New simulation tools to be developed for the ASTRID program

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A S T R I D

Advanced Sodium Technological Reactor for Industrial Demonstration

Astrid

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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Content

- ASTRID project
  - Objectives
  - Organization
  - Main features
  - Schedule
- Strategy for simulation
  - Objectives
  - The main steps
  - Approach description
- Examples of computation tools developements
  - Neutronics
  - Fuel behaviour
  - Core mechanics
  - Thermal-hydraulics
  - Coupling
  - Severe accidents
- Conclusions

The objectives

ASTRID : Advanced **S**odium **T**echnological **R**eactor for **I**ndustrial **D**emonstration

- **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,**

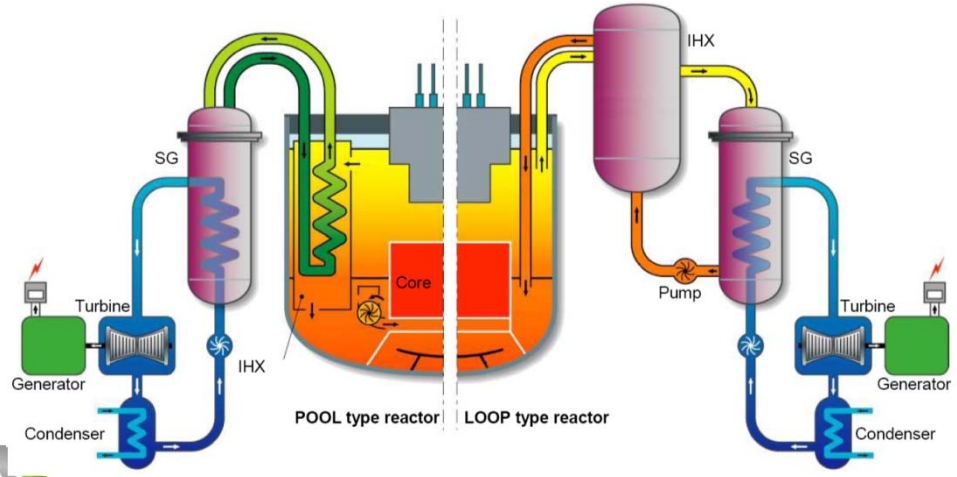
- **On the side of technical developments and experimental facilities, CEA is also willing to develop international partnerships.**

  Discussions for an agreement with Japan are in progress.

Preliminary design choices / open options

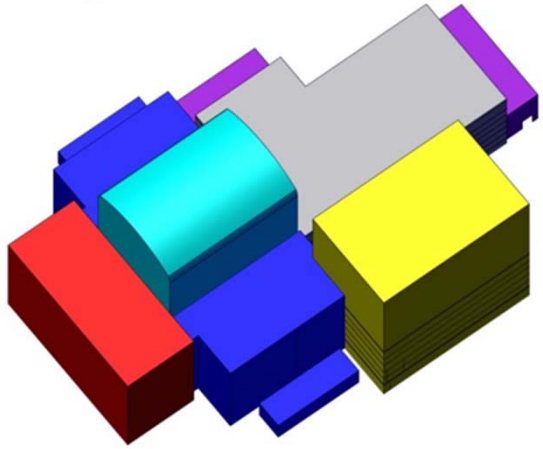
Main features

- 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 UO_2-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
- ….

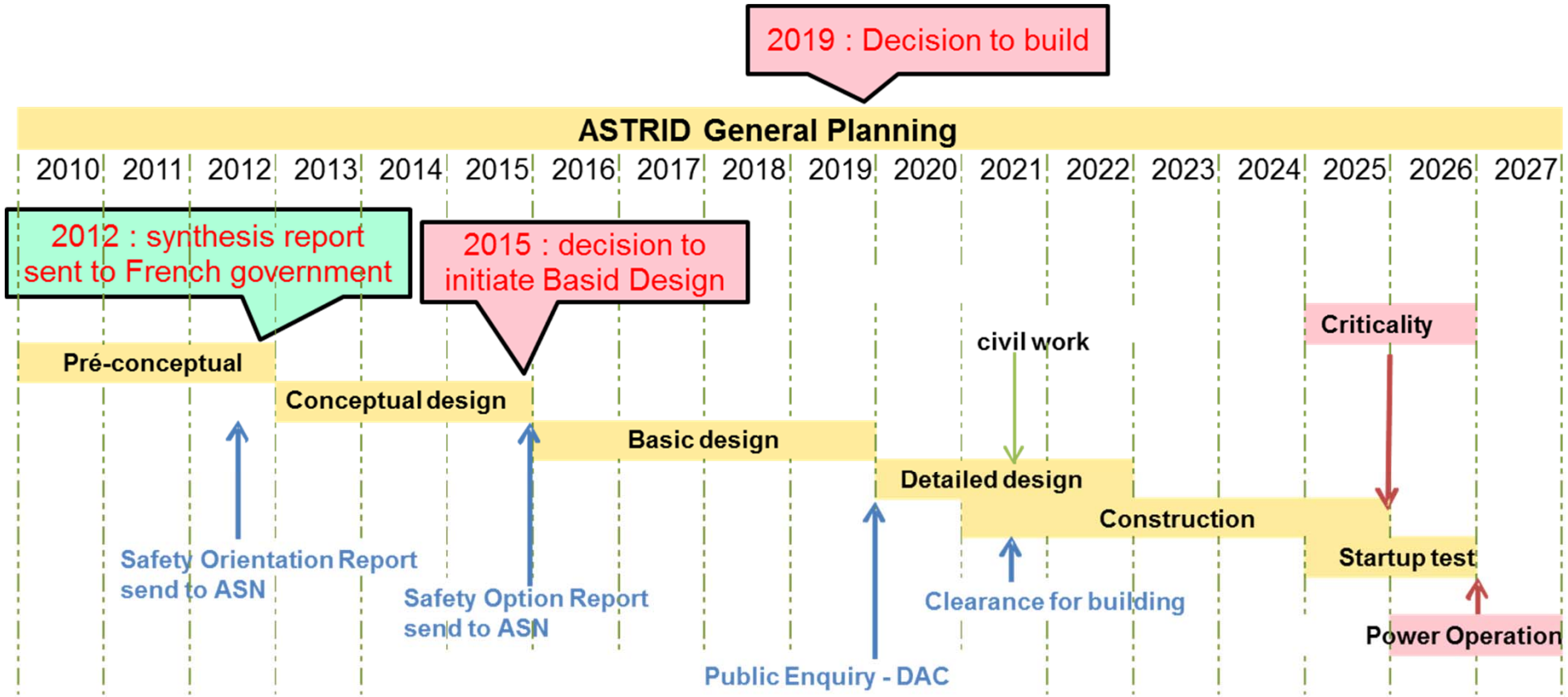


Open options

- 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



Strategy for simulation/objectives

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 begining 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

Neutronics

- **Goals : to design the core, to check the linear power criteria, the safety criteria, to determine the feedback coefficients …**

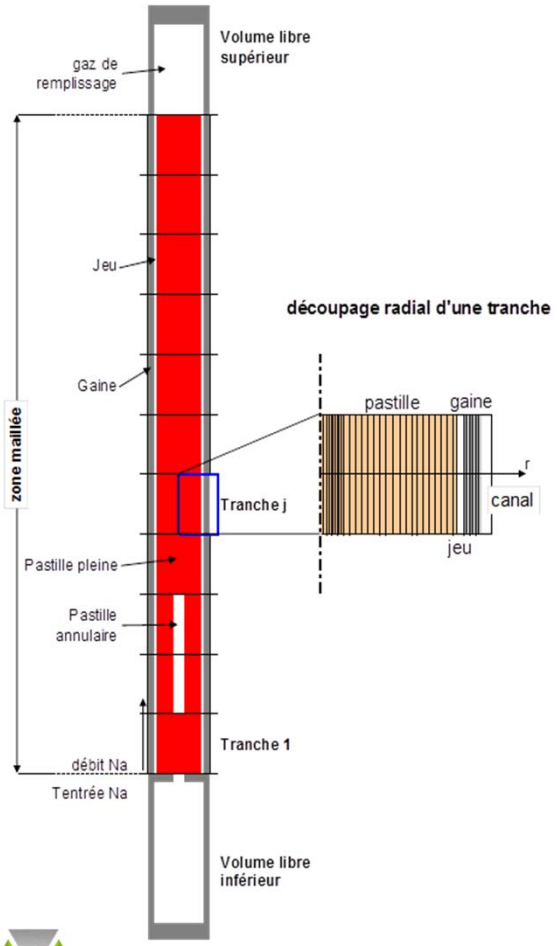
- **Development :**
  - **From PARIS-ERANOS during the conceptual design phase**
  - **To APOLLO-3 for the basic design phase**

- **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 …**

Fuel behaviour

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



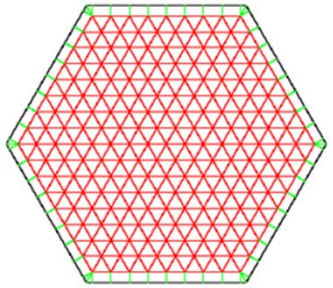
- **Development : GERMINAL is in continuous evolution**
  - **From GERMINAL V2.2 during the conceptual design phase**
  - **To GERMINAL V2.3 for the basic design phase**

- **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**

Core mechanics

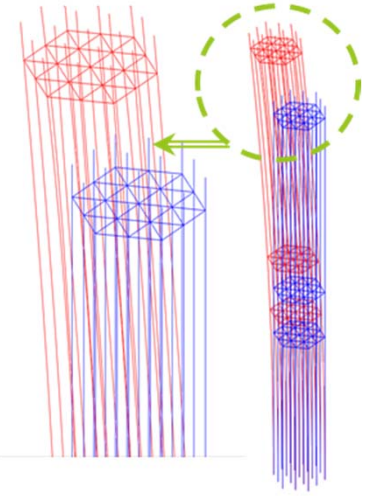
- **Goals: to design fuel sub-assemblies, to check the RAMSES criteria, to assess the core compactness …**

- **Development from DOMAJEUR 1 to DOMAJEUR 2 :**
  Purpose : 3D pin bundle thermal-mechanical behavior and its interaction with the wrapper tube



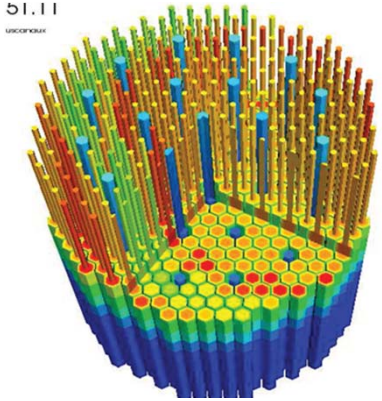
- **Development from HARMONIEV2 to HARMONIE2 V1/ and BASILIQ**
  Purpose : 3D core thermal-mechanical behavior and its interaction with the core restraint structures

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



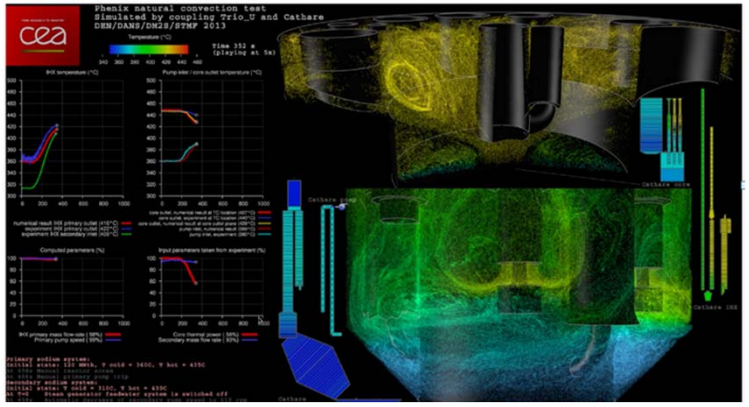
Thermal-hydraulics

- **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**

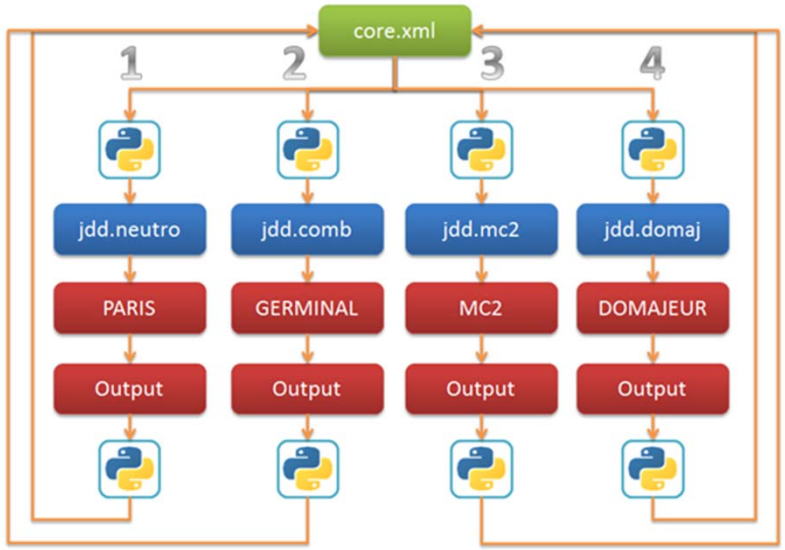


Coupling

- **Goals : to have unified data for all tools, to have an automatic coupling between several domains.**

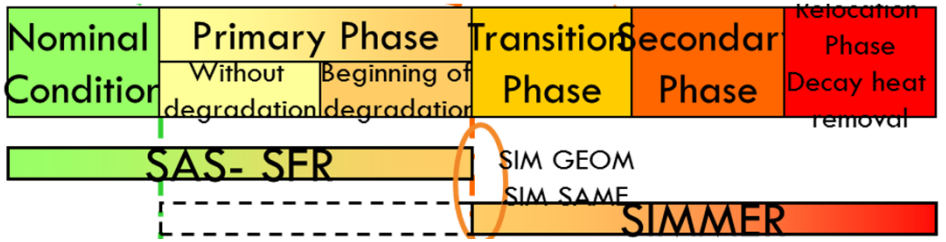
- **Development of PIC4SSO : Interdisciplinary platform of codes for the design and simulation of core.**
  PIC4SSO involves PARIS, GERMINAL , TRIOU-MC2 and DOMAJEUR.

- **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.**

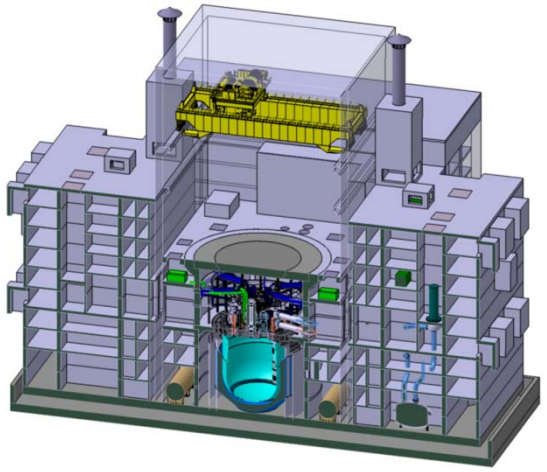
- **The goal of the SIMMER-SFR platform is :**
  - **to extend SIMMER capabilities in order to compute the initiating phase of severe accident and to make a smooth transition between the initating phase to transition phase.**
  - **to develop coupling and chaining systems (neutronics, fuel and thermal-hydraulics) 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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