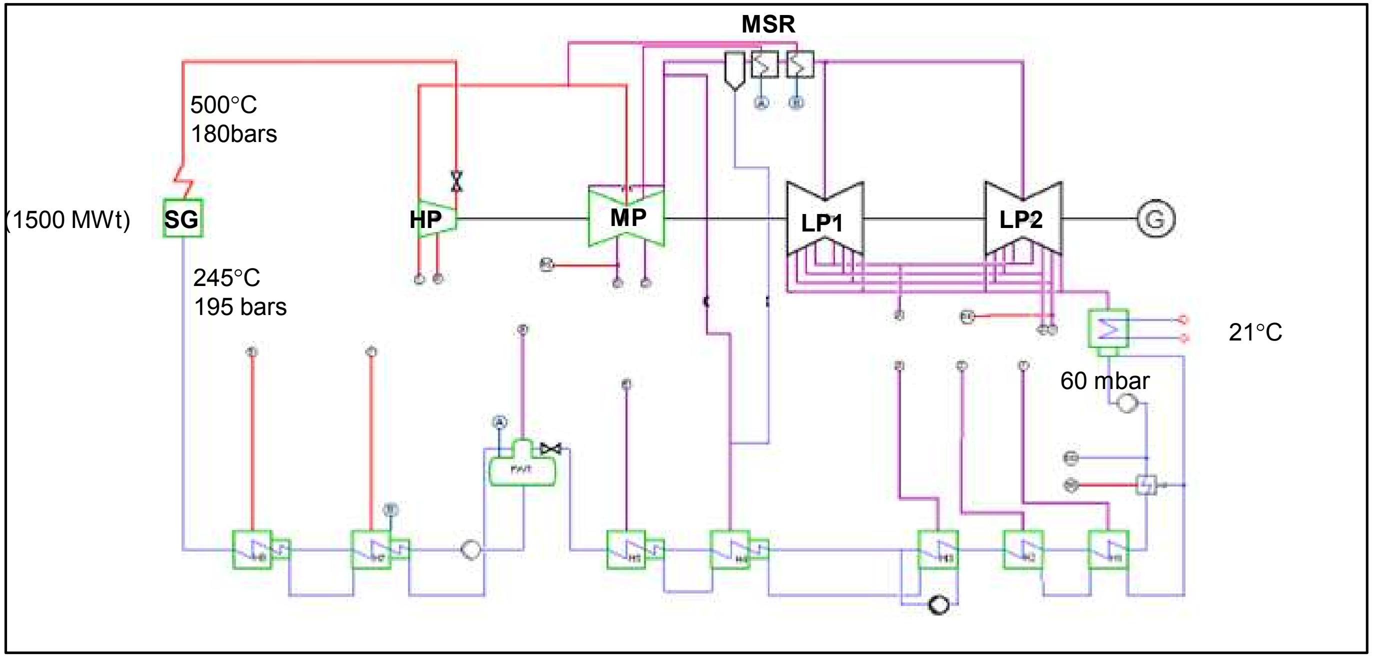
ASTRID pre-conceptual design

- Based on a sodium-cooled pool type reactor of 1500 MWth and generating about 600MWe.
- Four intermediate sodium loops.
- The target lifetime for ASTRID is 60 years.
- First pre-conceptual design phase (2010-2012) focusing on innovation and technological breakthroughs, while maintaining risk at an acceptable level.
- Among the numerous open options, two Power Conversion Systems (PCS) investigated :
  - Steam PCS option : mature option with a large experience and tens of unit-operating years, risk of sodium-water reaction as a strong design and operation constraint to be overcome.
  - Gas PCS option : very innovative option, inherently eliminating the water-sodium reaction risk by replacing water by inert gas.



ASTRID reference cycle and performances

- Rankine saturated steam cycle with steam and feedwater reheating,
- Moisture Separator Reheater (MSR) located downstream the intermediate pressure turbine (IP) with reheating by the outlet HP turbine (HP) steam.



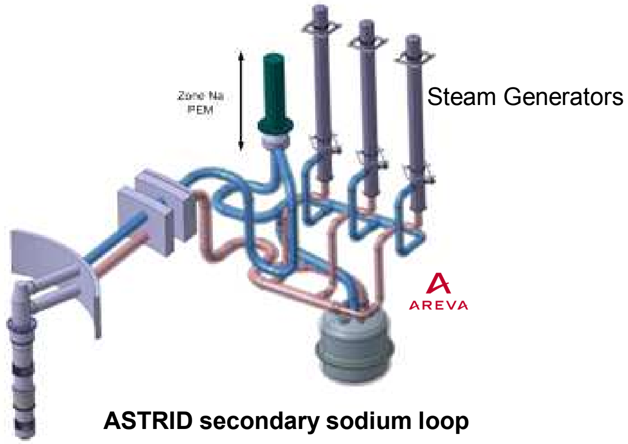
Expected net efficiency of 42%

Steam Generators (SG)

- Objective of SG development : better mastery of sodium-water reaction (SWR) and its consequences.

- Steam Generator design improvement to :
  - Reduce the risk of SWR occurrence ,
  - Limit its consequences in case of an <u>hypothetic</u> violent reaction.

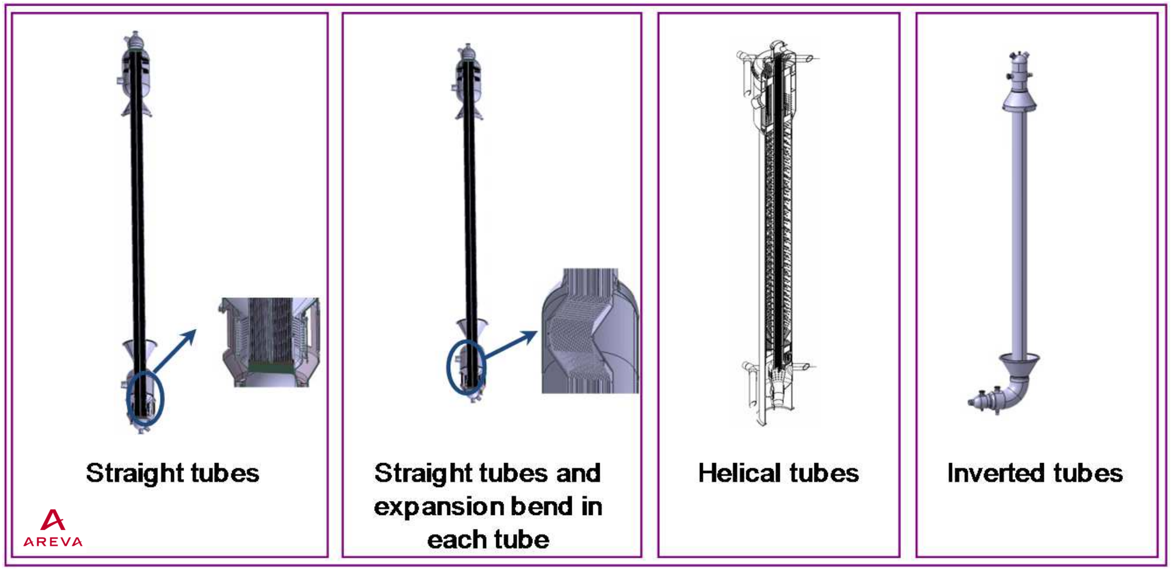
- <u>Modular Steam Generators</u> :
  - Taking into account the postulated envelope case of the quasi-simultaneous failure of all the tubes of a bundle,
  - Limiting the sodium available in a single module for the water-sodium reaction,
  - Protecting the secondary sodium loop against abnormal pressure increase,



ASTRID secondary sodium loop

Steam Generators (SG) design options

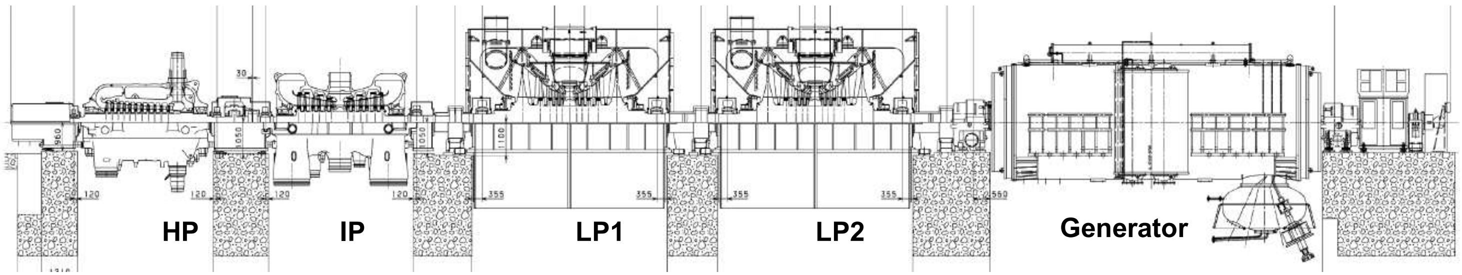
- Several design options investigated :
  - 9Cr straight tubes SG design with expansion bellow on the shell or expansion bend on each tube of the bundle : simplicity, cheaper, material issues on 9Cr (ageing, creep and fatigue, sensitivity to wastage effect),
  - A800 helical SG design : evolution of design (sodium inlet and outlet at the SG lower part) and fabrication issues (tubes bending, butt welding,..).
  - Inverted SG design (sodium inside the tubes) : expected to be preferable towards water-sodium reaction risk (no sensitivity to wastage effect), but ISI complicated and risk of displacement of the SWR in the header.



ASTRID steam Power Conversion system

Turbomachinery

- Multistage impulse type turbine, full speed (3000tr/mn), constituted with :
  - One single flow HP module,
  - One double flow IP module,
  - Two double flow LP modules.
- Generator GIGATOP-2poles with fast-acting excitation system
- Total shaft length about 48.5 m



Turbine hall equipments

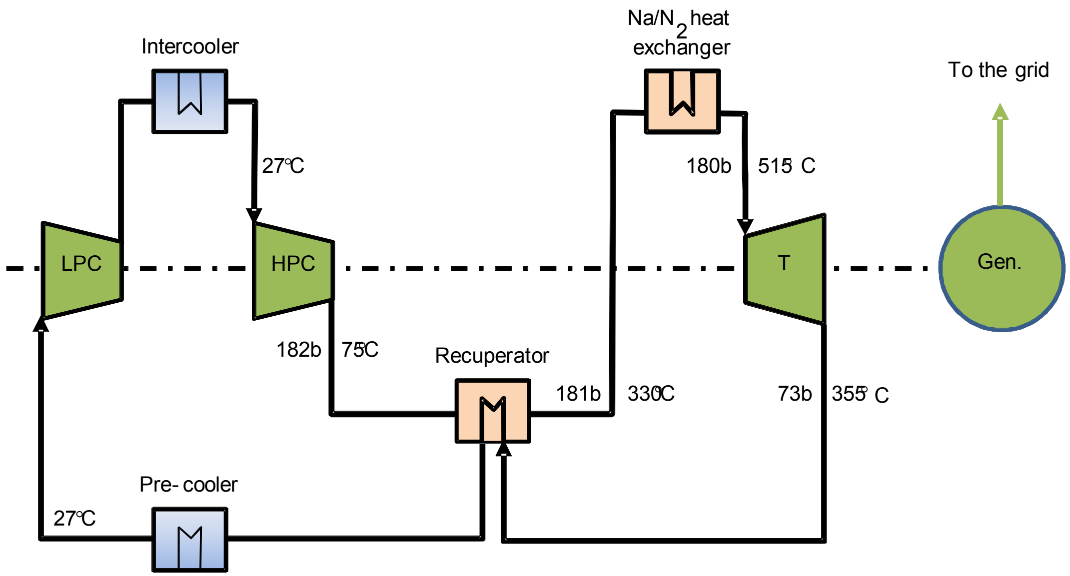
- Standard equipments included MSR,
- Normal range of use, in nuclear portfolio
- Main dimensions : 90m x 50m.

ASTRID gas Power Conversion system

ASTRID reference cycle and performance

- Brayton cycle with pure nitrogen at 180 bars.
- Design constraints :
  - Nitrogen mass flow rate at 7200kg/s,
  - Maximum gas pipe diameter = 1m : mechanical and fabrication limits,
  - Gas velocity limited at about 20m/s for pressure drops minimization

Multiple pipes in parallel for gas PCS architecture.



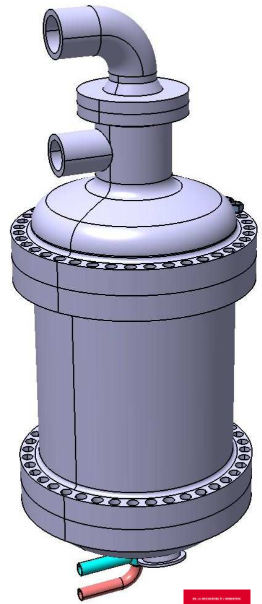
Expected net efficiency of 37.5%

Sodium-gas heat exchangers (1/2)

- Reference design : compact Plate Machined Heat Exchanger (PMHE) .
- High potential in terms of performance, safety and economics.

Main design options

- Modular component , unit power = 125MWth
- Assembling of plates stack by diffusion bonding with hot isostatic pressing (HIP)
- Component including 8 elementary modules of stacked plates (1 x 0.6 x 2.7 m).
- Modules placed in a pressure vessel (see poster CN-199-118 L. Cachon et al.)
  - Homogeneous distribution of gas,
  - Second confinement barrier for sodium,
  - Easier access for control and maintenance.

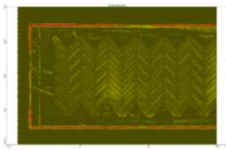


Key points

- Fabrication process : state of surface, diffusion bonding parameters (T, P, t), industrialization.
- Design rules and standards requires specific development of the French code RCC-MRx.
- Fabrication control and regular in-service inspection.

Straight channels on sodium side

Corrugated channels on gas side

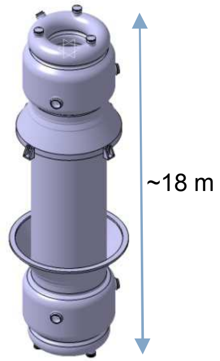


US control

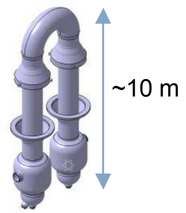
ASTRID gas Power Conversion system

Sodium-gas heat exchangers (2/2)

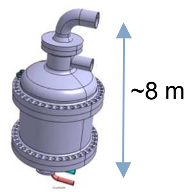
- More classical tube and shell design as back-up option
- More robust design for fabrication and inspection
- Two main designs (gas inside the tubes).
  - « U shape tube » concept
    - Unit power limited at 22MWth (tubular plates mechanical resistance)
  - « Annular concept » of straight tubes bundle
    - Ring shape tubular plate
    - Unit power limited to 80MWth,
- Major drawbacks
  - Fabricability of the thick tubular plates,
  - Heterogeneity of sodium distribution in the bundle,
  - Heavy and floor space requirement.



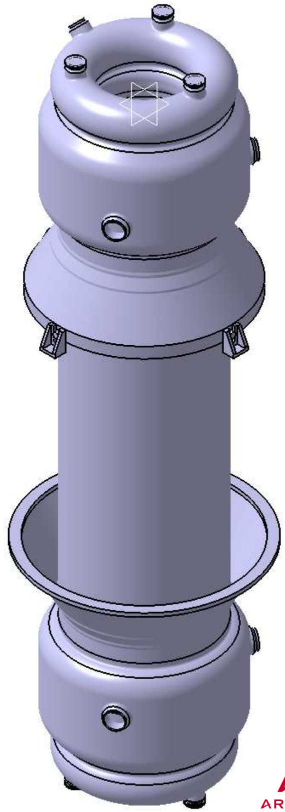
Annular design
80 MWth



U shape design
22 MWth



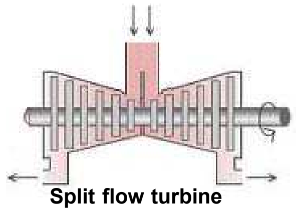
Compact PMHE
125 MWth

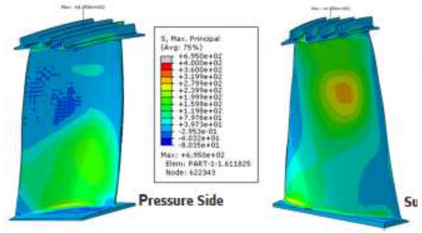


ASTRID gas Power Conversion system

Turbomachinery

- Multistage axial type split flow turbine.
- Radial LP and HP compressors face-to-face on the shaft line.
- Preliminary mechanical studies (blades, root, casing) has confirmed the feasibility of both the turbine and compressors.
- Preferred sealing system based on mechanical seals.
- Generator GIGATOP-2poles.



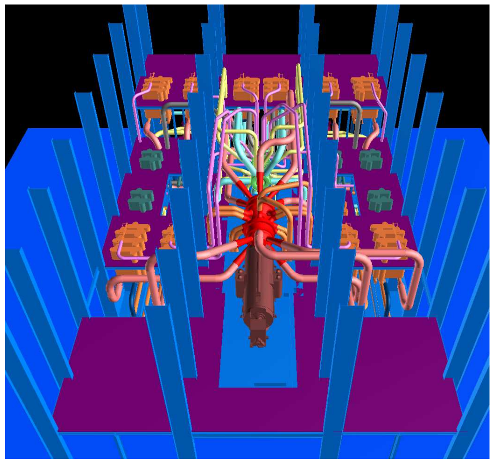


ALSTOM

Turbomachinery design is a technical challenge, but no showstopper identified

Turbine hall equipments

- Total shaft length about 45.5 m
- Gas PCS architecture including heat recuperators and coolers
- Parallel gas lines in the turbine hall.
- Main dimensions : 90m x 50m.



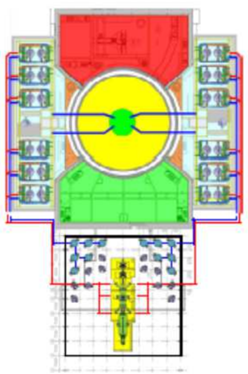
ASTRID reactor layout

Nuclear island architecture

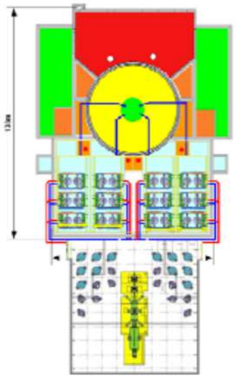
- Main constraints : architecture of reactor block and ancillary systems, reactor building confinement, geographic segregation of risks and safety systems, feasibility of civil engineered structures, operability and availability
- Several architectural options investigated : cross-shaped, rectangular, or circular.
- The cross-shaped architecture of the NI selected : robust and flexible enough to be compatible with different civil work options (simple or double shell, internal and external loadings).

Nuclear island and PCS architecture

- Cross-shaped architecture well adapted for Steam PCS : minimization of sodium routes, SG outside the reactor building for segregation of sodium-water-air reaction risk and protection against airplane crash.
- Optimization possible for gas PCS option : sodium gas heat exchanger inside or outside the reactor building, on or off the common seismic foundation raft, minimization of gas lines length and nitrogen inventory with frontal architecture.



Cross-shaped architecture



Frontal architecture

ASTRID PCS assessment

General assessment

- Net plant efficiency : the Rankine steam cycle efficiency is clearly much better than the Brayton gas cycle .
- General safety approach: main difference related to the SWR risk and the sodium-water-air reaction (SWAR) management and their consequences.
  - SG in a separate building on a common seismic raft and under a protective shell against airplane crashes.
  - Gas PCS eliminates the SWR risk and the specific associated systems (hydrogen detection, management of reaction products). Possibility to envisage locating the SGHE inside or outside the reactor containment and/or off the common raft which would greatly simplify the civil work.
  - Gas PCS eliminates the sodium-water-air reaction in case of the SGHE external vessel failure.
  - Specific risks related to the gas PCS have to be taken into consideration (leakage of gas in the secondary loop, rupture of a large gas pipe).
- Operability: preliminary RAM analysis concludes on close forced outage factors for both systems. For normal operation, gas system seems to be simpler for start-up and shut-down operational requirements. Contribution to heat removal in transient situations and inspection strategy to be investigated more in depth for the gas system.
- Balance of plant :
  - Water polishing system and auxiliary steam source required for the steam PCS.
  - Gas inventory management is a crucial issue for the gas PCS.

Conclusion

- Two power conversion systems have been investigated for the ASTRID prototype.
- Steam PCS
  - Most mature system based on a well-developed turbomachinery technology.
  - High plant efficiency.
  - Studies on steam generators designs and leak detection systems in progress with the aim of reducing the risk of large SWRs and of limiting its consequences.
  - Design and licensing safety assessment of a SFR must deal with the Sodium Water Air reaction (SWAR).
- Gas PCS
  - Strong advantage as it inherently eliminates the SWR and SWAR risks.
  - Very innovative option : major breakthroughs but feasibility and viability not yet demonstrated.
  - Remaining technological challenges but no showstopper indentified.
  - General architecture : investigations in progress to improve performances, operability and maintainability.

Thank you for your kind attention !