Asian Nuclear Prospects 2010

French SFR R&D Program and Design Activities for SFR Prototype ASTRID

F. Gauche*, J. Rouault

Commissariat à l’Énergie Atomique (CEA), Saclay, 91 191 Gif-sur-Yvette Cedex, France

1. Introduction

France has a long history of R&D, construction and operation of fast neutron reactors. However, with the shutdown of Superphenix reactor more than 10 years ago and of Phenix in 2009, we are now entering a phase where we must convince that fast neutrons reactors are part of the energy solution for the future, and that they can meet Generation IV requirements.

To that purpose, French R&D on fast reactors has been organized for the last 4 years around two systems: sodium cooled fast reactor SFR, as the reference option, and gas cooled fast reactor GFR as long term option. This paper concentrates on SFR R&D and prototype.

Along with the R&D, plans for the prototype ASTRID (as for Advanced Sodium Technological Reactor for Industrial Demonstration) have been prepared. As an industrial prototype, it is foreseen to be put into operation around 2020. End of 2009, in a broader investment plan for the future, ASTRID was identified as one of the priorities to receive governmental funding. Although collaborations and partnerships are sought, most of the financing for the design studies is secured.

Key words: SFR; fast reactor; sodium; ASTRID; prototype

*Corresponding author. Tel.: + 33 1 69 08 41 28; fax: + 33 1 69 08 58 91
E-mail address: francois.gauche@cea.fr

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2. SFR R&D program

The R&D performed in France on SFR is done in close collaboration between CEA and industrial partners AREVA and EDF.

The R&D program comprises research in four domains of innovations:

- The development of an attractive and safe core, taking into account the specificities of the fast neutrons and sodium, and also able to transmute minor actinides,
- A better resistance to severe accidents and external hazards,
- The search for an optimized energy conversion system reducing the sodium risks,
- The re-examination of the reactor and components design to improve the conditions of operation and the economic competitiveness.

Between 2007 and 2009, the R&D program provided very useful results and valuable status reports were issued on the followings topics:

- Loop designs
- Pool designs
- Review of innovative options: advanced energy conversion systems, advanced pool/loop designs
- Fuel handling
- Impact of reactor power level on safety and costs
- Core and fuel
- Safety and severe accidents
- Status on 9Cr potential for pipes and components
- Status on oxide dispersion strengthened steel ODS as cladding tube material
- ISI&R: sensors, inspectability, reparability, robotics

These reports covered broad R&D subjects like:

- The definition of a large reference core using oxide fuel and characterized by a very low reactivity loss (self-sustainable core) and attractive safety parameters,
- The realization of two irradiation tests in Phénix, concerning structural materials (ODS F/M steel) and oxide fuel elaborated with (U,Pu) co-precipitated powder,
- The definition and the realization of the end-of-life experiments in PHENIX in order to accumulate data for the qualification of the codes dedicated to the neutronics and thermohydraulics in SFR and to improve the knowledge of physic phenomena in a SFR core,
- The characterization of new solutions for the recycling of minor actinides in the heterogeneous mode,
- The first calculation of severe accident sequences with SAS4A and SIMMER multi-physic computational tools,
- Some innovative proposals for new concepts as an IHX/SG integrated component,
- The evaluation of alternate fluids to sodium for the secondary circuit,
- The establishment of the development plan of the technological loops necessary for the R&D and the prototype development, The definition and launching of a comprehensive program on In Service Inspection and Repair (ISIR),
- Preliminary reactor designs for innovations assessment (pool, loop, fuel handling options, advanced energy conversion systems).
- Innovative features proposals aiming to improve the safety cases, in line with Safety Authorities expectations for a GENIV reactor.
On safety, emphasis is put on the relationship with the safety authority. Interactions started in 2008 including the organisation of technical seminars. In 2010, main topic of exchange will be the feedback of operation of Phénix, Superphénix and other reactors. A special program is still ongoing to provide accurate analysis of the Phénix situations of scram due to negative reactivity (“AURN”) taking into account the end-of-life experiments. Current R&D includes passive safety devices as additional lines of defense in an enhanced core.

As far as energy conversion system is concerned, the goal is to minimize the frequency and the consequences of sodium-water reaction. R&D is conducted in two directions: alternative fluid to steam as working fluid (Brayton cycle), or design improvement to drastically improve the resistance to sodium-water reactions, like modular steam generators. Supercritical CO$_2$ is seen as a long term promising option, with issues like sodium-CO$_2$ interaction to be investigated furthermore.

In-Service Inspection and Repair (ISIR) is of outmost importance and an extensive R&D program is being performed. There are plans for a large refurbishment and construction program for testing facilities to support R&D activities and ASTRID development. Sharing of facilities in other countries is also envisaged.

3. ASTRID prototype and associated program

The ASTRID prototype (as for Advanced Sodium Technological Reactor for Industrial Demonstration) is seen as an industrial prototype prior to the first-of-a-kind, meaning that extrapolability of the technical options and of the safety demonstration is of outmost importance. The reactor will also provide some irradiation capabilities especially in order to validate the expected properties for the new fuel (big pin and ODS clad) and the ability to burn minor actinides up to an industrial scale.

The ASTRID program defined by CEA also includes the facility to manufacture the fuel for the reactor, of limited capacity from 5-10 tons heavy metal per year. The refurbishment of existing testing facilities and the construction of new tools is part of the program as well.

ASTRID shall be coupled to the grid with an electrical power of about 600 MW. It shall integrate operational feedback of past and current reactors. It is seen as a full Generation IV prototype reactor. Its safety level shall be at least as good as current 3$^{rd}$ generation reactors, with strong improvements on core and sodium-related issues. After a learning period, the reactor shall have a high load factor (e.g. 70 to 80%). The reactor shall provide capability for demonstration of transmutation of minor actinides, at larger scale than previously done in Phénix. And of course, the investment costs of the prototype shall be kept to the lowest possible, with technical options compatible with later deployment on a commercial facility.

The schedule associated to the ASTRID prototype is very ambitious and will be adapted in the course of the project, following R&D results and political decisions. First choices need to be made in 2010 in order to launch the pre-conceptual and the conceptual design, and start first discussions with the safety authority. Still, some technical options will be kept open until 2012. A second phase of conceptual design with the submission of the safety option file in 2014 will allow to start basic and detailed design from 2015. The objective is to put the reactor into operation around 2020.

End of 2009, in a broader investment plan for the future, ASTRID was identified as one of the priorities to receive governmental funding. Although collaborations and partnerships are sought, most of the financing for the design studies is secured (650 M€).

Industrial collaborations are being put into place, so that the preconceptual and conceptual design activities can start in the coming weeks.