RECENT DEVELOPMENTS TOWARD A FLEET OF FAST REACTORS IN FRANCE

V. BARBE[1], D. SETTIMO[1], A. DAUPHIN[2], J.M. HAMY[2], F. PAYOT[3], P. GAVOILLE[3]

[1]Electricité de France, Lyon, France
[2]Framatome, Lyon, France
[3]Commissariat à l'Energie Atomique et aux Energies Alternatives, Saclay, France

Corresponding author: V. BARBE, vincent.barbe@edf.fr

INTRODUCTION: France has been capitalizing on decades of experience in designing and operating Sodium Fast Reactors (SFRs) while maintaining a long-term goal of closing the fuel cycle by means of a fleet of fast reactors. The paper addresses some of the developments which would be needed to deploy such reactors while aiming at an optimal overall performance.

1. FRENCH CONTEXT

1.1. French experience regarding fast reactors

The French experience was punctuated by major realizations: three reactors (Rapsodie, Phénix, Superphénix) operated in the period from 1967 to 2009, a plutonium fuel fabrication workshop, an experience of spent fuel processing, a first experience of reactor dismantling. Both Phénix (250 MW(e)) [1] and Superphénix (1200 Mw(e)) [2] were connected to the grid for years and demonstrated the relevance and the viability of the SFR as a large-scale electricity production mean. The experience gained so far is significant in terms of maturity of the technologies (mixed uranium/plutonium oxide fuel, core monitoring, pool-type reactor and a suspended vessel, 316L(N) steel for the vessel and components, prevention and mitigation of sodium risks, etc). This knowledge was further enriched during the 2010s with the design study of the ASTRID reactor [3], including a smaller-power variant called New ASTRID [4]. Throughout these projects, CEA has worked in close collaboration with industry to develop innovative technological solutions, capitalize knowledge, provide efficient models and computing tools, a design and construction industrial code and data for industrial qualification and safety demonstration. This knowledge base is an essential asset for projecting towards the complete closure of the fuel cycle, which means nuclear power production with no need of natural uranium supply.

1.2. French policy in recent years

Since 2021, the French government has been taking measures in favour of a wide-scope nuclear strategy. The first decisions were related to the reactors: alongside the long-term operation program for the existing fleet and the launch of a series of new build PWRs (EPR2), the government issued a call for projects to foster the development of innovative nuclear reactors by providing financial and technical support to newcoming companies backed with private funding. In 2024, three new companies proposing sodium- or lead-cooled fast reactors preliminary concepts were awarded governmental support (see TABLE 1), among 11 awarded projects featuring various technologies.

Another set of decisions is related to the fuel cycle strategy. In 2024, it was decided to pursue and expand the spent fuel reprocessing-recycling strategy until the end of the century, i.e. to launch a sustainability/resilience program extending the life of the spent fuel reprocessing plant at La Hague, and MOX fuel fabrication plant at Melox, beyond 2040 and to start studies for their future replacement with new plants by 2045-2050. Then, in 2025, the government asked the nuclear industry for a roadmap toward the complete fuel cycle closure by means of a fleet of fast reactors and associated fuel cycle facilities needed.

TABLE 1. LIQUID-METAL COOLED FAST REACTOR PROPOSED MODELS SELECTED IN THE INNOVATIVE REACTOR TENDER FIRST ROUND – COMPARED TO ASTRID/NEW ASTRID

Designer	Model	Power (MW(e))	Coolant
Hexana	Hexana SMR	2x140	Sodium
newcleo	LFR-200	200	Lead
Otrera	ONE-110	2x110	Sodium
CEA/Framatome	ASTRID	600	Sodium
CEA/Framatome	New ASTRID	150	Sodium

2. SFR1000, A GW-SIZE REACTOR FITTED FOR A CLOSED-CYCLE SYSTEM

From 2017 to 2018, complementing the ASTRID project, a French working group composed of EDF, CEA and Framatome has produced an expression of needs of R&D necessary for the design and operation of a future industrial SFR. The group has produced both a specification and a first sketch of a SFR reactor to be introduced into the French nuclear fleet in the second half of the 21st century. The targeted power of 1000 MW(e) had been determined by industrial scenario studies considering the closure of the French fuel cycle. Since then, the reactor concept has been evolving to optimize the expected performances [5].

2.3. Main requirements

In order to take into account the objective of a closed fuel cycle, the SFR 1000 is required to feature an intrinsic flexibility between plutonium iso-generation and breeding. The flexibility must be achieved without changes in the reactor design itself, as the fuel cycle service of a given reactor could evolve over time. Targeting high fuel management cycle duration (i.e. the total time spent by a fuel assembly in the core) is another way of optimizing the fuel cycle economics.

However, the CAPEX of fast reactors is recognized to be one of the key drivers of a closed fuel cycle economy. Consequently, the reactor lifetime is of primary importance besides the construction cost itself. The design of the SFR 1000 will target a lifetime of at least 60 years (comforted by the recent achievements of R&D and engineering developments performed by Framatome [6]).

Load-following capability is also considered, since SFRs may account on the long term for a large part of the nuclear fleet in association with intermittent power sources.

Lastly, the SFR 1000 is required to comply with Generation IV International Forum (GIF) design criteria. This requirement includes a significant progress of in-service inspection and repair with respect of past or currently operated SFRs.

2.4. Design options

The design options reflect a balance between proven technologies, capitalizing on decades of unique French experience in the domain of large SFRs, and in-development ones, the latter being considered reasonably available in the envisaged deployment step (second half of the century). Nevertheless, the SFR 1000 design itself is evolving, mainly to optimize its performance while taking into account the state of the art.

The main design characteristics are the following:

- Core “compact heterogeneous” relying on the low void effect design principles developed for ASTRID but more compact.
- The primary system of SFR 1000 reactor is an integrated one, constituted by the main vessel, doubled by the safety vessel, and by the upper closures. It includes the internals that support the core, the primary sodium and four primary pumps. It also hosts four intermediate heat exchangers, the decay heat removal heat exchangers, and the fuel handling system. It is integrated in the reactor pit. Because of their large dimensions, intermediate heat exchangers and primary pumps are in the critical path of diameter of the main vessel. One intermediate heat exchanger per loop has been defined as design reference. A core catcher is installed at the bottom of main vessel, able to collect the full quantity of melted core.
- The choice of the primary sodium temperature at core outlet is still debated, as it should be a trade-off between lifetime of hot plenum components (above core structure, inner vessel, intermediate exchanger) with a target of 60 years, reliability and efficiency
- Sodium secondary loop with expansion bellows in order to reduce the size of the buildings (around 30% of the steam generator building)
- Decay heat removal is insured by diversified systems: passive Direct Reactor Auxiliary Cooling System (DRACS), active DRACS and a Reactor Vessel Auxiliary Cooling System (RVACS) installed in the reactor pit.
- As SFR1000 is designed to be built by pair, fuel handling architecture is designed to share as much as possible components between the two reactors.
- Fuel storage is shared between the reactors. Fresh and irradiated fuels are stored in the same water pool. Fuel handling is insured by a gas cask. The objective is to avoid any external sodium fuel storage to reduce the CAPEX.
- Common handling systems (fuel and components) are installed between both reactor buildings.

3. NEEDS FOR FUTURE DEVELOPMENTS

The technological solutions included in the SFR 1000 sketch have been selected following two main criteria: (a) they are optimal with respect to the reactor’s performance and (b) they are considered reasonably available in the second half of the century. A consequence of this process is that the selected technological bricks can exhibit various readiness levels as of today, so that the SFR 1000 sketch can also be used as a tool to identify and prioritize future technological developments. While a comprehensive R&D program is under way under the leadership of the CEA [6] in cooperation with EDF and Framatome in particular [7][8], this section focuses on three illustrative domains:

- Firstly, the core design (especially, the dispositions for severe accident prevention and mitigation), the fuel subassembly (pin cladding materials), the control rod (B_4C/stainless steel interaction), all aspects related respectively to the safety requirements of the reactor and the fuel cycle performance, count among the less mature solutions within the SFR 1000 sketch. For the two latter, they also have in common the need for a representative fast-spectrum test bench to characterize and qualify their properties. A refined understanding and modelling of the core physics will be a key support for those developments, in line with French continuous effort in this domain.
- Increasing the lifetime of non-replaceable or costly components is also one of the main drivers of the R&D needs (focused on material properties), while design activities are still on-going toward the limitation of in-service loadings on the equipment.
- The last domain is related to sodium specific constraints. The assigned goals are to reduce the uncertainties of sodium-related calculations (sodium fires, sodium-water or sodium-fuel

interaction), which will help targeting potentially overconservative design options, and to develop dedicated technologies such as in-service inspection solutions.

4. CONCLUSION

While the French government recently asked the nuclear industry to propose a roadmap toward the fuel cycle closure, the SFR 1000 sketch can be used as reference targeted reactor model. Its main options have been selected in order to achieve the objective of a closed cycle system, although some of them need decade-long developments which would be consistent with a deployment in the second half of the century. A prioritization of those developments can be inferred as a function of their actual benefit on the system's performance and of their readiness level.

REFERENCES

[1] GUIDEZ J., Phenix, The Expérience Feedback, edpsciences (2013)

[2] GUIDEZ J. and PRELE G., Superphenix, Technical and Scientific Achievements, Atlantis Press (2017)

[3] VARAINE F. et al, ASTRID project general overviewand status progress, GIF Symposium "the 4th GIF Symposium at the 8th edition of Atoms for the Future, Paris, France, 2017

[4] RODRIGUEZ G. et al, France-Japan synthesis concept on sodium-cooled fast reactor: review of a joint collaborative work, EPJ Nuclear Sci. Technol. 7, 15 (2021)

[5] BARBE V. et al, "SFR1000 general overview, a strong technical heritage to design the future SFR fleet", International Congress on Advances in Nuclear Power Plants, Juan-les-Pins, France, 2025

[6] GARNIER J.C. et al, "CEA R&D program on GenIV reactors", International Congress on Advances in Nuclear Power Plants, Juan-les-Pins, France, 2025

[7] MARTIN A. et al, "Analysis of the new RCC-MRx methodologies for creep-fatigue damage" / IAEA-CN-327-84

[8] MAY E. et al, "SOFI 3D – 3D CFD methodology for sodium spray fire calculations used for French SFR 1000 design support", International Congress on Advances in Nuclear Power Plants, Juan-les-Pins, France 2025