Status of the astrid sodium fast reactor project from conceptual design to basic design phase


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Abstract - The ASTRID project is pursuing its progress and has reached at the end of 2015 the Conceptual Design phase followed by the starting of the Basic Design phase from 2016 to 2019.

The transition from the Conceptual Design phase (2010-2015) to the Basic Design phase (2016-2019) was validated by the production of the Conceptual Design files. According to the production of this report, at the end of the Conceptual Design phase (December 2015), the French ministries representatives agreed to launch the Basic Design Phase due to the good progression of the program: all the milestones have been met during the Conceptual Design phase, and relevant innovations have been proposed in order to propose a technological demonstration reactor that could fulfilled Generation IV objectives.

For the Basic Design phase, the ASTRID project has consolidated its industrial partnership with fourteen industrial partners especially strengthened with JAEA / MHI – MFBR.

The Basic Design phase started with a particular step named Confirmation Configuration Phase (P2C) where during the first nine months of the 2016 year, the project - with all partners – has:

- re-analyzed several structural options regarding three main drivers: safety, operability and cost killing,
- implemented the Gas (Nitrogen) Energy Conversion system within the plant design,
- and built a coherent reactor layout shared by all partners as a starting point of a new ASTRID configuration for the Basic Design phase.

Therefore, this paper aims at presenting the recent progress of the ASTRID project either in terms of project management and organization, than in terms of technological progress in reactor design and support studies.

I. INTRODUCTION

After 6 years of Conceptual Design phase (AVP), the Project is involved since January 2016 in Basic Design phase. It is a four years duration phase with different milestones at the project level and also reporting with the relevant state organization.

Therefore, this papers aims at presenting the recent progress of the ASTRID project either in terms of project management and organization, than in terms of technological progress in reactor design and support studies.

II. STATUS OF THE ASTRID SODIUM FAST REACTOR PROJECT: FROM CONCEPTUAL DESIGN TO BASIC DESIGN PHASE

This paper that can be considered as an annual progress report of the ASTRID project allows synthesizing the past year by giving a synthetic and global vision of the salient advances of the project and its organization. The year 2016 was an important one for the project on several points:

- Change of the project phase, with the start of Basic Design Phase.
- Major modification of the Power Conversion System (PCS), with the decision to integrate a gas (nitrogen) circuit instead of a conventional water-steam system.
- Renewal of industrial partnerships.
- Increase of Japanese activities under the implementing arrangement signed in 2014.
- Adjustment of the project organization.

The Basic Design phase was launched on January 2016, 1st. This decision was accepted by 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 consists in 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 out 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 3rd, 2015, chaired by the Director of Nuclear Energy on the basis of:

- Reviews of a Scientific Council, which evaluated the CEA work,
- 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 an equivalent level than 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 prepare all the files required for the next step of the project.

Basic design phase is split in 3 sub-phases which apply to all the industrial partners in charge of the different ASTRID components (see Fig. 1).

![Fig. 1: ASTRID Project driver schedule](image)

**The P2C Phase:**

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 drawbacks 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,
• Core catcher,
• Hot cell,
• I&C and electrical plant cost estimate,
• Components lifetime,
• Strategy for the classification of components in relation to the ESPN decree (French regulation),
• Front and back end of the fuel cycle,
• In-Service Inspection 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.

• The new configuration was endorsed by the “4th Generation program” during the configuration confirmation review held in Cadarache on 18th and 19th October 2016. This new configuration changes 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 MWth) integrating innovative exchange modules. Eight exchangers are required, two per secondary loop. Two machine halls, 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 required nitrogen inventory.
  • A fuel handling route:
    o With an External Buffer Storage in sodium to decouple the handling phases for fuel loading / unloading from those of subassembly cleaning and water storage (see Fig. 2). This choice makes it possible to reduce the handling time around 9 days whereas it was previously 20 days.
    o The choice has been made to limit, for cost reasons, both the Na storage capacity around 100 subassemblies and to limit the residual power of each assembly by only discharging it, after a phase of decay heat of one cycle in a limited internal storage in the primary vessel.
    o Mutualized storage for fresh and spent fuel subassemblies in the same water pool, the fresh subassemblies being stored in gas cask themselves placed inside the water 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.
  • Mutualized truck hall, now shared by the hot cell and the water storage pool.
  • A decreasing of in vessel Decay Heat Removal System by reducing from five to four trains (two active and two passive).
Other points need to be reinforced or clarified in the coming months during the consolidation phase of the reassembly (PCR) and they relate mainly to:

- Simplification of the core catcher (in case of severe accident scenario and corium release),
- Reactor pit lay-out including ex-vessel Decay Heat Removal system,
- Creep-fatigue regarding life duration of ASTRID large components.

Finally, other developments have to be noted that do not come directly from the P2C phase but are linked either to the regular progress of the project, or in unexpected performances modifications or to the consideration of external constraints:

- At the core level:
  - Taking into account plutonium quality from used PWR MOX fuel.
  - Modification of the fuel cladding material performance.
- At the civil engineering level [3]:
  - Addition of a building on a raft incorporating a DHRS system.
  - Choice of the seismic pad insulation design, jointly proposed by Bouygues and CNIM as a reference.

**The consolidation phase and beyond:**

From November 2016 until 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 remained opened, 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 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 important 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 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. In addition, 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 cost estimation.
- ASTRID PCS Selection Review (Gas vs Steam / Water).
- Implementation of a Design To Cost approach.
- Update of the qualification program with the objective of increasing the level of maturity of the critical components.

**Partnerships:**

All of the partnerships around ASTRID, established during the APS phase, were renewed (except for the one with Rolls Royce, which was still under discussion at end 2016), with some changes or modification of the scope (Fig. 4).

**Concerning industrial partnerships:**

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

• 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.

Concerning the partnership with Japan:
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.

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, in the scope of the Joint Team, to have discussions for preparation of future Design Task Sheet or Joint Evaluation.

This subject is largely presented in the dedicated paper, see ref [2].

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 (see Fig. 6):
• 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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NOMENCLATURE

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>APS</td>
<td>Avant Projet Sommaire (Preliminary Design)</td>
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<tr>
<td>ASTRID</td>
<td>Advanced Sodium Technological Reactor for Industrial Demonstration</td>
</tr>
<tr>
<td>AVP 1/2</td>
<td>Conceptual design studies, phase 1 and 2 of ASTRID project</td>
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<tr>
<td>BD</td>
<td>Basic Design</td>
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<td>CEA</td>
<td>French Atomic Energy Commission</td>
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<td>DHR</td>
<td>Decay Heat Removal</td>
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<td>DHRS</td>
<td>Decay Heat Removal System</td>
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<tr>
<td>EBZ</td>
<td>External Buffer Zone</td>
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</table>
ESPN: Equipement Sous Pression Nucléaire
(French Nuclear Rule)
FBR: Fast Breeder Reactor
GEN IV: Fourth Generation Reactor
I&C: Instrumentation & Control
ISI&R: In-Service Inspection & Repair
JAEA: Japan Atomic Energy Agency
MHI: MITSUBISHI Heavy Industry
MFBR: Mitsubishi FBR Systems
PCS: Power Conversion System
P2C: Confirmation Configuration Phase
R&D: Research and Development
SFEN: Société Française de l’Energie Nucléaire
(French Nuclear Society)
SFR: Sodium Fast Reactor
3D: Three-Dimensional

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