DE LA RECHERCHE À L'INDUSTRIE

CEA CADARACHE

ASTRID

Advanced Sodium Technological Reactor for Industrial Demonstration

Status of ASTRID nuclear island pre-conceptual design

Manuel SAEZ[1], Jean-Charles ROBIN[1], Bernard RIOU[2], Alexandre VILLEDIEU[2], Dominique DEPREST[3], Gérard PRELE[3]

[1]: CEA, Nuclear Energy Direction FRANCE, [2]: AREVA NP FRANCE, [3]: EDF FRANCE

www.cea.fr

DEN/CAD/DER/CPA

afaq QSE Qualité Sécurité Environnement AFNOR CERTIFICATION ISO 9001 - OHSAS 18001 ISO 14001

CEA AREVA EDF

Contents

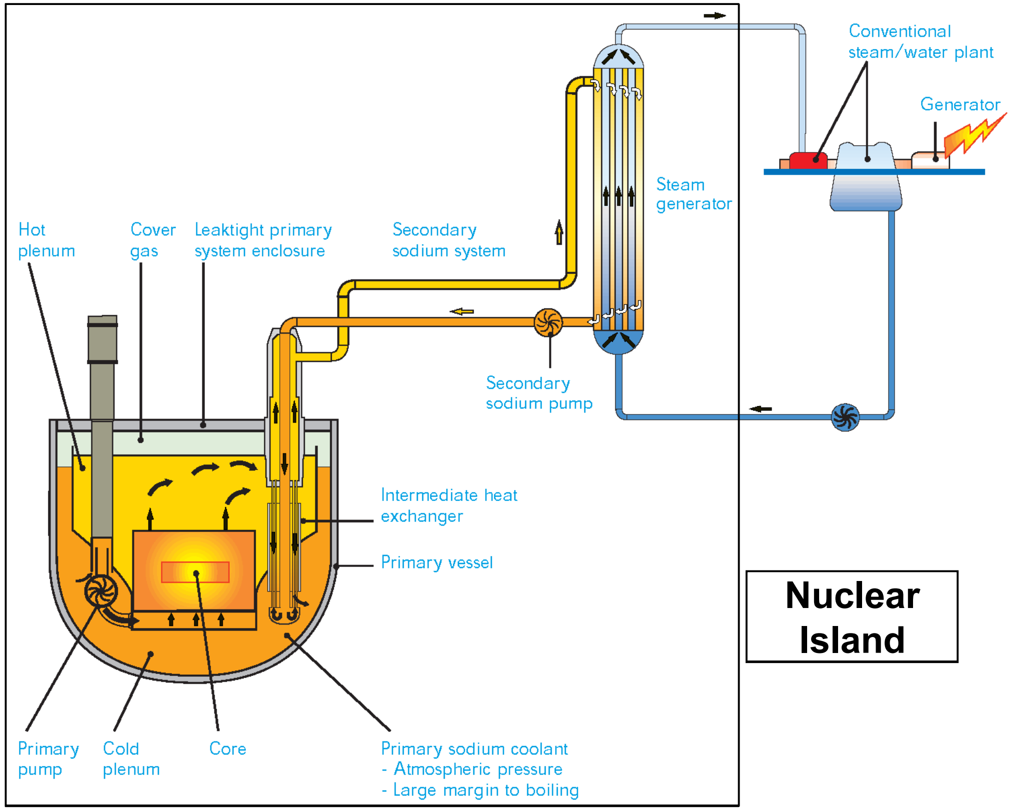
- ASTRID objectives
- Nuclear Island scope
- Primary circuit architecture
- Secondary loop architecture
- Steam Generator
- Sodium/gas heat exchanger
- Conclusions

ASTRID objectives

- **ASTRID design guided by the following major objectives compared to previous Sodium-cooled Fast Reactors:**
  - ***Improved Safety***
  - ***Simplification of structures***
  - ***Improved ISIR (In Service Inspection and Repair)***
  - ***Improved manufacturing conditions for cost reduction and increased quality***
  - ***Reduction of risks related to sodium fires and Sodium-Water Reaction (SWR)***
  - ***Improved robustness against hazards***

Nuclear Island scope

- **Nuclear Island**
  - ***Primary circuit***
  - ***Components (heat exchanger, pump, Steam Generator, sodium/gas heat exchanger)***
  - ***Components handling systems***
  - ***Fuel handling systems***
  - ***Core catcher***
  - ***Vault***
  - ***Secondary circuits***
  - ***Decay Heat Removal***
  - ***Na auxiliary systems***
  - ***Gas auxiliary systems***



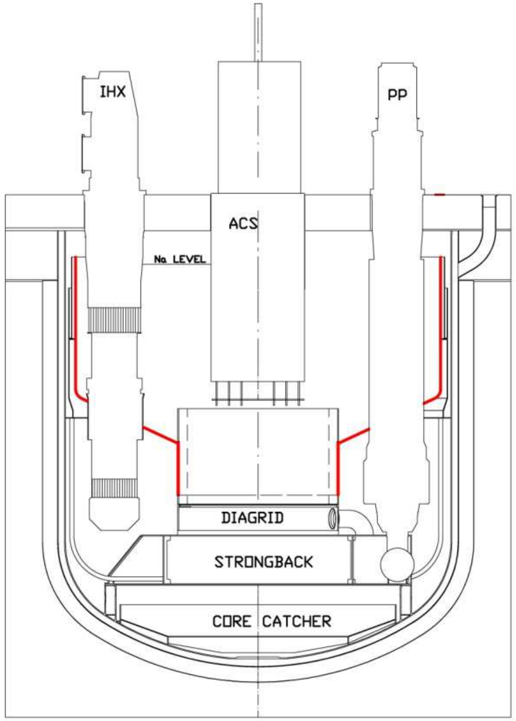
Nuclear Island

Inner vessel

- **Functions: separate the hot pool from the cold pool**

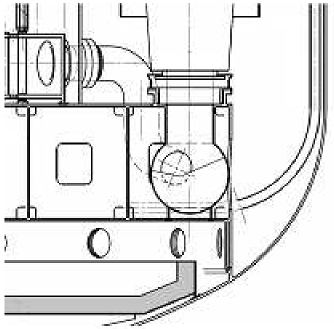
- **Options as for end 2012**
  - ***Conical redan (extrapolated from previous reactors and EFR project, with expected improvement related to ISIR, especially with regard to accessibility)***
  - ***Redan bottom welded on the peripheral shell of the diagrid***
  - ***Mechanical seals between components and the inner vessel (limit risk of gas entrainment into the core)***

- **Options discarded**
  - ***Cylindrical vessel considered as insufficiently mature and offering poor ratio "technological challenge versus potential benefits"***

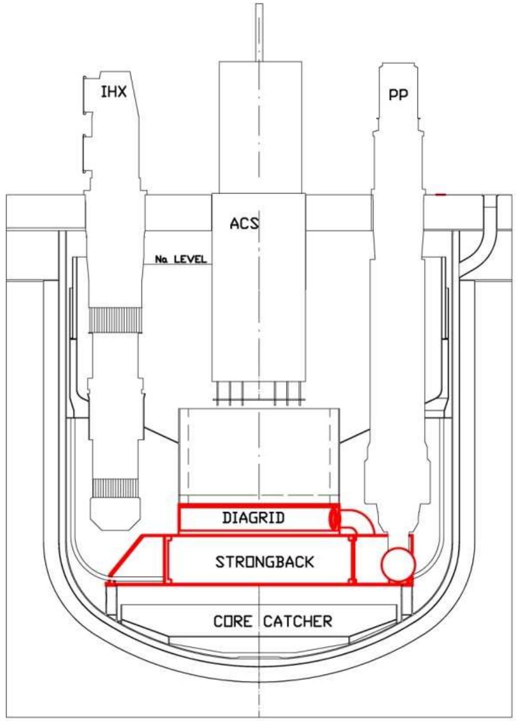


Core support structure

- **Functions: support the core and position the assemblies in order to ensure the reactivity control and rods fall in normal and accidental conditions**



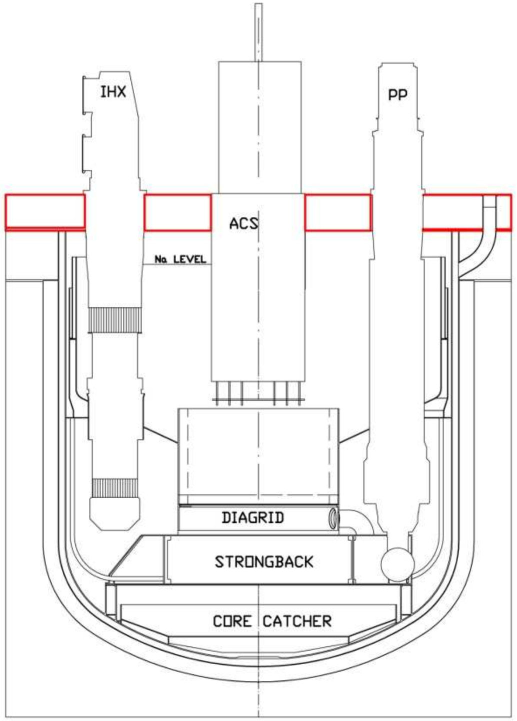
- **Options as for end 2012**
  - ***Core support structure design improved regarding ISIR, with redundant load path at periphery***
  - ***Diagrid able to slide onto the strongback and fed by primary pipes connected by pipes coupling to the pumps outlet***
  - ***Strongback supported by a skirt welded onto the main vessel at the bottom***
  - ***Cold plenum extended to primary vessel bottom***



Roof and rotating plugs

- **Roof functions**
  - ***Containment of the primary circuit in the same way as the main vessel and the rotating plugs***
  - ***Support of the components, rotating plugs and Above Core Structure***
  - ***Radiological protection of the personnel in normal operation and during maintenance periods***

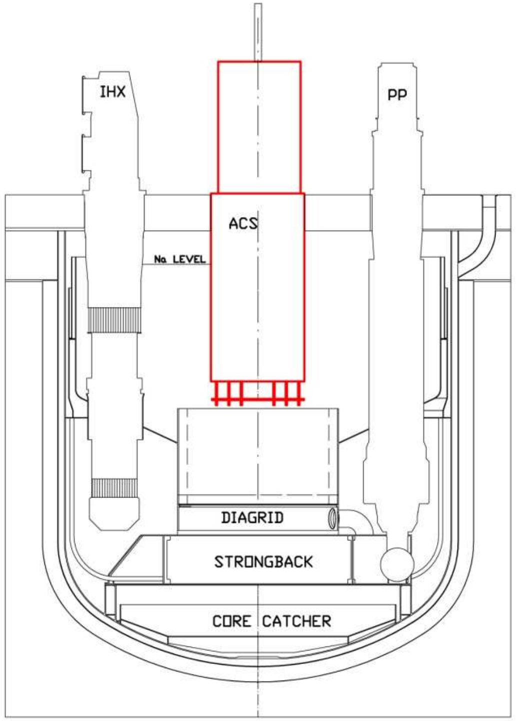
- **Options as for end 2012**
  - ***Metallic roof cooled, without water, down to 120°C at the lower surface, to avoid sodium aerosols deposition. Enhanced resistance to Core Disruptive Accident***
  - ***Rotating plugs made of thick plate steel, making a consistent closure design regarding core accident***



Above Core Structure (ACS)

- **Functions**
  - *Supports the control rod drive mechanisms and core instrumentation*
  - *Control the primary sodium flow distribution into the hot pool to achieve the required thermal-hydraulic conditions and quality of the sodium free surface*
  - *Supports the Direct Lift Charge Machine that allows for core centre fuel sub-assemblies handling*

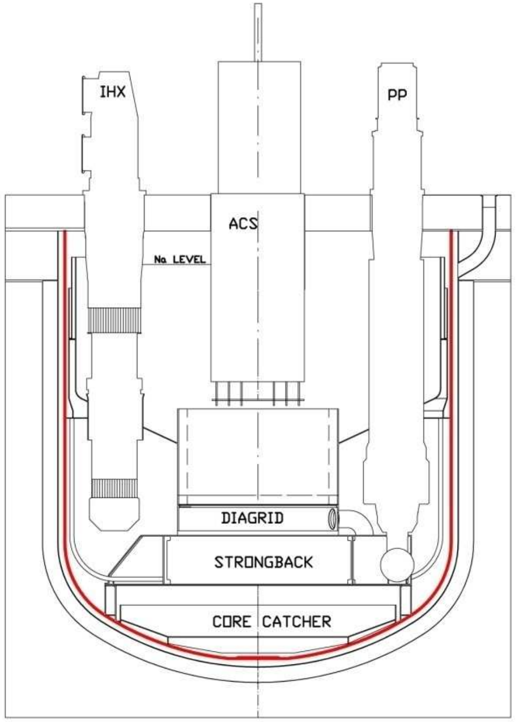
- **Options as for end 2012**
  - *Main sub-assemblies: outer shell, baffle plate, grid plate, shroud tubes, instrument guide tubes, thermocouples and multiple layer insulation*
  - *Extends over one row of radial steel reflector*
  - *Cylindrical ACS, for the integration of full core instrumentation (thermocouples, failed fuel location sampling, fission chambers…)*



- **Challenge: lifetime. Initially foreseen for 60 years operation, but ACS replacement considered**

Main vessel

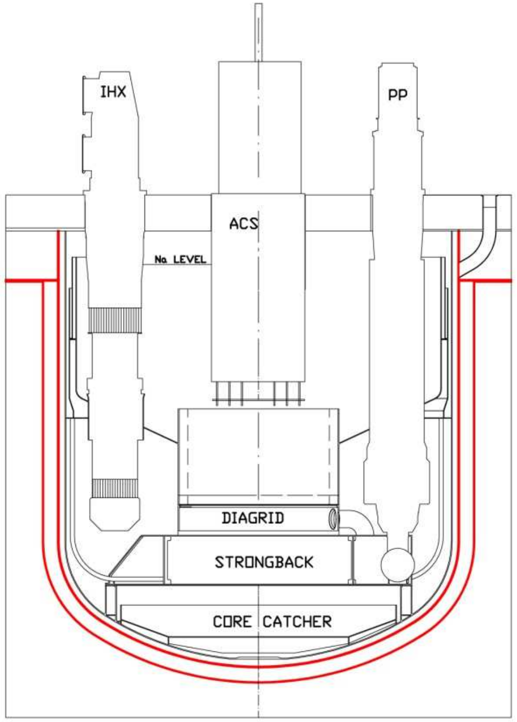
- **Options as for end 2012**
  - ***Main vessel fabricated in austenitic steel (316L(N))***
  - ***Main vessel cooling system achieved using a derived cold flow from the diagrid lower plate through pipes routing to the main vessel cylindrical part***
  - ***Immersed weir limits the risk of gas entrainment and ensures creep and fatigue resistance of the main vessel over 60 years***
  - ***Automatic welding for 316L(N) foreseen for vessels and inner components***



Safety vessel, guard vessel

- **Functions**
  - ***Contribute to confinement***
  - ***Prevent core uncovering in case of sodium leakage outside the main vessel***

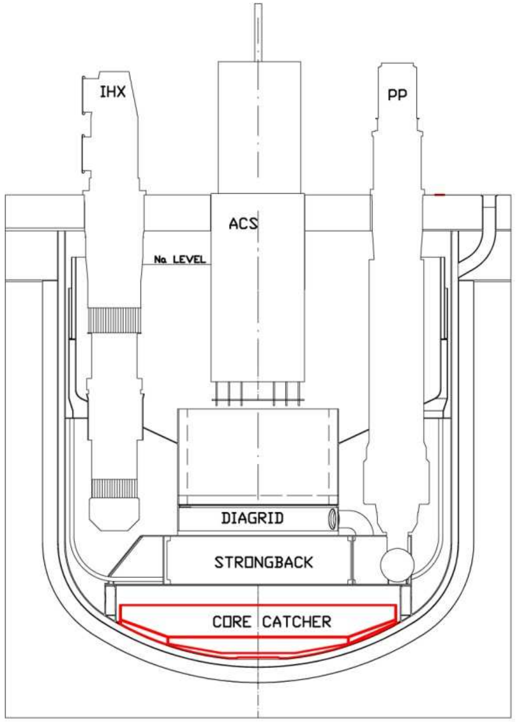
- **Options as for end 2012**
  - ***Two options are kept open in the pre-conceptual design, associated to the different concepts of core catcher:***
    - **Suspended vessel (with core catcher in the main vessel or outside the safety vessel)**
    - **Supported vessel (with core catcher between the main vessel and safety vessel)**



Choice of options at the end of 2013; trends presented here are preliminary.

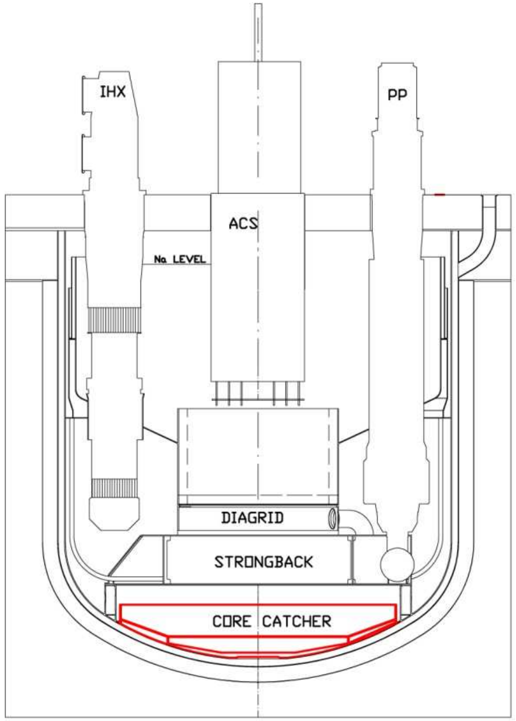
Core catcher (1/2)

- **Functions: collect and manage the corium (melted core and metallic structure) after the Core Disruptive Accident, contributing to the 3 main Safety requirements**
- **Design including the tray to collect the corium, plus one or more material layer(s) to protect the component and/or to maintain corium subcriticality**
- **Mechanical structure resisting to the highest energetic accident considered (Core Disruptive Accident) and to external aggressions (earthquake, aircraft crash…)**
- **Lifetime of 60 years, plus post-accident management period integrated in design**
- **Materials compatible with its environment in normal and accidental conditions (sodium, gas, corium)**



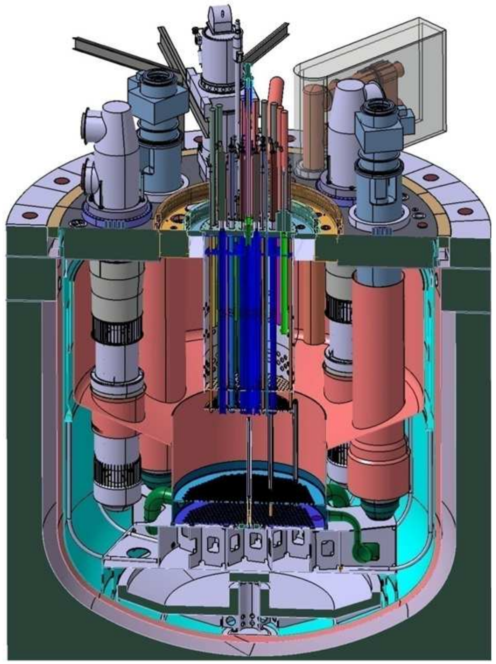
Core catcher (2/2)

- **Options as for end 2012**
  - ***Internal core catcher (inside the main vessel)***
    - **Main vessel protected**
    - **Core catcher kept in sodium environment for the whole lifetime of the reactor due to its location below core support structure, raising difficulties associated to material selection, accessibility for inspection and repair…**
  - ***Inter-vessel core catcher, located between the main vessel and the safety vessel***
    - **Safety vessel protected, without drawback associated to long time residence in sodium**
    - **Concept would also increase the inter-vessel gap width, with consequences on sodium level drop in case of main vessel leakage**
  - ***External core catcher, placed at the bottom of the reactor vault, below safety vessel***
    - **Concept eliminating drawbacks associated to long time residence in sodium, and presenting an easier access for inspection of core catcher, and a limited interference with reactor operation or ISIR**



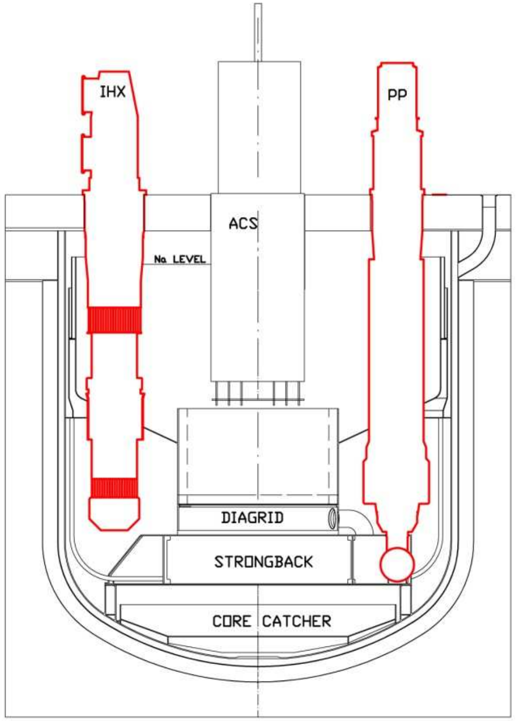
Decay Heat Removal

- **Options as for end 2012**
  - ***4 in-vessel decay heat exchangers: two in the hot plenum, and two in the cold plenum (better behaviour in case of vessels leak and in case of Core Disruptive Accident)***
  - ***Decay Heat Removal system through the vessel with the objective to complement Direct Reactor Cooling systems***
  - ***Decay heat exchangers protected above roof for resistance in case of load fall***



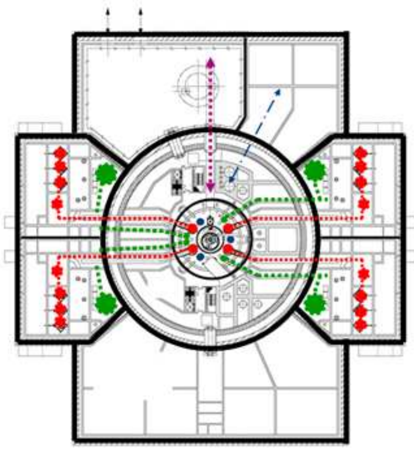
Intermediate Heat Exchanger, primary pump

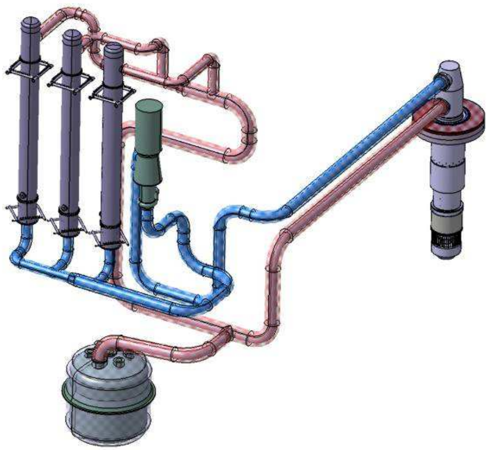
- **Options as for end 2012**
  - ***4 Intermediate Heat Exchangers (375MW, straight tube counter flow heat exchanger with primary sodium on the shell side of the tubes)***
  - ***3 primary mechanical pumps (cylindrical casing and vertical shaft machine, single flow impeller, top inlet entry flow to the impeller, subcritical drive-shaft, oil bearing (or magnetic thrust and radial bearing), hydrostatic sodium bearing)***



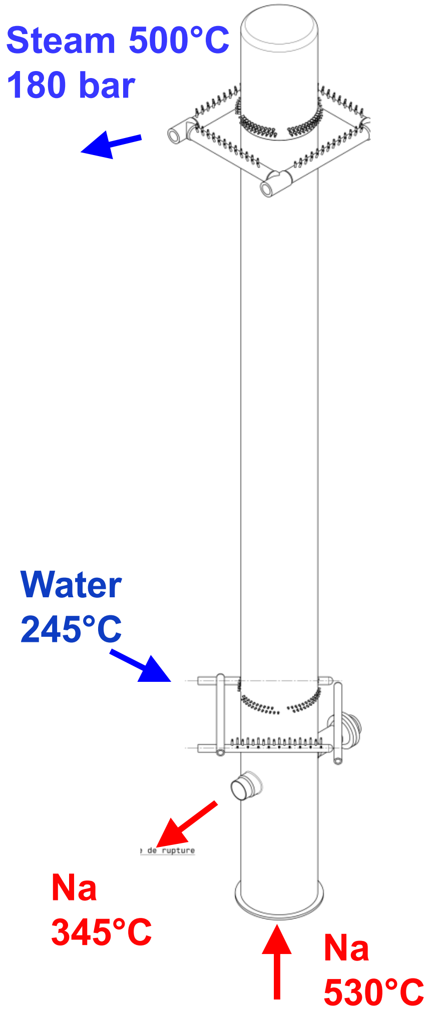
Secondary loop architecture

- **Options as for end 2012**
  - ***Sodium footprint reduced***
  - ***Short secondary loop***
  - ***Pump at low / high level (depends on Steam Generator technology and layout of plant)***
  - ***Modular Steam Generators protecting the loop against abnormal pressure increase (Sodium-Water Reaction)***
  - ***Large flow electromagnetic pumps in replacement of mechanical ones***
  - ***Loop architecture depends on Energy Conversion System***
    - **Steam water Energy Conversion System: Steam Generator technology (helical, straight tubes, inverted)**
    - **Gas Energy Conversion System: sodium/gas heat exchanger (plate, shell and tubes)**





- **Options as for end 2012**
  - ***Modular Steam Generators***
  - ***Helical Steam Generator of Alloy 800***
    - **Adapted to a secondary loop with hot leg and cold leg connected at the bottom part of the SG**
    - **Fabrication issues to be solved**
  - ***Straight tubes Steam Generator of 9Cr***
    - **Cheaper component**
    - **Drawback: faster wastage effect**
  - ***Inverted (Na inside the tubes) Steam Generator of 9Cr***
    - **Innovative approach without any leak propagation by wastage as opposed to classical SG**
    - **Speed up the leak detection**
    - **Issues: modelling of the SWR, design with external pressurized shell, In service inspection**



Sodium/gas heat exchanger

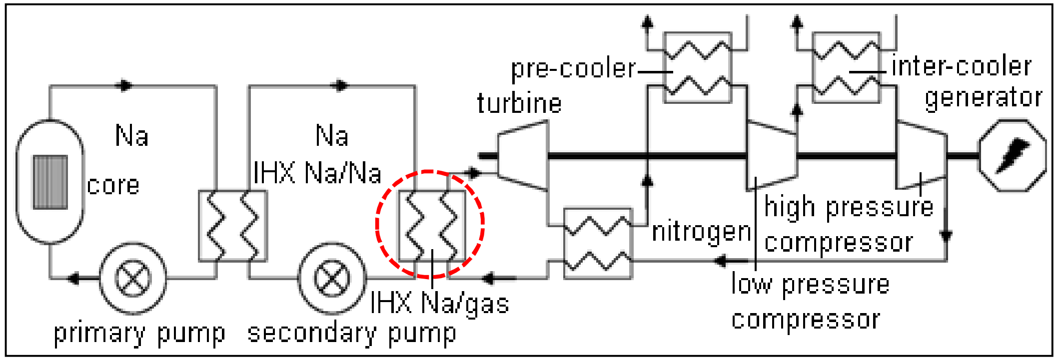
- **Options as for end 2012**
  - ***Shell and tubes heat exchanger***
  - ***Plate heat exchanger***

Shell and tubes

Plate heat exchanger

PCHE

(Printed Compact Heat exchanger)



Conclusions

- **ASTRID nuclear island design based on updated Safety objectives**

- **ASTRID will take into account the operation feedback from previous Sodium-cooled Fast Reactors, in particular regarding to materials, components and operability**

- **Nuclear island options show a differentiation with previous Sodium Fast Reactors → innovative options**

- **Pre-conceptual design delivered by the end of 2012, conceptual design delivered by the end of 2015**

Thank You for your kind attention