ASTRID PROJECT, GENERAL OVERVIEW AND STATUS PROGRESS

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Abstract

After 6 years of conceptual design phase, the French ASTRID project has started at the beginning of 2016, a 4 years basic design phase. The objective of this paper is to show and underline ASTRID progress and status and to give information of what we have intended for the next 2 years. The ASTRID project is based on a very efficient partnership, allowing versatility and manageability. Very high level and up-to-date project management methods are performed, including technical control with engineering System tools and 3D mock-up consolidation.

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.

ASTRID design has also evolved, taking into account new progresses on design to reach better consistency according to high level of reliability and safety, consistent with Generation IV objectives. A cost killing methodology is provided and feedbacks will be expected during 2018 and 2019 years. In the same time, an ongoing effort started two years ago is underway to map all the qualification needs and define all associated processes consistent with safety regulator requirement.

I. INTRODUCTION

As a prototype of SFR technology ASTRID has the main objective of demonstrating advances on an industrial scale by qualifying innovative options. ASTRID must integrate in its own design French and also international SFRs feedback.

As GEN IV system, ASTRID 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 demonstrations.
- Durability aspects 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 (ISI&R).
- Capabilities on minor actinides transmutation demonstrations.

The Genesis of the ASTRID Project was done in the frame of 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 FRAMATOME to investigate a range of innovative solutions, the project itself so-called ASTRID 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 11th September 2010 [2].

Since 2010, when the first studies were launched to define the ASTRID project, over 3000 technical documents were produced to design the ASTRID reactor.

After 6 years of conceptual design phase, the French 600eMW ASTRID reactor has started at the beginning of 2016, a 4 years Basic Design phase (BD). The project is now at mid-term of this phase and significant milestones were achieved.

This four-year BD phase has for objective at the end of 2019:

- To achieve a consistent definition of all ASTRID systems and components.
- To provide an optimized reactor design.
- To provide all the documents required for the continuation of the project, aiming to increase, as priority, the level of maturity of the most innovative components.

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 (nitrogen) 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 preliminary 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.

All the working groups carried out around a hundred technical meetings in total 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.

II. ASTRID CONFIGURATION FOR BASIC DESIGN

The new configuration was endorsed by the CEA "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 [3], [4].

II.A. Gas PCS

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 (see Figure 1), 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 for the nitrogen inventory (~ 130 tons) [5].

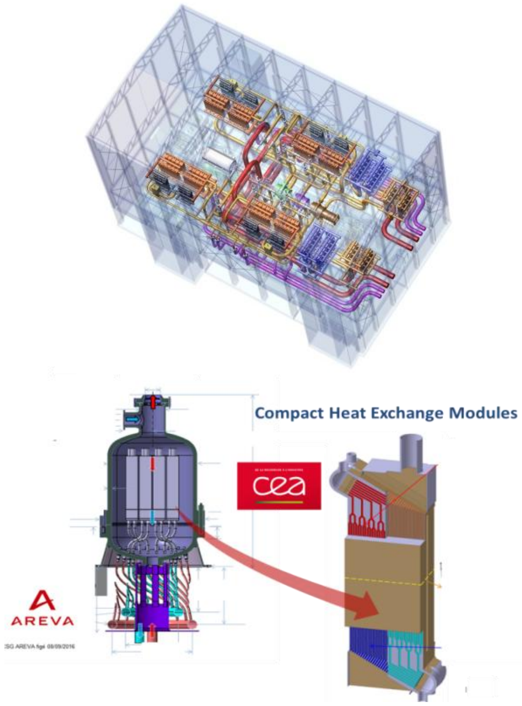

Figure 1: 3D View of Machine Hall and detail of Compact Na-Gas Heat Exchanger (© CEA-FRAMATOME-GE)

II.B. Fuel Handling and storage

It was decided to add an external Buffer Storage Vessel in sodium to decouple the handling phases for fuel loading/unloading from those of fuel cleaning and storage. This choice makes it possible to reduce the handling time around 9 days whereas it was previously 20 days [6].

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 heat of one cycle in a limited internal storage in the primary vessel.

Mutualized storage for fresh and spent fuel subassemblies in the same pool was designed. The fresh subassemblies being stored in gas cask themselves are placed in the pool. This solution limits the footprint of the storage areas and makes it possible to share some common resources (see Figure 2). It allows storage allocation to be adapted to the needs of the plant. The nominal capacity is set to 300 fresh subassemblies (~ 1 core) and 900 spent subassemblies (~ 3 cores).

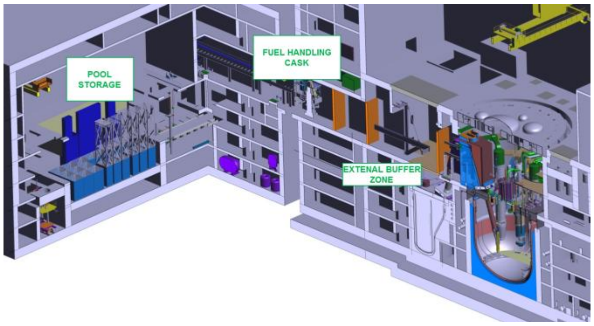

Figure 2: View of primary and secondary fuel handling and mutualized pool storage (© CEA-FRAMATOME)

II.C. Main Vessel and components

ASTRID reactor is a pool type reactor with a conical inner vessel with an internal core catcher (see Figure 3).

The main core catcher function is to collect and manage the corium (melted fuel and metallic structure) coming from the 21 corium guides after a hypothetical Core Disruptive Accident scenario.

Three primary pumps are devoted to the circulation of the sodium from the cold plenum to the diagrid to ensure sodium supply of the core. Four Intermediate Heat eXchangers (IHX) are used to transfer heat resulting from nuclear reactions from the primary sodium to the secondary sodium and they are linked to four secondary circuits.

Concerning the Decay Heat Removal System dedicated to evacuate the power in case of normal supplies loss (IHX and secondary loop), four diversified in-vessel decay heat removal circuits (two passives and two actives) and one circuit in the reactor pit were designed.

Figure 3: View of reactor vessel (© CEA-FRAMATOME)

II.D. Secondary Loops

The secondary loops transfer the thermal power from the primary circuit to the Power Conversion System (PCS) (see Figure 4). They ensure a forced circulation of the secondary sodium from the IHX to the sodium-gas heat exchanger according to the Brayton gas. Secondary loops must be designed to ensure natural convection onset in the primary circuit in case of loss of supply station power.

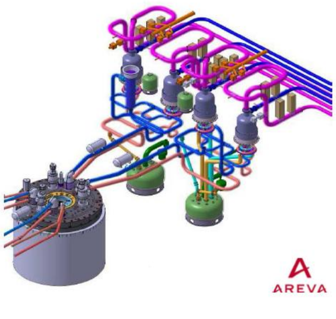

Figure 4. 3D View of secondary loops (© CEA-FRAMATOME)

II.D. Core

The reactor configuration at the end of 2017 includes a CFV core (low void sodium worth) (see Fig. 5) referenced ‘CFV BD 16-10’ (Ref. 5). In CFV core, low sodium void effect is achieved by an heterogeneous fissile zone with sodium plenum in the upper part of the assemblies, Upper Neutron Shielding in boron carbide and an axial fertile plate in the internal core.

Complementary safety devices for prevention (DCS-P) and for severe accidents mitigation (DCS-M) have been implemented in the core:

- three hydraulic absorber rods which fall if the core sodium flow decreases under a given threshold (DCS-P-H)
- Curie point electromagnet will release Diversified control rods by loss of bearing capacity if the core temperature increases too much.
- 21 crossing tubes (DCS-M-TT) to discharge the corium towards the core catcher in case of a hypothetical core disruptive accident scenario.

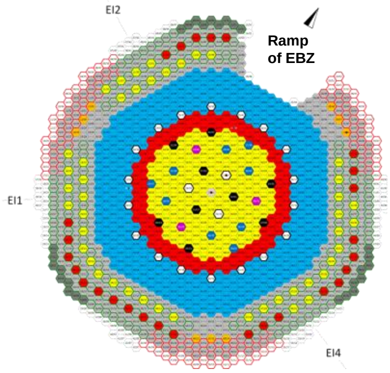

Figure 5. CFV BD 16-10 (© CEA-FRAMATOME)

II.E. ACS and polar table

Upper closures complete the envelope of the primary circuit at the top of the main vessel and participate in the confinement of the cover gas.

The Above Core Structure (ACS) (see Figure 6) supports the twenty-one control rod drive mechanisms, all the core instrumentation and the Direct Lift Charge Machine. Instrumentation supported by the ACS includes 351 temperature and flowrate measuring poles, high temperature fission chambers to detect local reactivity effect, tubes for sodium sampling over each fuel subassembly to localize fuel cladding failure and high Temperature Ultra-Sonic Transducers (active and passive detection).

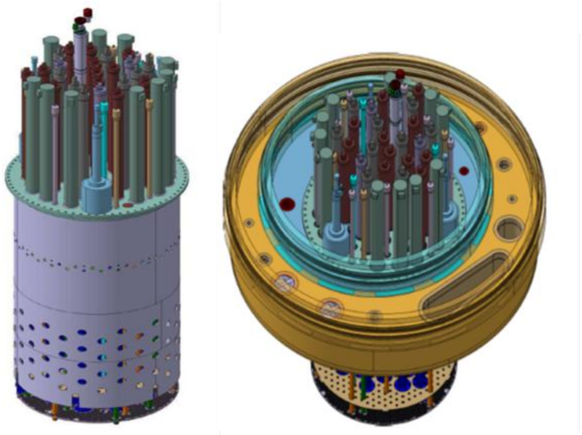

Figure 6. 3D view of the ASTRID ACS (© CEA-FRAMATOME)

The general arrangement of ASTRID reactor building has determined a closed space between the ASTRID upper closure and the reactor building: it is called the above roof area. This area (see Figure 7) is delimited on its lower part by the upper reactor closure (also called the reactor roof) and on its upper part by the Polar table. This polar table is conceived to limit the pressure loading in the reactor building in case of sodium fire in the above roof area. In addition, it prevents from the risk of heavy charge fall on the reactor roof.

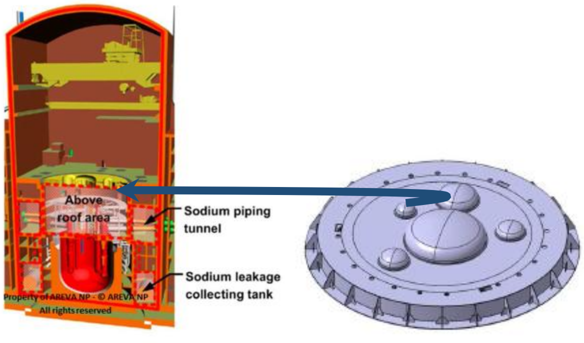

Figure 7. Reactor Building and Polar Table (© CEA-FRAMATOME)

II.F. Reactor Pit

The concrete reactor pit withstands the dead weight of the reactor vessel and the primary circuit (Figure 8). Its design is governed by the severe accident load case scenario, applying a huge upward tensile force.

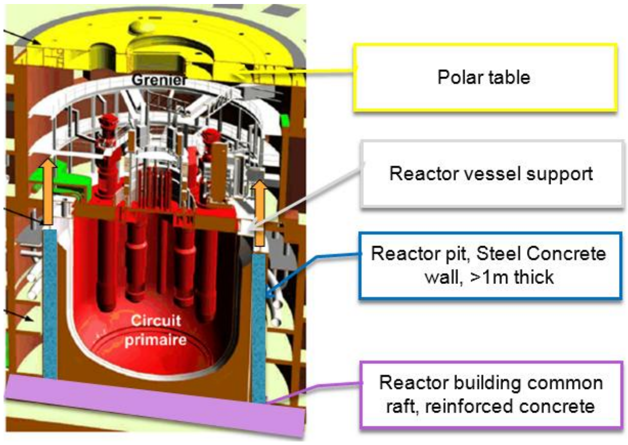

Figure 8. Steel Concrete Reactor pit (in blue) in the reactor vessel environnment (© CEA-FRAMATOME-BOUYGUES)

II.G. Seismic insulation

For ASTRID, preliminary studies concluded to isolate directly all the buildings of the nuclear island on a para-seismic raft equipped with para-seismic pads (see Figure 9). The goal on ASTRID project is to decrease the horizontal building accelerations from 5 to 10 times.

Based on European standards, based on previous solutions used elastomeric rubber with metallic parts pads. ASTRID Project and its partners (BOUYGUES and CNIM) have chosen to improve the material, using polyurethane material instead of natural rubber. Several advantages are expected [7].

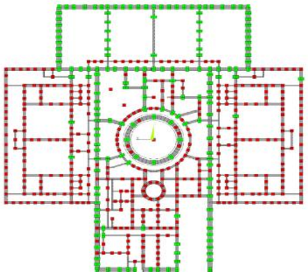

Figure 9. Plan view of the location of the seismic pads (© CEA-FRAMATOME-BOUYGUES)

II.H. Balance Of Plant and General Layout

To implement studies in real conditions, a reference site was selected as a possible one. That makes it possible to apprehend the whole of the site interfaces with the installation design. A project management process ensures impacts follow-up on the reference site (geology, seismic conditions, climatology, external aggression, plugin to networks and so on) in order to manage and quantify them during studies. This approach allows to identify clearly all the design options linked to the reference site and to compare several sites between them.

The present reference site is located at Marcoule CEA Center. [8], and a global layout is presented in the Figure 10.

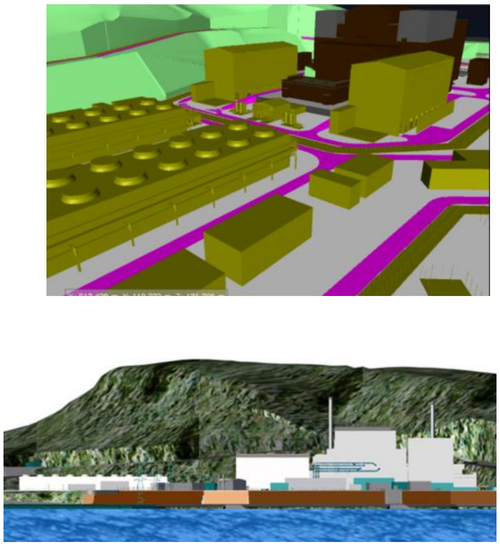

Figure 10. Global layout of ASTRID environnment and East/West cutting view of the nuclear island (© CEA-NOX)

III. PARTNERSHIP

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

III.A. Industrial Partnership

The main scopes for the Basic Design are recalled below for each industrial partner (see Figure 11):

- FRAMATOME: Engineering of the nuclear island, I&C, industrialization of the sodium-gas compact exchanger.
- EDF: Operation and project management feedback from Phenix and SUPERPHENIX operation.
- SEIV: Hot cell design.
- CNIM: Industrialization and fabricability of large components, gas cycle heat exchangers, seismic pads.
- BOUYGUES: Civil engineering, seismic pads.
- NOX: General layout and site infrastructure.
- GENERAL ELECTRIC: Tertiary energy conversion system.
- VELAN: Sodium isolation valve for secondary circuits.
- TOSHIBA: Secondary circuit electro-magnetic pump.
- ARIANE GROUP: Operability, waste management.
- JAEA/MHI/MFBR: see 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 mist 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.

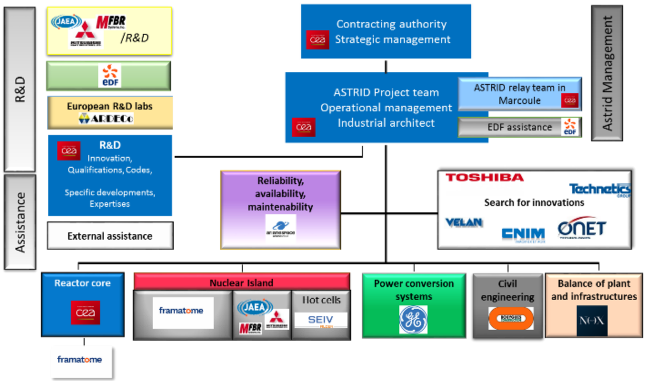

Figure 11. The ASTRID Project engineering and partnership organization

III.B. Japanese 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), FRAMATOME and CEA, contribution, of ASTRID Design activities increased significantly during the year 2016 from three Task Sheets to nine, then ten in 2018. [9] [10]. Subjects treated in Design Task sheets are:

- Task Sheet D1: Astrid Active Decay Heat Removal System (DHRS),
- Task sheet D2: Curie Point Electro Magnet (CPEM) for diversified Astrid control rods,
- Task Sheet D3: Seismic Isolation System of Astrid reactor (SIS),
- Task Sheet D4: Fabricability and thermo-mechanical calculations of the Astrid Above Core Structure (ACS),
- Task sheet D5: Fabricability of the Astrid Polar Table,
- Task Sheet D6: Contribution to propose technical solutions of the design of the Astrid Core Catcher,
- Task Sheet D7: Transient evaluation of Astrid plant,
- Task sheet D8: Thermomechanical analyses of Astrid main and inner vessel,
- Task sheet D11: Evaluation of Astrid Core characteristics and core shielding,
- Task Sheet D12: General discussions on the Astrid reactor system.

In addition, a Declaration of Intent between France and Japan including the proposal to strengthen future ASTRID collaboration was signed in March 2017. Thus, in addition to working groups, a special effort was made at the end of 2017 to share and converge on the requirements of possible common specifications.

IV. CONCLUSIONS

After 6 years of conceptual design phase, the French 600 eMW ASTRID project has started at the beginning of 2016, a 4 years basic design phase. The project is now at mid-term of this phase, The ASTRID project is based on a very efficient partnership, allowing versatility and manageability. Very high level and up-to-date project management methods are performed. 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.

ASTRID design had also evolved, taking into account new advanced on design to reach better consistency according to high level of reliability and safety, consistent with Generation IV objectives.

For 2018, the project will launch a phase of design to cost to allow cost decreasing and preparation of the future. In the same time an ongoing effort started two years ago is underway to map all the qualification needs and define associated 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.

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NOMENCLATURE

ACS:	Above Core Structure
ASTRID:	Advanced Sodium Technological Reactor for Industrial Demonstration
BD:	Basic Design
CEA:	French Atomic Energy Commission
CFV:	Low Void sodium worth Core
CPEM:	Curie Point Electro-Magnetic system
DCS-M:	Complementary Safety Device for Mitigation
DCS-M-TT:	Complementary Safety Device for Mitigation – Transfer Tube
DCS-P:	Complementary Safety Device for Prevention
DHRS:	Decay Heat Removal System
FBR:	Fast Breeder Reactor
GEN IV:	Fourth Generation Reactor
IHX:	Intermediate Heat Exchanger
ISI&R:	In-Service Inspection & Repair
JAEA:	Japan Atomic Energy Agency
MHI:	MITSUBISHI Heavy Industry
MFBR:	Mitsubishi FBR Systems
MW:	MegaWatt
PCS:	Power Conversion System
P2C:	Confirmation of Configuration Phase
PWR:	Pressurized Water Reactor
R&D:	Research and Development
SC:	Steel Concrete structure
SFR:	Sodium Fast Reactor
SIS:	Seismic Isolation System

SPX:	Superphenix (*French SFR*)
TS:	Task Sheet
WG:	Working Group
3D:	Three Dimension

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