ASTRID reactor
Design overview and main innovative options for Basic Design

Frédéric Chanteclair[1], Gilles Rodriguez[1], Jean-Marie Hamy[2], Remy Dupraz[2],

[1] CEA Cadarache, DEN/DER/CPA, 13108 Saint-Paul lez Durance Cedex, France

[2] AREVA NP, 10 rue Juliette Récamier 69456 Lyon Cedex 06, France

E-mail contact of main author: frederic.chanteclair@cea.fr

Abstract.

Sodium-cooled Fast Reactors (SFR) is one of the Generation IV reactor concepts selected to secure the nuclear fuel resources and to manage radioactive wastes. In the frame of the June 2006 French act 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 in collaboration with industrial partners.

The ambitious objectives of ASTRID reactor are to fulfil the GEN IV requirements. It has led to the implementation of innovative technological solutions which go beyond the current proven ones. Necessarily, these innovations will have to be consolidated within the framework of Research & Development actions and qualification programs.

In its Basic Design stage, ASTRID has built a coherent conceptual design configuration with innovative techniques and systems across all domains: core, fuel assembly technology, nuclear island, civil engineering, energy conversion system, plant layout, ISI&R, manufacturability, etc. and even in the project management.

The object of this document is to provide an overview of the significant innovations under consideration on ASTRID. It will also present the partners contribution to this quest for innovations for better performances and/or enhanced safety.

Key Words: ASTRID - innovation - overview

1. Introduction

Fast neutron reactors have a large potential as sustainable energy source. In particular, Sodium Fast Reactors (SFR) with a closed fuel cycle and potentialities for managing radioactive waste, allow improved use of natural resources and minimization of long-lived radioactive wastes. Among the fast reactor systems, the sodium cooled reactor has the most comprehensive technological basis as result of the experience gained from decades of worldwide operation of several experimental, prototype and commercial size reactors.

A June 2006 French law on sustainable management of radioactive materials and wastes requests that, concerning transmutation of long-lived radioactive elements, studies and investigations shall be conducted, in order to provide by 2012 an assessment of the industrial prospects of those systems. Fast Reactor strategy was confirmed in May 2008 at Ministry level and in September 2010 an agreement was published between CEA and French Government in order to conduct design studies of ASTRID prototype and associated R&D facilities [1].

The ambitious objectives of ASTRID require the implementation of innovating technological solutions which go beyond the current feedbacks. These solutions will be further developed in the next phases of ASTRID design studies, keeping a strong interaction between design, R&D and programs of qualification. [2]

The object of this document is to list the innovations under consideration on ASTRID and the profit expected compared to the reactors of the past. Both water-steam Power Conversion System and gas Power Conversion System, specific innovations are described. The objective is to provide a large overview of the significant innovations under consideration on ASTRID (without being exhaustive). This document covers not only the technological innovating solutions but also the innovations in terms of methods and tools.

2. Technological innovating solutions

2.1. Core innovations

Low sodium void effect core is achieved by axial heterogeneous Core with sodium plenum in the upper part of the assemblies, dismountable Upper Neutron Shielding in boron carbide enriched in 10B, axial fertile plate in the internal core. *(Contributor: CEA)*

Fuel-pin clad in austenitic steel for the first core and then planned with ODS steel (Oxide Dispersion Strengthening) for a better lifespan. *(Contributor: CEA)*

ASTRID design allows **Recycling Pu** from PWR. *(Contributor: CEA)*

Electromagnet Curie point: A Safety Complementary Device for Prevention of core severe accident will release control rod by loss of bearing capacity of the electromagnet if the core temperature increases too much. *(Contributors: JAEA-MHI-MFBR & CEA & AREVA NP)*

Hydraulic rods: A Safety Complementary Device for Prevention will fall if the sodium flow decreases too much. *(Contributor: CEA)*

Lateral neutron shielding assemblies in boron carbide (B4C) are made up of a sealed clad containing a stacking of natural B4C sleeves. *(Contributors: CEA & AREVA NP)*

Reflectors: MgO Reflectors with tight pencils containing MgO pellets, have better efficiency than steel reflectors. *(Contributors: CEA & AREVA NP)*

2.2. Primary circuit and other systems in direct interface

Rotating plug sealing: Polymeric joints (inflatable joint type or - π shaped joint) are envisaged for the dynamic sealing of the rotating plug. It offers a more compact design than liquefiable metal seal. *(Contributors: TECHNETICS & AREVA NP)*

Main vessel cooling system is achieved using a derived cold flow from the strongback lower plate through pipes routing to the main vessel cylindrical part. Immersed weir limits the risk of gas entrainment and ensures creep and fatigue resistance of the main vessel over 60 years. *(Contributor: AREVA NP)*

Metal joints for the crossings of inner vessel by the intermediate heat exchangers: Metal joints "piston ring seal" type will replace the gas chamber concept used on Phenix reactor. It will avoid risk of gas transfer in the cold plenum. *(Contributor: AREVA NP)*

Tee fitting between diagrid and primary pump: A tee fitting is recessed in the strongback to connect primary pumps with diagrid. Tee fitting is less cumbersome than a spherical connection and got a better thermo-mechanics properties. *(Contributor: AREVA NP)*

Optimized thermo-mechanics Intermediate Heat Exchanger (IHX): IHX have got tube bundle with expansion loops which give better thermo-mechanics properties. *(Contributor: AREVA NP)*

Automatic welding of the vessels in 316L (N) by TIG process or other automatic processes (wire flow, welding with Metal inert gas MIG or with Metal active gas MAG…). These processes will provide a better quality and productivity gain. *(Contributor: AREVA NP)*

Replacement of stellite coating: Coatings based on nickel are considered to replace Stellite. The closest structures to the core are less activated. *(Contributor: AREVA NP)*

A Strongback backup skirt is dissociated from the strongback principal supporting skirt. The strongback is supported by a skirt and a safety supporting skirt welded onto the main vessel at the bottom. *(Contributor: AREVA NP)*

2.3. In Service Inspection and Repair (ISIR) in primary circuit [3]

Non-Destructive Test (NDT) under Na: Ultrasonic transducers are considered for NDT under Sodium with damping acoustic solution by silicone layer. Tests could be done at 200°C. *(Contributors: CEA & AREVA NP)*

Carrier under Na: Carrier called "All-in-one" enables the inspection of the welds of the strongback. Carrier is mainly made up of a mast and a pushing-chain on which is fixed an attachment plate with the sensors. *(Contributor: AREVA NP)*

In Service Inspection accessibility studies are made to increase access quantity and to optimize the positioning. In particular alignments between slab penetrations, inner vessel chimneys and strongback penetration are implemented to facilitate the inspection under strongback. In addition, external inspection of the main vessel has been facilitated. *(Contributors: AREVA NP & COMEX Nucléaire)*

Hollow crosspieces for strongback inspection: The strongback is a box-section structure whose junction between tightening veils consists of cross-shaped elements. For in service inspection, these "cross pieces" are hollow in order to enable the insertion of ultrasonic sensors for the examination of the vertical welds. The access to the hollow crosspieces is done via candles inside the diagrid. *(Contributor: AREVA NP)*

2.4. Decay Heat Removal Systems (DHRS)

DHRS Exchangers in cold plenum: Active DHRS exchangers are long and located in the cold plenum. They have potentially a better operation during and after a severe accident. *(Contributors: JAEA-MHI-MFBR & AREVA NP)*

DHRS through vessels: Exchangers are in the reactor pit (behind the safety vessel). Thus this system is well diversified. It is mainly dimensioned to hand over the in vessel DHRS during the mitigation situation (cooling of core catcher), and to contribute in all other situations. Cooling fluid is oil and final heat sink is water. *(Contributor: AREVA NP)*

Surface treatment improves the vessels emissivity (main vessel and safety vessel). A surface treatment will improve DHRS - through vessels - efficiency. *(Contributors: CEA & AREVA NP)*

2.5. Mitigation of the severe accident

The corium is conveyed through diagrid and strongback to the core catcher in order to avoid re-criticality and melting propagation to the internal storage. The advance is ensured by Corium guides (Through Tube safety complementary devices), specific candles in the diagrid and evacuation tubes through the strongback. *(Contributors: CEA & AREVA NP & JAEA)*

The core catcher is today designed to collect and to maintain subcritical the corium of the whole core melting plus up to 3 reflector rows. *(Contributors: CEA & AREVA NP)*

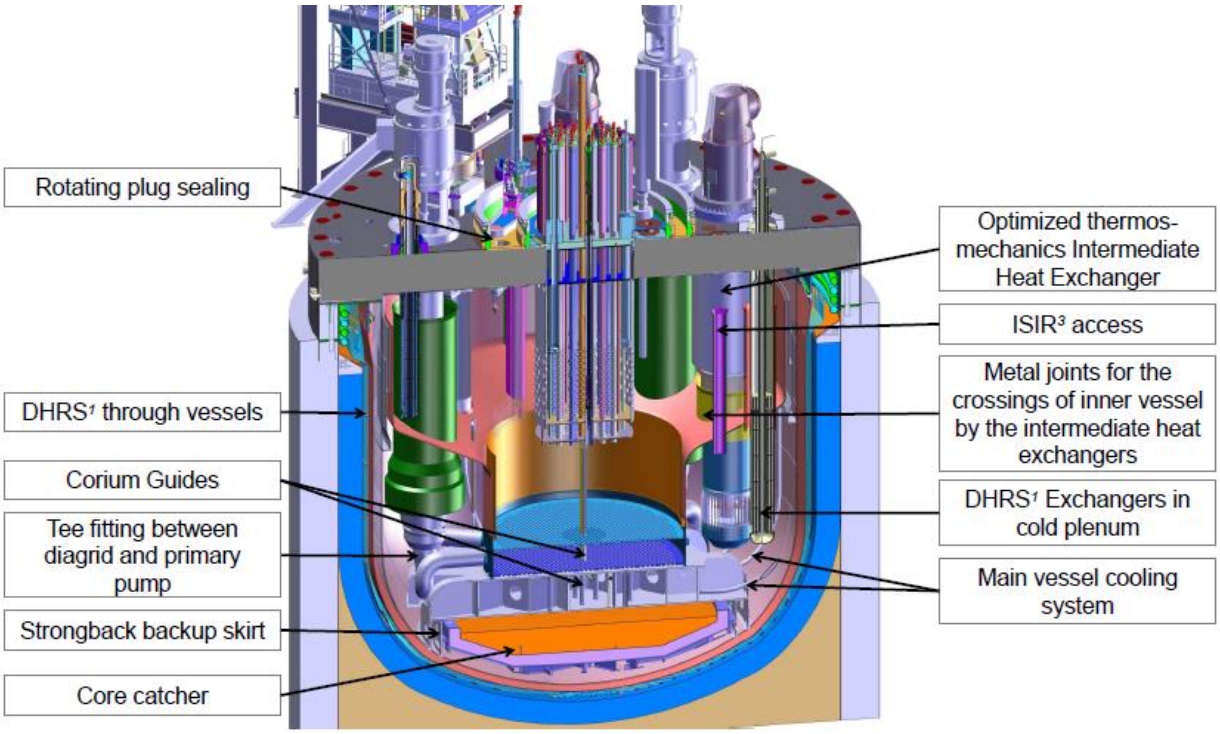

FIG. 1. - Innovations location in the primary circuit

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

2.6. Secondary circuits

Isolating valves on Secondary Sodium Loop are implemented on the hot and cold legs. These two large valves per loop (butterfly valve diameter of 700mm) guarantee an extension of the confinement in long term in case of energetic accident leading to a loss of the Intermediate Heat Exchanger integrity. *(Contributor: VELAN)*

Electro Magnetic Pumps are implemented on Secondary Sodium Loop on the cold leg. Electromagnetic pumps are designed to procure a large sodium flow. This choice is motivated by a reduction of length and complexity of the loop, a simpler technology than mechanical pump, a higher reliability and a reduced maintenance. *(Contributor: TOSHIBA)*

Effective leak detection systems: 3 concepts development are in progress on: Multi-layer Heat insulator (in air or inert medium), shifted heat insulator, detection by fiber optic. *(Contributor: CEA)*

2.7. Water steam Power Conversion System & Steam Generator

Hydrogen detection at low temperature: Sodium circuits of the Hydrogen detection are heated in order to initiate the decomposition of soda and to maintain a correct permeability of the membranes. This device enhances the detection time in case of a leak in the tubes of the steam generator at low temperature (between 200 and 350°C). *(Contributor: AREVA NP)*

Passive acoustic detection is envisaged for the average and large leak detection (> 100 g/s) in the tubes of the steam generator. *(Contributor: AREVA NP)*

Inspection of tube bundle of the Steam Generator: Ultrasonic inspection of tube bundle of the Steam Generator is performed via immersed autonomous flexible probes (in water). *(Contributor: AREVA NP)*

Sodium flow (inlet-outlet) in the Steam Generator in the lower part: This concept is based on the creation of a buffer zone at an intermediate temperature between the inlet and the outlet pipes in order to reduce the thermal loadings on the structures of the Steam Generator. The benefit is a reduction of the steam generator building height. *(Contributor: AREVA NP)*

2.8. Gas Power Conversion System (Brayton Cycle) & Gas Heat Exchangers

Plate heat exchanger: Sodium / Gas Heat Exchangers are Plate heat exchangers (plates are engraved or machined). The power of the Sodium Gas Heat Exchanger is 187.5 MWth. The Heat exchanger modules are located inside a pressurized vessel, playing also a “header / gas pipes / safety containment” functions. *(Contributors: AREVA NP & CEA)*

2 Gas Turbomachinery are implemented in the Gas PCS design. Each shaft line contains 2 split flow face to face turbine, 3 « three stages » radial compressors, 1 generator. *(Contributor: GENERAL ELECTRIC)*

2.9. Auxiliary circuits

External purification with removable cartridge: Primary sodium purification is performed with an external sodium-cold trap and removable cartridges. Configuration is with 2 sodium cold-traps of small capacity. It enables to retreat the cartridges regularly. *(Contributor: AREVA NP)*

Cesium trap: A Cesium trap is considered before primary sodium purification system. *(Contributor: AREVA NP)*

2.10. Civil Engineering

Steel-concrete structure is a structure made up of two steel plates bound by radial stiffeners. Space remaining is filled by connectors/steel spacers and normal filler concrete. Steel-concrete structures are envisaged for the steam generator bunker, Reactor building roof, reactor pit. *(Contributor: BOUYGUES)*

Sodium Retention System: In double leakage configuration of the main vessel and the safety vessel, this device ensures the retention of primary sodium and protects concrete structures from interactions with Na. This device must also contribute to the thermal protection of the structural concrete during all conditions. *(Contributors: BOUYGUES & AREVA NP)*

Horizontal seismic insulation system: the anti-seismic protection of the principal buildings (the nuclear island) is performed by elastomers supports with weak damping (5%). *(Contributors: BOUYGUES & JAEA)*

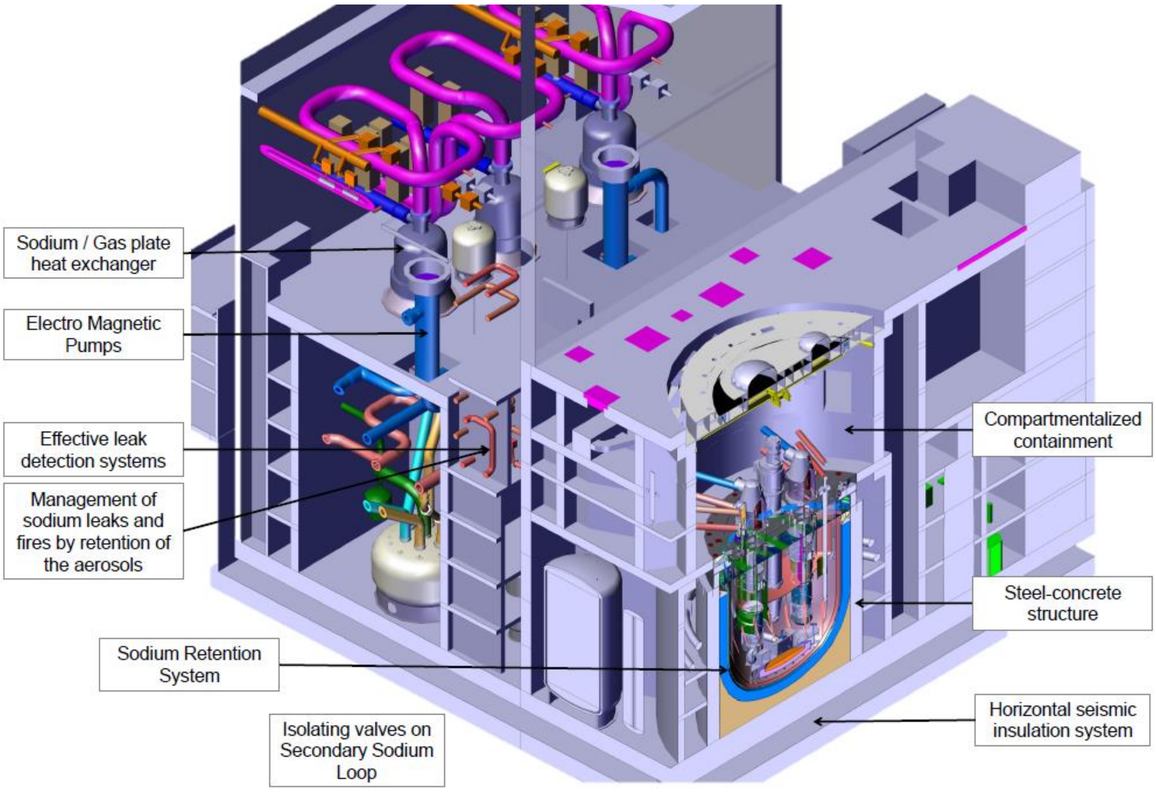

FIG. 2. - Innovations location in the nuclear island

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

2.11. Hot Cell

X-ray Tomography gives accurate and high-precision 3D-scan of the fuel pins bundle before dismantling. A 2nd generation CT scanner is considered, comparable to the Fuel Monitoring Facility Computer Tomography-facility in JOYO. *(Contributor: SEIV)*

Computer assisted remote handling is implemented in the hot cell with electrically operated slave arms in the cell, master arm with force-feedback in remote operator room and HD vision by cameras. The waiting advantages are reduce operator dose, improve working conditions, computer assistance for repetitive tasks, collision avoidance, increased surveillance and safety. *(Contributor: SEIV)*

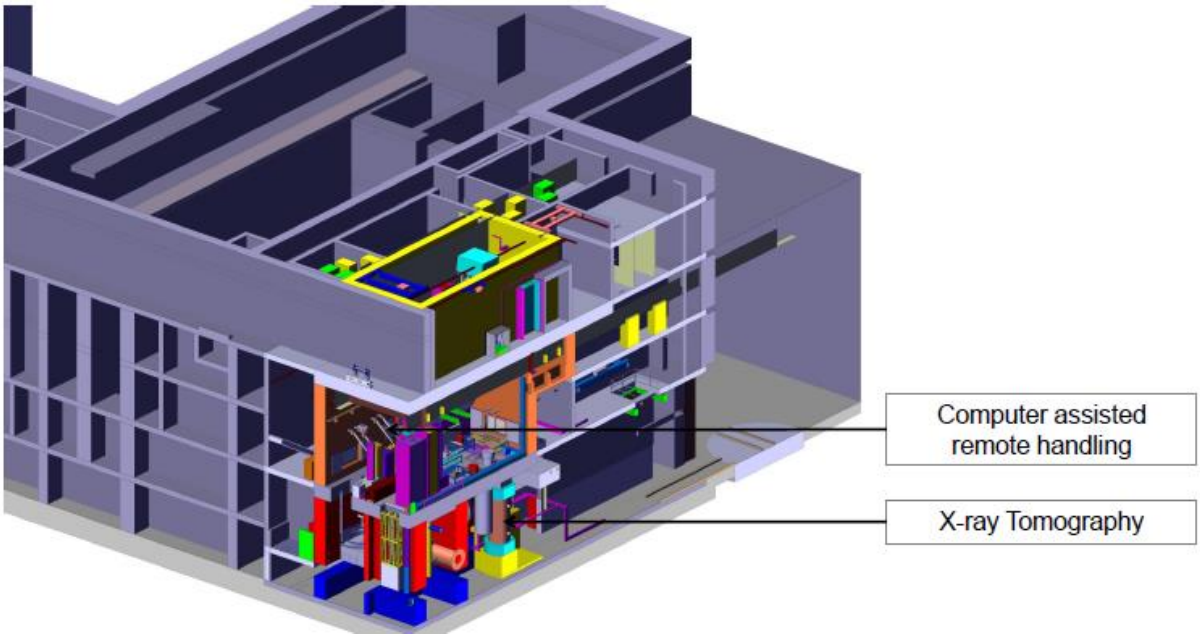

FIG. 3. - Innovations location in fuel handling building

ASTRID Project Business Confidential Information, CEA, AREVA NP and SEIV property designs

2.12. Handling and specialized maintenance

Safety brake in the transfer basket for large components: Implementation of a safety brake in the transfer basket enables, in the event of a rupture of an element of the kinematic chain, on the one hand to slow down the component in its fall inside the basket and on the other hand to make the deceleration of the component more progressive. *(Contributor: AREVA NP)*

2.13. General installation

Distant and compartmentalized containment: The containment is compartmentalized with a polar table, above the slab, which create an attic with low leak rates. The containment is realized by the building with steel liner or sealing resin or steel concrete structure. *(Contributors: AREVA NP & BOUYGUES)*

Management of sodium leaks and fires by retention of the aerosols and partitioning: There is no non-isolable outside discharge of the containment, in particular no outside discharge of sodium fires overpressure. Sodium leaks and fires are managed by the installation of sodium compartments adapted to the various zones. Inerting systems, to avoid fires, are also considered in secondary loop channels. These provisions are applied to the reactor building and Steam Generator buildings. *(Contributor: AREVA NP)*

2.14. Instrumentation &Control

Instrumentation & Control Structure with remote acquisition: The acquisition units are at nearest position with possibility of local pre-treatment and transmission of information to the centralized control by fiber optic. *(Contributor: AREVA NP)*

Smart sensors are implemented. Transmission of the data is performed with a connection to the automats by fiber optic connection. *(Contributor: AREVA NP)*

3. Engineering, Management and Computational tools innovations

3.1.Engineering & management methods

Beyond the technical innovations described, ASTRID plays a part of precursor in the implementation of new engineering methods such as:

System engineering (in particular with the implementation of the requirements traceability, Product and Functional Breakdown Structures, interface data management, technical data management, configuration & evolution management),

3D Mock up: For the general layout definition of the various buildings exchanges are done via a 3D Mock up.

Transversal analyses are done on the design to take into account transversal needs such as: physical protection, organizational and human factors, codes and standards aspects, waste, environmental aspects, operability availability, operating conditions.

Studies are undertaken in close cooperation with many partners in all technical areas of work. Each company brings its expert testimony in terms of design and construction to produce a new global layout as presented on *FIG.4*.

The CEA has set up partnerships with French and foreign industries who are providing both technical and financial support. These partnerships are based on bilateral collaboration between the CEA and the relevant industrialist. This type of agreement, a win-win relationship, enables an easier collaborative work.

FIG. 4. Global layout of ASTRID at starting of Basic Design

ASTRID Project Business Confidential Information, CEA, AREVA NP and NOX property designs

3.2. Computational tools

The selection process of certain design options and the safety studies of the ASTRID reactor rely on the use of scientific computing tools, some of which require the development of new functionalities to fully address the needs and particularities of this new reactor.

A new generation of tools is implemented for the Basic Design phase of the ASTRID project, in compliance with the regulatory and schedule requirements such as:

Computing Fluid Dynamic and System Codes Coupling for thermal-hydraulic studies of the primary circuit,
Neutron & thermo-hydraulic chaining for the neutron activation calculation of primary sodium,
3D dynamic models for the structures of the primary circuit,
Methodology of determination of the chemical impacts due to discharge of soda products.

4. Conclusion

The ambitious objectives of ASTRID require the implementation of innovating technological solutions which go beyond the current feedbacks; and significantly different compared to the former projects. These solutions will have to be consolidated with R&D and qualification programs in the next steps of the project.

Acknowledgments

The authors wish to thank all ASTRID partners :

Appendix 1: References

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