



# New simulation tools to be developed for the ASTRID program

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DE LA RECHERCHE À L'INDUSTRIE

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ASTRID

*Advanced Sodium Technological Reactor  
for Industrial Demonstration*

## **New simulation tools to be developed for the ASTRID program**

**Technical meeting on Priorities in Modelling and Simulation  
for Fast Neutron Systems**

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DEN/CAD/DER/CPA

*Technical meeting-IAEA- 14-16 April 2014*

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# The objectives

**ASTRID : Advanced Sodium Technological Reactor for Industrial Demonstration**

- ❑ **Technological Demonstrator for Sodium Fast Reactor**
- ❑ **Integrating French and International SFRs feedback**
- ❑ **A GEN IV system**
  - **Safety :**
    - ✓ **Level at least equivalent to GEN III systems**
    - ✓ **Progress on Na reactors specificities**
    - ✓ **Integrating FUKUSHIMA accident feedback**
  - **Operability :**
    - ✓ **Load factor of 80% or more after first “learning” years**
    - ✓ **Significant progress concerning In Service Inspection & Repair (ISIR)**
  - **Ultimate wastes transmutation :**
    - ✓ **Realization of demonstrations on minor actinides transmutation according to June 28, 2006 French Act on Wastes Management**
  - **A mastered investment cost**
- ❑ **Irradiation services and options test**

# Organization

- ❑ CEA/Nuclear Energy Division is the leader of the ASTRID project
- ❑ CEA is organizing an industrial network made of bilateral collaborations between CEA and each industrial partner,



- ❑ On the side of technical developments and experimental facilities, CEA is also willing to develop international partnerships.

Discussions for an agreement with Japan are in progress.

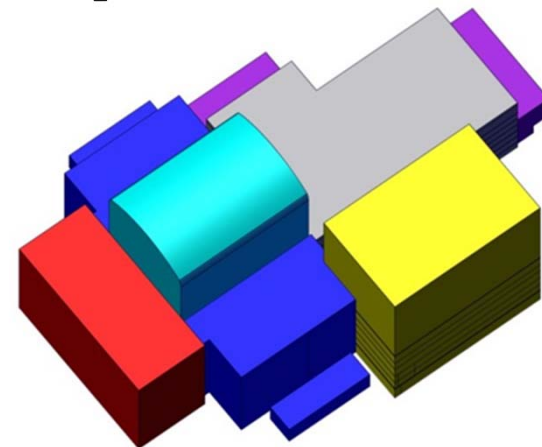
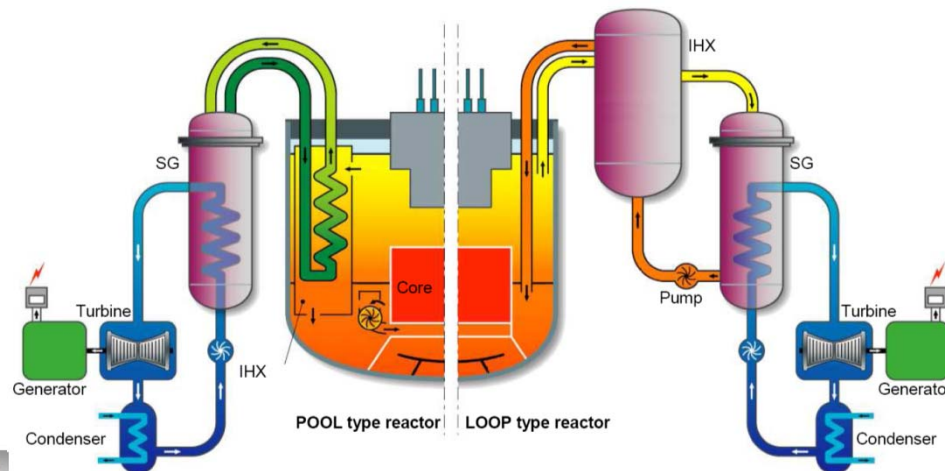
# Preliminary design choices / open options

## Main features

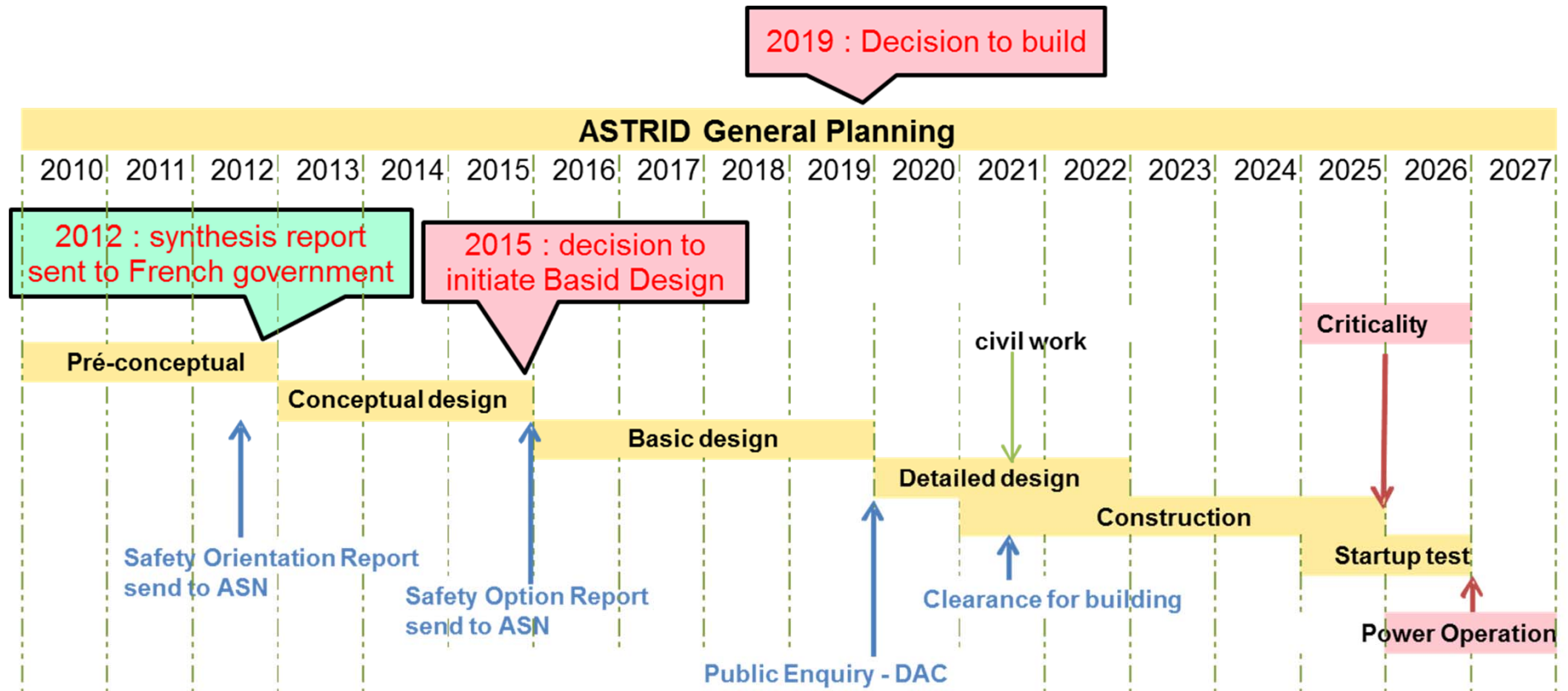
- 1500 thMW - ~600 eMW
- Pool type reactor
- High level expectations in terms of safety demonstration : choice of the low sodium void effect core (CFV), plant installed on anti-seismic bearing pads...
- Core outlet temperature : 550°C
- Mixed oxide fuel  $\text{UO}_2\text{-PuO}_2$
- 3 primary pumps and 4 secondary loops (each with an intermediate heat exchanger)
- Presence of a core catcher
- Diversified decay heat removal systems
- ....

## Open options

- Core design
- Energy conversion system : steam generators or sodium-gas heat exchangers. Continuous development of the gas power conversion system, associated with compact sodium-gas heat exchangers (the most innovative solutions) while keeping the steam power conversion system as a back-up solution.
- Innovative options of shutdown rod architecture
- Core catcher technology
- Innovative technologies for Na fires detection and mastering
- ...



# ASTRID project general planning



**Simulation is more and more used, with the following objectives :**

- ☐ to obtain confidence on the feasibility of proposed innovations,**
- ☐ to help to steer R&D priority according to most promising innovations and needs of ASTRID project,**
- ☐ to quantify performances of components,**
- ☐ to limit conservatisms which involve extracosts,**
- ☐ to favor acceptance of safety demonstration by the Safety Authorities,**
- ☐ to help to develop new experimental program and to size experimental devices.**



## Strategy for simulation/ main steps

**The schedule for development and V&V of simulation tools is defined by the schedule of safety files :**

- ❑ Conceptual design phase → safety option report (end of 2015).**
  - **Beginning of development of performing reference tools in order to use them for the basic design phase.**
  - **Set up development plan and V&V plan for each of this reference tool.**
  
- ❑ Basic design phase → preliminary safety report (2019)**
  - **Industrialized version of each of this reference tool (2017) in order to provide studies.**
  - **Finalized V&V files (2019).**
  
- ❑ Later, the safety report : let us time necessary to**
  - **Provide new validation results**
  - **Improve confidence in the tools ability**

## Strategy for simulation/ approach

From the beginning of the ASTRID program, CEA is continuously improving its simulation tools and their V&V level. It is done closely with the R&D programs.

□ During the pre conceptual design phase :

- Start with the available tools principally coming from PHENIX and SUPERPHENIX studies.
- First step devoted to restore production
- Second step : the work was continued, and the effort aimed to the training on these tools in order to lead to provide specifications for improvements.
- Specifications for new tools
- Beginning of the development

□ During the conceptual design phase :

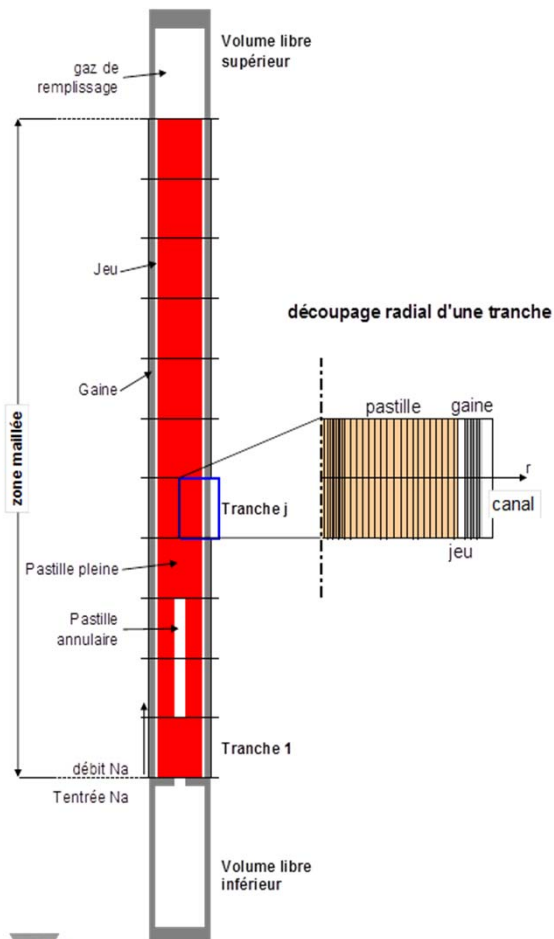
- On-going development of new tools for the ASTRID design
- Preparation for the transition to these new tools for the basic design phase in order to use them for the preliminary safety report

➔ A few examples of computation tools developements in the fields of neutronics, fuel behaviour, core mechanics, thermal-hydraulics, coupling and severe accidents.

➔ The developments are made in close relationship with Simulation program of the Nuclear Energy Division

- ❑ **Goals :** to design the core, to check the linear power criteria, the safety criteria, to determine the feedback coefficients ...
  - ❑ **Development :**
    - From **PARIS-ERANOS** during the conceptual design phase
    - To **APOLLO-3** for the basic design phase
  - ❑ **APOLLO-3 will provide a modern tool to design an innovative core :**
    - A new numerical formulation that is more robust and faster to converge
    - A new architecture software making it a more lasting tool
- In order to match the specific issues regarding the low sodium void effect (CFV) core :**
- great heterogeneity of the core in the axial direction and enhanced neutron leakage
  - power distribution and its stability to perturbation ...

❑ **Goals : to design the fuel element and the fuel sub-assemblies.**



❑ **Development : GERMINAL is in continuous evolution**

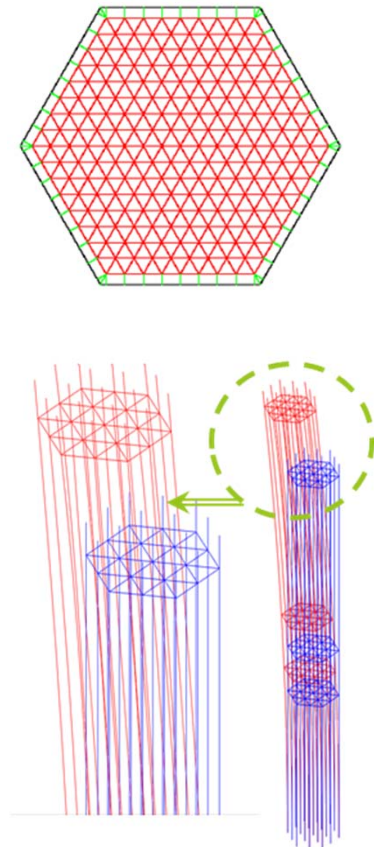
- From **GERMINAL V2.2** during the conceptual design phase
- To **GERMINAL V2.3** for the basic design phase

❑ **GERMINAL V2.3 involves thermal, mechanical, physical and chemical properties of the fuel and its cladding. V3.2 will provide a better description of :**

- The thermal conductivity and the creeping of the irradiated fuel
- The fuel/clad gap filling
- The fission gaz retention and fuel swelling
- Improvment of the calculation time

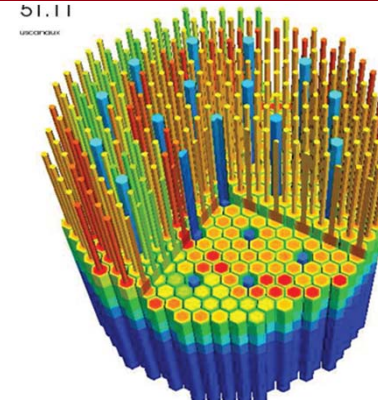
- ❑ **Goals:** to design fuel sub-assemblies, to check the RAMSES criteria, to assess the core compactness ...
- ❑ **Development from DOMAJEUR 1 to DOMAJEUR 2 :**  
Purpose : 3D pin bundle thermal-mechanical behavior and its interaction with the wrapper tube
- ❑ **Development from HARMONIEV2 to HARMONIE2 V1/ and BASILIQ**  
Purpose : 3D core thermal-mechanical behavior and its interaction with the core restraint structures

**HARMONIE** is a static model whereas **BASILIQ** is a dynamic one with fluid-structure interaction.  
These 3 tools are developed on **CAST3M** basis.



## □ Core thermal-hydraulics **TRIO\_U-MC2**

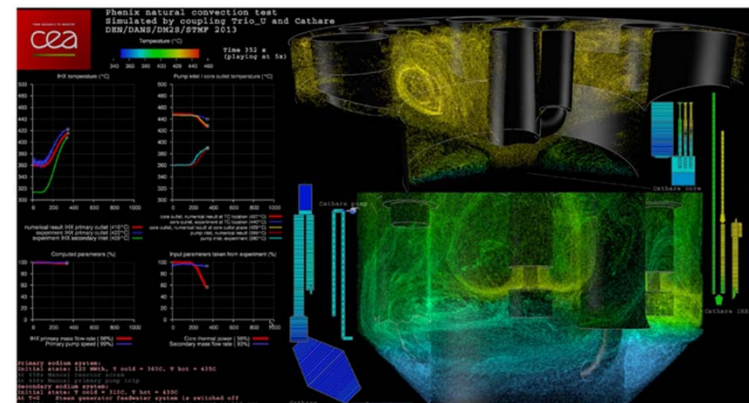
- Goals: to design the core ie. to optimize the flow distribution, to check the clad temperature criteria...



## □ System thermal-hydraulics : **CATHARE**

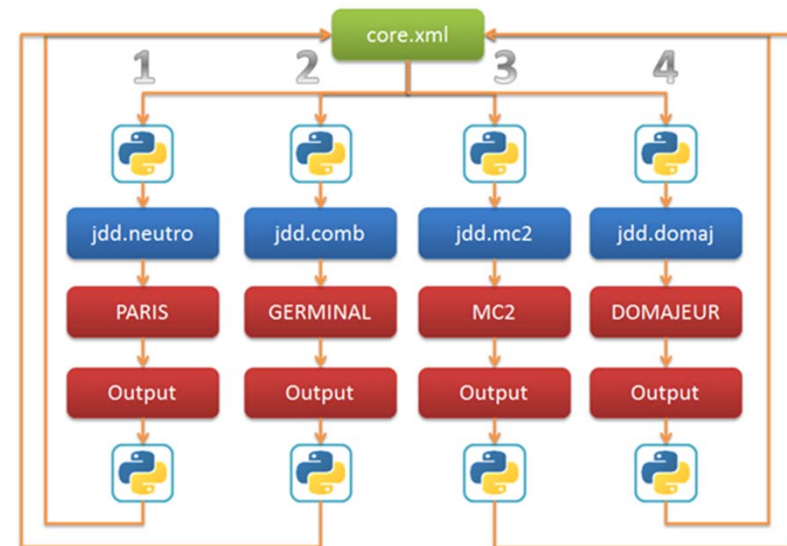
- Goals : capability to predict reactor power and temperature evolutions during all transients (rod withdrawal, pump overspeed/rundown, loss of heat sink...)
- From **CATHARE V2.5** during the conceptual design phase
- To **CATHARE 3** for the basic design phase

## □ Whole system model for primary natural circulation situations : **CATHARE** coupling with **TRIO\_U-MC2**



- ❑ Goals : to have unified data for all tools, to have an automatic coupling between several domains.
- ❑ Development of **PIC4SSO** : Interdisciplinary platform of codes for the design and simulation of core.  
PIC4SSO involves PARIS, GERMINAL , TRIOU-MC2 and DOMAJEUR.

- ❑ By the end of 2014, **PIC4SSO** will also include HARMONIE

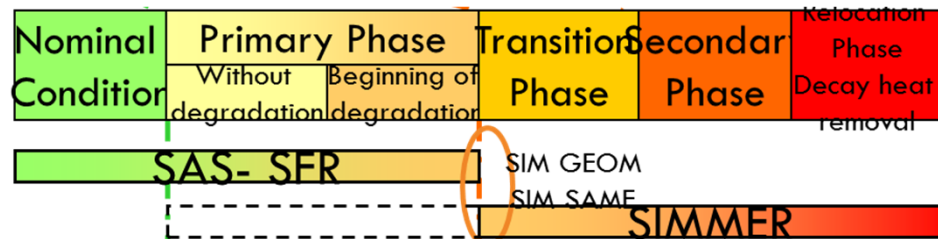




# Severe accidents

- Goals : to demonstrate the achievement of high level safety goals

Ex: mitigation of core melting → no energetic phase (by design/natural behaviour + specific mitigation devices)



- Development :

- from **SAS-SFR** (collaboration with KIT, JAEA and IRSN) and **SIMMER** (coll with KIT and JAEA) during the pre-conceptual design phase
- to **SIMMER-SFR platform** during the conceptual design phase and the basic design phase. Discussions are in progress for a collaboration with Japan.

- The goal of the **SIMMER-SFR** platform is :

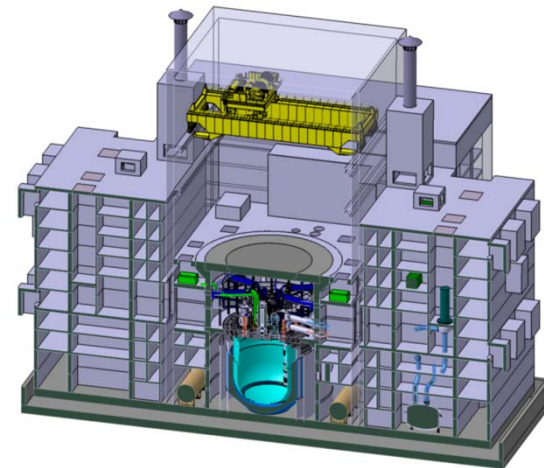
- to extend SIMMER capabilities in order to compute the initiating phase of severe accident and to make a smooth transition between the initiating phase to transition phase.
- to develop coupling and chaining systems (neutronics, fuel and thermal-hydraulics) to simulate the whole core degradation.



# Conclusions

- ❑ **ASTRID will be the prototype of a new generation of Sodium Fast Reactor, designed according to the best standards of safety and including innovations developed for safety improvements.**
- ❑ **The development program of new simulation tools is ambitious in order to meet the challenges to integrate innovative options to meet the objectives of the 4th generation reactors.**

**ASTRID reactor layout  
Nuclear Island**



# Thank you for your attention

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