DE LA RECHERCHE À L'INDUSTRIE

FAST REACTORS

TECHNICAL PROGRESS

FRANCE

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SIGNIFICANT IMPROVEMENTS IN SFR DESIGN FOR ASTRID (1/2)

Feedback of previous SFRs	R&D directions	ASTRID Orientations
Core Sodium voiding reactivity **→ Safety**	Optimization of core design to improve natural behavior during abnormal transients.	CFV core (Patented in 2010): innovative approach, <u>negative</u> overall <u>sodium voiding reactivity</u>
	Exploration of heterogeneous cores	Better natural behavior of the core, for instance in case of loss of flow (e.g. due to loss of supply power)
Sodium-Water interaction **→ Safety - Availability**	Modular Steam Generators	Limitation of total released energy in case of sodium-water interaction
	Reverse Steam Generators (sodium into tubes) – studied until Feb 2013.	Limitation of wastage propagation
	Gas Power Conversion System (nitrogen in place of steam/water)	Design studies conducted by ALSTOM. No show stopper.

SIGNIFICANT IMPROVEMENTS IN SFR DESIGN FOR ASTRID (2/2)

Feedback of previous SFRs	R&D directions	ASTRID Orientations
Sodium fire **→ Safety**	Innovative Sodium leak detection systems R&D on Sodium aerosols	Improving detection (Patent of detection system integrated in the heat insulator) Close containment (inert gas + restriction of available oxygen)
Severe accidents **→ Safety**	Core catcher Research on corium and sodium-corium interaction	Internal core catcher.
Decay heat removal **→ Safety**	Reactor vessel auxiliary cooling system (scaling rules)	Combination of proved Decay Heat Removal systems and Vessel Natural Air draft cooling
In-Service Inspection and Repair **→ Safety – Availability**	Simplification of primary system design ISI&R taken into account from the design stage New techniques : Acoustic Detection, Laser techniques, CRDS Signal processing Ultrasound at high temperature, High temperature fission chambers, Optical Fibers, Flow meters for subassembly Remote handling for inspection or repair Under-sodium viewing	

CORE DESIGN APPROACH

ASTRID core design is mainly guided by safety objectives

1. Prevention of the core meltdown accident

- by a natural behavior of the core and the reactor (no actuation of the two shutdown systems)
- with adding passive complementary systems if natural behavior is not sufficient for some transients

2. Mitigation of the core melting accident

To garantee that core melting accident do not lead to significant mechanical energy release, whatever the initiator event

- by a natural core behavior
- with adding specific mitigation dispositions if natural behavior is not sufffficient

CORE DESIGN OBJECTIVES

- Natural behavior favorable for transients of unprotected loss of flow and loss of heat sink
  Target criteria : no sodium boiling for a ULOSSP transient
- Sodium void effect minimized
  Target criteria : Na void effect < 0
- Natural behavior favorable for a complete control rod withdrawal (with no detection)
  Target criteria : no fuel melt
- Improved performances
  Target criteria : Cycle length ≈ 480 efpd, High fuel burnup, and breeding gain ≈ 0

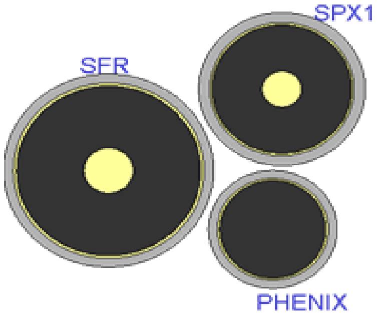
+ Core design is extrapolable to higher power

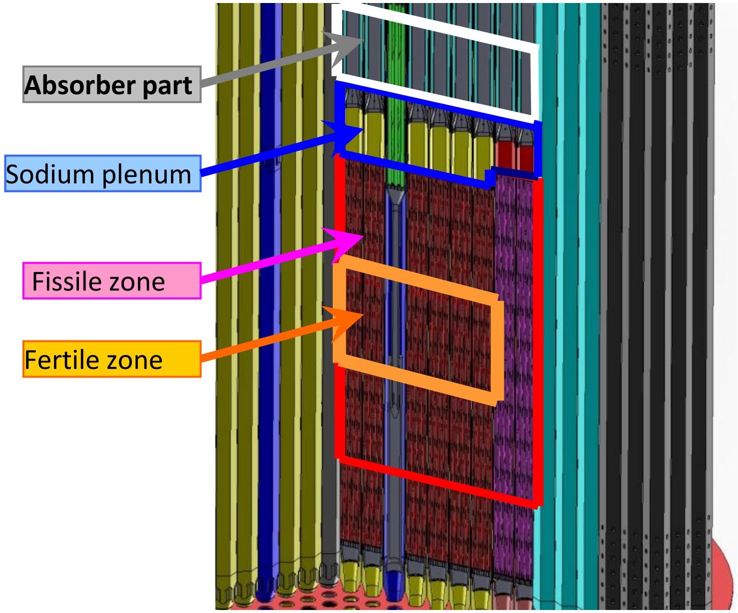
CORE DESIGN

Design

- Heterogeneous axial core with an inner fertile zone
- Asymetric geometry (inner vs outer core)
- Core height reduction
  - ➢ Neutron leaks favored

- Sodium plenum : cavity filled with sodium and located as close as possible to the fuel
  - ➢ Neutronic reflection on nominal cases
  - ➢ Reflector effect reduction in case of sodium temperature increase
  - ➢ Neutron channel in case of sodium draining (boiling)
- Fuel fraction increase in the fuel bundle to reduce reactivity loss



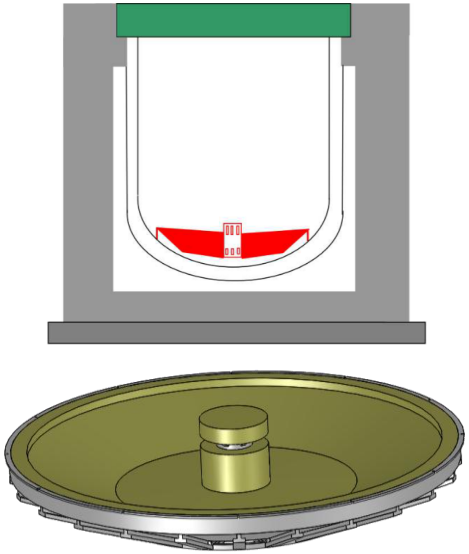


CFV Core

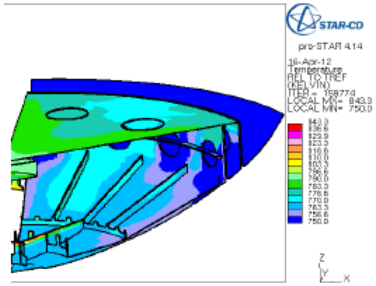
CORE-CATCHER DESIGN OPTIONS

In-vessel core catcher

- Design
  - Located inside the main vessel below the core support structure
  - ZrO_2 covered for corium jet impingement protection (preliminary design)
  - Cooled by sodium natural convection
- Advantages
  - Protection of the main vessel (Integrity)
  - Well adapted to pool type reactor (large tray)
  - Could use Main Vessel DHR if available
- R&D on material
  - Need of sacrificial materials (corium jet)
  - Long term Na compatibility of sacrificial materials
- Studies carried out
  - Thermo-hydraulics: Core-catcher cooling, DHR
  - Mechanics: supporting structure, seismic resistance…



In-vessel core catcher design



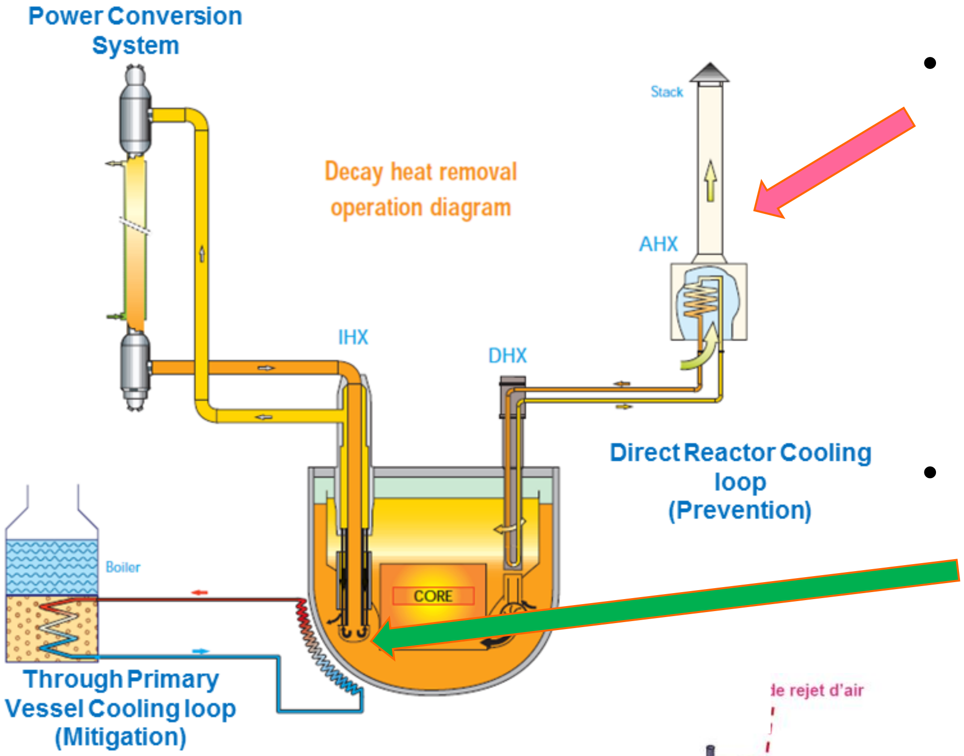
In-vessel core catcher cooling studies

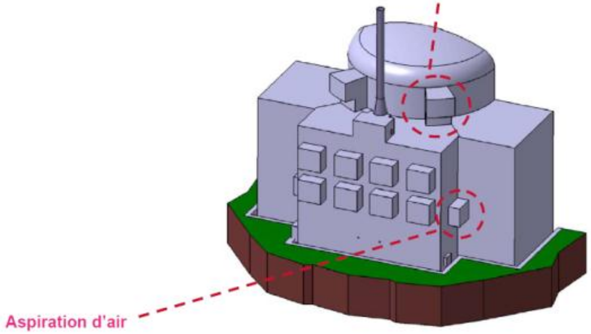
DECAY HEAT REMOVAL

- Goal of Decay Heat Removal systems is to ensure reactor cooling after shutdown in all conditions.
- Decay Heat Removal is one out of the three main safety functions for nuclear reactors. Consequences of a failure of Decay Heat Removal function include increase of sodium temperature, sodium boiling, and degradation of structures.
- However, Sodium-cooled Fast Reactors present advantages when compared to other reactors:
  - Large margin before sodium boiling (Tcore outlet 550°C / TNa boiling 881,5°C)
  - Extended grace period due to large thermal inertia
  - Architecture favours natural convection initiation .

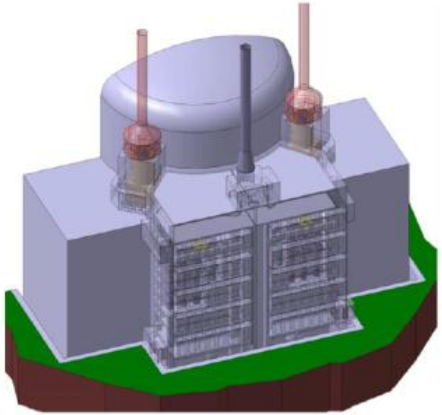
ASTRID design aims to the "Practical Elimination" of the long duration total failure of Decay Heat Removal systems

DECAY HEAT REMOVAL



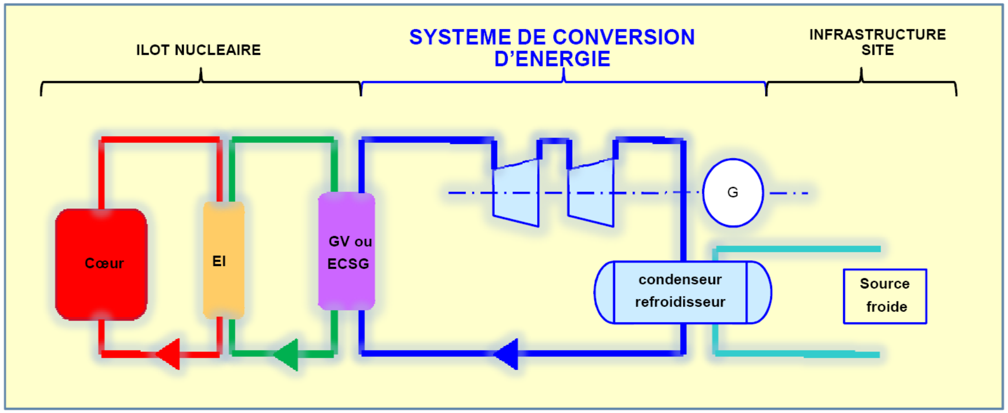


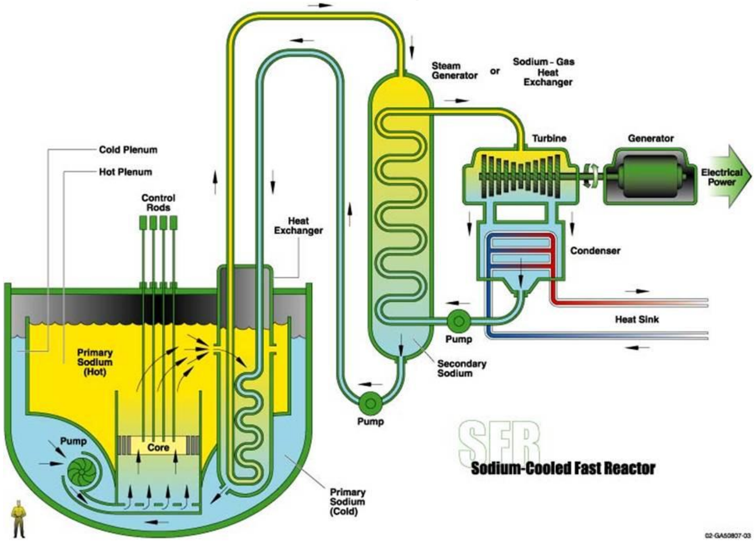
- 2 systems for direct reactor cooling :
  - Na/Na in the main vessel
  - air as cold source,
  - Redondancy : 2 or 3 trains per system (2*100% and 3*50%-66%)
  - System n°1 : natural convection
  - System n°2 : forced convection
- 1 complementary system (mitigation) :
  - Through the Primary Vessel Reactor
  - Cold source to be confirmed (water/air)



ORIENTATIONS TO REDUCE THE SODIUM WATER RISK

- The first measure of prevention is the presence of the intermediate and non radioactive sodium circuit to separate chemical risk and radiological risk.





- 2 ways to reduce the SWR risk
  - To review the SG design of the steam PCS (Rankine cycle) in order to :
    - reduce the risk of SWR occurrence
    - limit the consequences of an hypothetical violent reaction
  - To move to a gas PCS (Brayton cycle with pure nitrogen at 180 bar) in place of steam cycle to eliminate de facto the SWR risk
    - Feasibility to be demonstrated but no showstopper identified up to now.

« LOD » & « LOM » METHODS

	S.A. Prevention	**S.A. Mitigation**
Method	**Lines of defense** (LoD)	**Lines of Mitigation** (LoM)
Approach type	"Bottom-Up"	"Top-Down"
Objective	Probabilistic targets	Consequences reduction
Lines validation criteria	Number of lines, reliable, independent, common mode absence	Equipment ensuring all functions of one LoM. Each LoM homogeneous: approach ''weak link of chain''
Demonstration	Equivalent to ''2 strong + 1 medium'' lines	Minimization of radiological release with 'decoupling' approach
Application domain	Prevention including PES*	Complementary to ''analysis by barrier'' method
Safety classification of SSC	Complementary to "analysis by function"	Complementary to ''analysis by function''
« Hard Core » contents	One LoD per PES	All equipment involved in one same LoM

* Practically Eliminated Situations

ASTRID – PRELIMINARY BASIS FOR SAFETY APPROACH

Main safety orientations that are structuring for the design and R&D

Objectives of “Practically elimination”

- Events that could lead to a prompt-critical state with an kinetic incompatible with the reactivity control systems and the capabilities of the feedback reaction coefficients
- Abrupt voiding of the core due to a large gas bubble
- Major reactivity insertion due to excessive core compaction or fuel handling mistakes (shutdown state)
- Collapse of core support structures
- Fuel melting due to loading error
- Large insertion of moderating materials (fuel storage)
- Events that could lead to the loss of the decay heat removal means or their inefficiency
- (long term) loss of all decay heat removal circuits
- Primary sodium drainage leading to the loss of exchangers
- Instantaneous whole loss of flow in the core

First list of limiting events (Prevention of core damage)

- Leakage of main and safety vessels
- Total and instantaneous SA blockage
- Large water/sodium/air reaction
- Large SG accident
- Large sodium leak on the roof
- Large secondary sodium leak outside the confinement

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