

## Astrid Project, from Conceptual to Basic Design: Progress status

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### Abstract :

*Since the beginning of this year, after 6 years of conceptual design phase, the French 600 eMW ASTRID project has started a 4 years basic design phase. The ASTRID project is funded during basic design phase (2016-2019) through France Future Investments Program. All the Industrials partners involved in the project during the last phase have decided to pursue in the ASTRID project, and the strategic partnership with Japan is going to be reinforced. This very efficient industrial network with CEA as contracting authority is an original and effective project management. Very high level and up-to-date project management methods are performed, including technical control with engineering System tools and 3D mock-up consolidation.*

*On the technical point of view, the first ten months have been kept for a reopening options phase called P2C (Configuration Confirmation Phase) concluded by a configuration review in October. According to conclusions of conceptual design phases, several items had been checked and challenged through three main drivers: safety, cost killing and operability. Global consistency was also watched over.*

*It has been also decided for the next two years, to investigate and integrate Gas Power Conversion System in the basic design configuration. The objective for the ASTRID project is to raise Gas PCS integration studies at the same level that was achieved for Water/steam PCS at the end of 2015. A go-no go decision for Gas PCS integration will be organized at the end of 2017.*

*In the same time an ongoing effort started two years ago is underway to map all the qualification needs and define all joined processes consistent with safety regulator requirement. A more realistic planning has been prepared, adding a four years consolidation phase between basic design and detailed design, in order to increase the level of confidence and progress on the technology feasibility including experimental validations of the ASTRID's main innovative options.*

**Key Words:** ASTRID, Basic Design, GEN IV, SFR

### 1. Introduction

The Sodium-cooled Fast Reactor (SFR) is one of the Generation IV reactor concepts.

As GEN IV system, ASTRID (acronym for Advance Sodium Technological Reactor for Industrial Demonstration) must answer to main requirements and objectives devoted to these concepts with a mastered investment cost and non-proliferation warranty:

- Safety level is targeted according to GEN IV requirements and at least equivalent to GEN III concepts, taking into account Fukushima Daichi accident feedback with improvement against external hazards compared with previous

SFRs, including progresses on SFR specificities with a robustness of safety demonstration.

- Durability aspect in order to preserve natural resources using Pu multi-recycling from spent PWR MOX fuel [1] along with utilisation of natural depleted uranium which allow in France, producing electricity for few thousands of years.
- Operability demonstration with load factor of 80% or more after first “learning” years associated to significant progress concerning In Service Inspection & Repair (ISIR).
- Capabilities on minor actinides transmutation demonstrations.

As a prototype of SFR technology ASTRID has the main objective of demonstrating advances on an industrial scale by qualifying innovative options. ASTRID as a technological demonstration reactor (*a step before a First Of A Kind*), also must integrate French and international SFRs feedback. The Genesis of the ASTRID Project was done in the frame of the the French Act of 28 June 2006 on sustainable management of radioactive materials and wastes, French Government entrusted CEA (French Commission for Atomic Energy and Alternative Energy) to conduct design studies of ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) prototype. After a first period of studies and R&D jointly performed by the CEA, EDF and AREVA to investigate a range of innovative solutions, the project itself was launched in late 2009 and a project team was set up in the first half of 2010. Funding was granted through an agreement between the French Government and CEA within the scope of the “investments for the future” program published in the Official Journal on 11 September 2010 [2].

## 2. Schedule of Astrid Program until end of Basic Design

The pre-conceptual design phase – AVP1 conducted from mid-2010 to the end of 2012 – has been focusing on innovation and technological breakthroughs, while maintaining risk at an acceptable level. This phase was followed by the AVP2 conceptual design phase planned until the end of 2015 whose objectives were to focus on the design in order to finalize a coherent reactor outline (see figure 1).

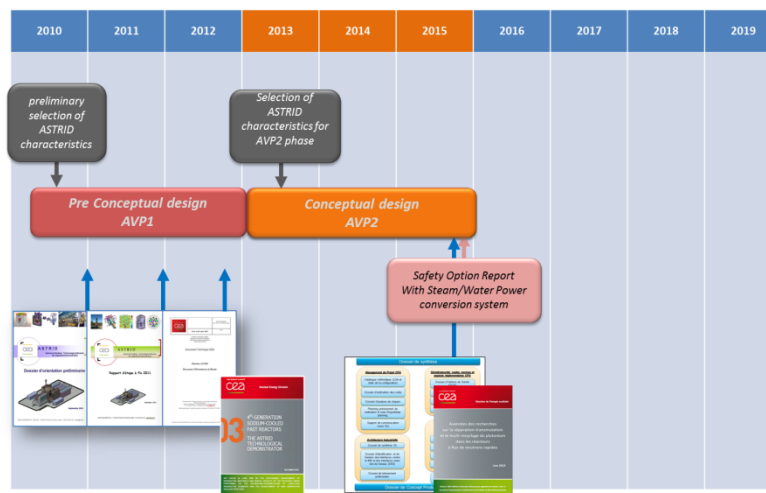


FIG. 1: ASTRID Conceptual design schedule

The Basic Design phase was launched on 1 January 2016. This decision was done a project monitoring committee after analysis of several documents mainly based on the conceptual design studies synthesis files, and associated safety options.

The end-of-Conceptual Design file [3] consists of a synthesis file as a snapshot of the reactor at the end of 2015 to decide on the entry into the next phase of the project. This dossier contains a series of documents carried by the ASTRID Project Unit:

- The safety option report for the water / steam power conversion cycle,
- The design choices justification,
- First systems and components technical specifications,
- The level of performance achieved in relation to requirements of functional specifications,
- ASTRID's preliminary qualification plans for critical components,
- Roadmap for the development of scientific computing tools,
- A preliminary ASTRID Cost estimation,
- Preliminary Planning for implementation.

It also includes many technical files issued by the engineering on systems or subsystems under their area of responsibility, the whole constituting the Product Design File. In addition to the conceptual design file, a specific report on the gas power conversion system was set up.

A project review on ASTRID's power conversion system was held on December 3, 2015, chaired by the Director of Nuclear Energy on the basis of:

- Reviews of a Scientific Council, which evaluated the work of the CEA,
- Taking into account the opinion of EDF and AREVA on the gas PCS,
- Independent expertise (CEA, AREVA, EDF, ALSTOM).

It was decided to extend studies on the gas PCS to bring them to the end of 2017 at the same level as those reached on the water-steam version at the end of 2015.

A specific review will be organized at the end of 2017 to decide whether or not to pursue further development.

The Basic Design phase, which will run until 2019, aims to:

- To carry out a preliminary definition of all Astrid systems and components. The level of maturity of the most innovative components will be monitored and the maturity level will be increased as possible.
- To provide a detailed and optimized design of the reactor,
- To prepare all the files required for the next step of the project.

Basic design phase is split of 3 sub-phases which apply to all industrial partners in charge of the various components of ASTRID as shown in figure 2.

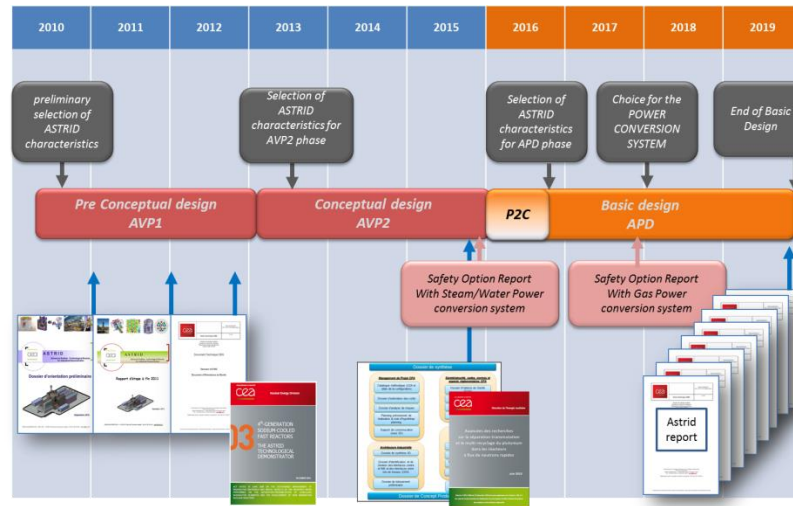


FIG. 2: ASTRID schedule until end of Basic Design

### 3. The Confirmation of Configuration Phase (P2C)

From January 2016 to October 2016, the Confirmation of Configuration Phase (P2C) for Basic Design took place. During this period, it was necessary to integrate in the design studies the gas PCS and, in particular, the opportunities for techno-economic optimizations which can result from this integration. On the other hand, optimization and targeted risk reduction on some end-of-APS design options was reached. Around fifteen thematic working groups have been set up to deal with these issues in order to converge towards stabilized choices that were approved during a design review in October 2016.

The entire configuration of ASTRID has been re-analyzed with the following objectives:

- To take into account Conceptual Design phase feedback to reduce costs or simplify systems.
- On several technical points: to reopen the possibility of other technical choices.
- To manage risks and costs.
- To make sure of the overall coherence.
- The components or systems and the themes analyzed during this phase are the following:
  - Integration and opportunities related to Gas PCS,
  - Fuel handling,
  - Integration and optimization of the nuclear island architecture,
  - Reactor Pit Arrangement,
  - Corium core-catcher,
  - Hot cell,
  - I&C and electrical plant estimate,

- Lifetime of components,
- Strategy for the classification of components in relation to the ESPN decree,
- Front and back end,
- Inspection in Service and Repair (ISI&R),
- Safety strategy and design associated to Decay Heat removal System (DHRS),
- Natural convection behavior in primary vessel.

Around 100 technical meetings were held by all the working groups and more than 300 technical points were analyzed. Finally, an expert group carried out an evaluation to ensure that the objectives of this P2C phase were reached, in particular in regards with cost-mastering, operability, safety and extrapolability to a commercial power reactor.

#### 4. The New Configuration of ASTRID for Basic Design

The new configuration was endorsed by the "4th Generation" program during the configuration confirmation review held in Cadarache on 18 and 19 October 2016. This new configuration changed a lot compared to the previous one, integrating:

- The Gas PCS in its completeness: Integration and industrialization of compact sodium-gas heat exchangers (power unit ~190 thMW) integrating innovative exchange modules. Eight exchangers are required, two per secondary loop. Two machine rooms, each with a gas turbine with three compression stages, are located on each side of the exchanger buildings, so as to minimize the pipes length. Under these turbine halls are placed the storage tanks of the necessary nitrogen inventory (~ 130 t) [4].

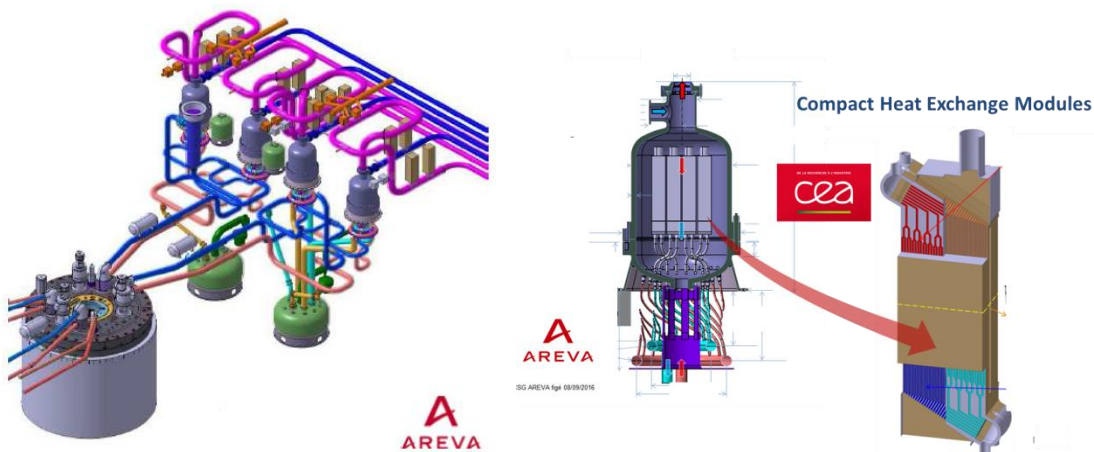


FIG 3: 3D View of secondary loops and detail of Compact Na-Gas Heat Exchanger  
*ASTRID Project Business Confidential Information, CEA and AREVA property designs*

- A fuel handling route:

- With an external Buffer Storage in sodium to uncouple the handling phases for fuel loading/unloading from those of washing and storage. This choice makes it possible to reduce the handling time around 9 days whereas it was previously 20 days [5].
- The choice has been made to limit, for cost reasons, both the storage capacity around 100 subassemblies and to limit the residual power of each assembly by only discharging it, after a phase of decay of one cycle in a limited internal storage in the primary vessel.
- Mutualized storage for fresh and spent fuel subassemblies in the same pool, the fresh subassemblies being stored in gas cask themselves placed in the pool. This solution limits the footprint of the storage areas and makes it possible to share some common resources. It allows storage allocation to be adapted to the needs of the plant. The nominal capacity is set at 300 fresh subassemblies (~ 1 core) and 900 spent subassemblies (~ 3 cores).
- Reduction of the size of the hot cell through optimization and by deporting some functionality to the external buffer zone [6].
- Mutualized the truck hall, now shared by the hot cell and the storage pool.
- A decreasing of in vessel Decay Heat Removal System by reducing from 5 to 4 trains.

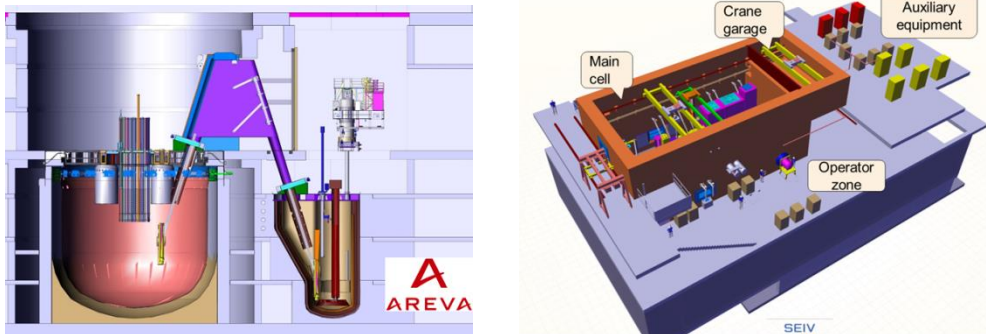


FIG 4: Fuel handling and hot cell layout

*ASTRID Project Business Confidential Information, CEA and AREVA property designs*

Other points need to be reinforced or clarified in the coming months during the consolidation phase of the reassembly (PCR) and relate mainly to:

- Simplification of the corium core catcher,
- Reactor pit lay-out including ex-vessel Decay Heat Removal system,
- Creep-fatigue Life duration of Astrid components.

## 5. The consolidation phase and beyond

From November 2016 until the end of December 2017, the consolidation phase of the Basic Design will take place. During this period, studies with industrial partners should lead to an ASTRID design file with the gas PCS comparable to that produced at the end of 2015 for the water/steam PCS. In particular, the technical file at the end of 2017 will summarize the achievements and points remaining open, the justification of the design choices related to the integration of the gas PCS, the traceability of the requirements and performances and the justification of the capability of the gas PCS at different operating regimes of the reactor, in particular with regard to the targeted safety objectives. It will integrate also, the Preliminary Technical Requirement Specifications for the main systems and components of the nuclear island. It will be complemented by an update of the costs evaluation and investment, the preliminary schedule with identification of the major risks, the updating of performances and the portfolio of risks and associated action plans. This end of phase will be marked by a choice of option for the PCS as an intermediate milestone.

From January 2018 to December 2019, studies will continue to support the completion of the definition file, which will make it possible to pursue the increase in the overall maturity level of ASTRID and by emphasizing firstly that of the components considered as critical. An update of all files produced at the end of the previous phase will also be carried out. All these works and studies will allow constituting the file at the end of the design phase in support of the project review, which will decide on the transition to the next phase of the project. Following the configuration review of October 2016, it was decided to propose a Design To Cost approach around ASTRID which will have to be implemented in the course of 2017 and will aim to be fully operational in 2018.

The main milestones expected for 2017 are:

- Production of complete Safety option report of ASTRID in its basic design configuration (with gas PCS).
- Update of the cost estimation.
- ASTRID PCS Selection Review (Gas vs Steam/Water).
- Implementation of the Design to Cost approach.
- Updated the qualification program with the objective of increasing of the critical components maturity level.

## 6. Partnership

All of the partnerships around ASTRID, established during the Conceptual Design phase, were renewed (except for the one with Rolls Royce, which was still under discussion), with some changes or modification of the scope.

### a. Industrial Partnership

The main scopes for the Basic Design are recalled below for each industrial partner (see Fig. 5):

- AREVA: Engineering of the nuclear island, I&C, industrialization of the sodium-gas compact exchanger.

- EDF: Operation and project management drawback.
- SEIV: Hot cell design.
- CNIM: Industrialization and fabricability of large components, gas cycle heat exchangers, seismic pads.
- BOUYGUES: Civil engineering, seismic pads.
- NOX (ex JACOBS France): General lay-out and site infrastructure.
- GENERAL ELECTRIC (ex-ALSTOM): Tertiary energy conversion system.
- VELAN: Sodium isolation valve for secondary circuits.
- TOSHIBA: Secondary circuit electromagnetic pump.
- AIRBUS SAFRAN LAUNCHERS: Operability, waste management.
- JAEA/MHI/MFBR: see the Japan Partnership sub-chapter.
- ONET TECHNOLOGIES: Inspection carrier system, concept of innovative control rod mechanism.
- TECHNETICS: Insulation seals for several reactor areas and in particular for the rotating plugs.

It should be noted that the responsibility for the engineering of the core and associated subassemblies is carried over to the CEA through the core design engineering and is not formalized through a specific endorsement.

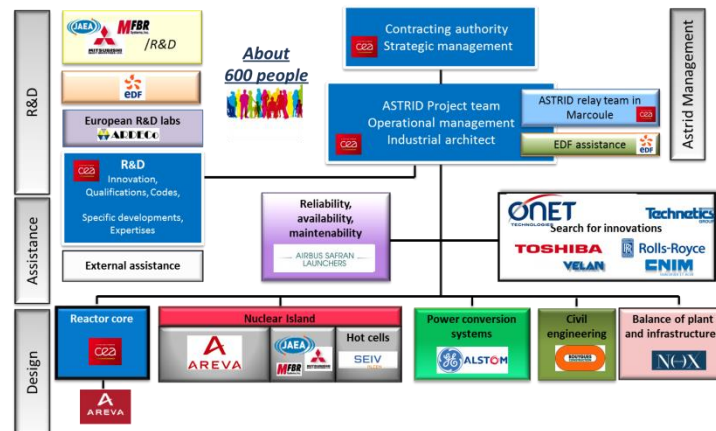


FIG 5: The ASTRID Project engineering and partnership organization

### b. Japan Partnership

In the framework of the Implementing Arrangement of August 7th, 2014 signed between Japan Atomic Energy Agency (JAEA), Mitsubishi Heavy Industry (MHI) Mitsubishi Fast Breeder Reactor System (MFBR), AREVA and CEA, contribution, of ASTRID Design activities increased significantly during the year 2016 from three Task Sheets to nine. In particular, through evaluation activities by the Japanese



part of the technological solutions selected by the project which could lead, in a second time to proposals for improvement. [7].

The current list is as follows:

- Task Sheet D1: Active Decay Heat Removal System (DHRS),
- Task sheet D2: Curie Point Electro Magnet (CPEM) for diversified control rods,
- Task Sheet D3: Seismic Isolation System (SIS),
- Task Sheet D4: Fabricability and thermo-mechanical calculations of the Above Core Structure (ACS),
- Task sheet D5: Fabricability of the Polar Table,
- Task Sheet D6: Contribution to design the Core Catcher,
- Task Sheet D7: Transient evaluation of ASTRID plant,
- Task sheet D8: Thermomechanical analyses of main and inner vessel,
- Task Sheet D12: General discussions on the ASTRID reactor system.

## **7. Management and project life**

The organization of the ASTRID project in charge of project management and global consistency has been adjusted in accordance with the requirements of the basic design phase:

- Significant consolidation was achieved in the transverse safety segment,
- Implementation of a process and associated transverse segment common to scientific computational tools and the technological qualification,
- Implementation of a new transverse environment and waste work package,
- Removal of the transverse ISI&R work package, the function being now attached to the components,
- Strengthened project management and global consolidation

At least, the project was distinguished in 2016 by the SFEN (Société Française de l’Energie Nucléaire – The French Nuclear Society) for the high quality of the work carried out during the conceptual design phase through the "SFEN 2016 Grand Prix.

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