The New French Nuclear Initiative and ORANO's Role

Ulf KUTSCHER
ORANO GmbH
Sudwestpark 65, 90449 Nuremberg, Germany
ulf.kutscher@orano.group

Philippe VALBUENA
Orano AS
124 rue de Paris, Chatillon, France
philippe.valbuena@orano.group

Abstract

During the second part of the 20th century, France has developed a strong independent energy policy based on nuclear electricity generation. The current nuclear power reactors are reaching 40 years of operation, and France's future electricity generation system needs to be defined.

Against the background of the existing uncertainties related to geopolitics, climate change and technological evolution, France needs to decide about the future of its nuclear energy generation. The respective decisions have just been announced by French President Macron. In the future, France is planning to use both nuclear power and renewable energy sources to cover its power demand. Nuclear power and renewables will thus become the two key pillars of the country's power system.

ORANO, the multinational nuclear fuel cycle company, has anticipated this decision, and, therefore, has renewed a part of its production facilities. It is now ready to support the nuclear renaissance in France, contributing to the implementation of MOX fuel in EDF's 1300MWe NPP fleet and by developing new technologies such as multi-recycling in PWRs and further strengthening of fuel cycle activities.

1 The very beginning of French nuclear history

After World War II, France established a state-owned company, CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives). The main mission of this new company was to develop civil and military nuclear activities in France.

After ten years of research, CEA developed its own design for nuclear reactors based on natural uranium, graphite moderator and carbon gas carrier (UNGG). A first prototype (called "G1") was built in 1953, with the two other units, G2 and G3, following in 1955 and 1957. The aim of these reactors was twofold:

- Producing plutonium. For this purpose, a dedicated facility for reprocessing the used fuel assemblies was built next to the reactors. With this plutonium, France was able to develop its military nuclear arsenal. Based on that, France decided in 1954 to build nuclear driven submarines and nuclear weapons;
- Verifying technology and design in order to build this type of reactor for the purpose of generating electricity.

At the same time, to fuel these 3 reactors and to keep its independence, France developed its uranium mines by opening several ones in Limousin and Vendée.

In 1958, General de Gaulle was elected president. He decided to adopt the nuclear electricity generation policy based on the CEA technology: UNGG. With the success of G1, G2 and G3, EDF was mandated by General de Gaulle to design and build electricity generation reactors. Six reactors were built: Chinon A1, A2, A3 – Saint Laurent A1, A2 – Bugey -1. They were in operation between 1960s and end of 1980s.

In 1966, as France opted for a closed nuclear fuel cycle, a first plant for spent fuel reprocessing in La Hague was commissioned.

In parallel, the CEA developed new technologies for reactors: fast neutron and heavy water. A heavy water reactor was built in 1967 in Brennilis, called EL4. This reactor was shut down in 1985 because of its low profitability.

At the same time, another design of electricity generation reactor was developed in the USA: the PWR, based on enriched uranium and pressurized water with the pressure preventing the water from boiling within the reactor. For EDF, this reactor type had several advantages compared to the UNGG technology and therefore a 310 MW PWR prototype reactor (Chooz A) was built between 1962 and 1967. In the late 60s, EDF and CEA were not in agreement about the technology to select for new nuclear plants, and Georges Pompidou, who became the French president after the resignation of General de Gaulle in 1968, decided to abandon the UNGG technology and to only further develop the PWR technology. EDF's arguments in favor of PWR were its higher safety, higher profitability and smaller design requiring less space.

2 Acceleration of the French nuclear program

In 1973, after the first oil crisis, the French nuclear program was accelerated. This decision led to the construction of 58 nuclear reactors between 1970s and 1990s based on the PWR technology. In the meantime, a new state-owned company was created and put in charge of the fuel cycle activities: COGEMA. At the beginning of the 21th century, the nuclear power plants generated more than 75 % of the French electricity.

In the meantime, the CEA built two reactors based on the fast neutron technology in the 70s and 80s, Phenix and Superphenix. Superphenix was shut down in 1998. It was a political decision made after several incidents. Phenix remained in operation until 2010.

The PWR technology required enriched uranium. To be able to fuel the nuclear reactor fleet, in 1978 it was decided to build an enrichment plant based on the gaseous diffusion technology, called Eurodif. This facility was operated from 1978 to 2011. It has been replaced by a new one, called Georges Besse II, producing 7.5 MSWU/y, implementing the most efficient enrichment technology, centrifugation.

The uranium mines operated in France were shut down, and COGEMA developed new mines all around the world.

To reprocess more and more fuel assemblies burnt in the nuclear power plants, a new reprocessing plant was built at the La Hague site to extend the capacity. It was commissioned in 1990.

In 2005, an independent authority called 'ASN' was established to monitor the nuclear activities.

3 Current situation with the civil nuclear energy generation in France

After the Fukushima accident in 2011, some countries decided to phase out nuclear power. In France, following an agreement with the green party needed to win the presidential election, French President Francois Hollande decided to reduce the share of the nuclear electricity generation in France's energy mix, which planned the closing of 12 nuclear reactors. Consequently, the nuclear market decreased to such an extent that the French nuclear industry had to be restructured.

Today, fifty-six reactors are in operation producing more than 67% of electricity in France. Two PWR reactors, the two first ones connected to the grid, have been shut down. One reactor is under construction in Flammaville based on the new PWR reactor generation: EPR. This decision was made before the Fukushima accident.

In terms of the closed fuel cycle, France covers the entire scope from uranium mines to reprocessing and recycling of spent fuel:

- ORANO, (former AREVA group), owns mines in different countries (Niger, Kazakhstan, Canada) to feed EDF reactors and other electricity producers.
- ORANO built a new conversion facility in 2018 and renewed the enrichment plant in 2011.

- FRAMATOME has been transferred from AREVA group to EDF; it operates facilities for manufacturing uranium fuel assemblies.
- For the back-end activities, ORANO owns the site of La Hague which is able to reprocess fuel assemblies and separate uranium and plutonium from actinides and fission products. The latter are vitrified. The La Hague site has been in operation since 1966. Melox fabrication plant located near Marcoule site in the south of France, manufactures mixed plutonium, uranium oxide fuel for PWR and BWR.

4 Status of decommissioning of shut down reactors

The first generation of reactors, which was based on the UNGG technology, has been shut down. The total of nine reactors were shut down permanently for two main reasons: they had reached their expected end of life time and they were not profitable anymore.

The first two PWR power reactors, which marked the start of extended nuclear electricity production in the 1970s and 1980s, were shut down in 2020.

The table below gives information on the shut down reactors in France.

NPP Location	Name	Type	Power (W)	Beginning of construction	Operational date	Shut down date
Marcoule	G1	UNGG	0 MWe5	1955	1956	1968
Chinon	Chinon-A1	UNGG	70 MWe	1957	1963	1973
Marcoule	G2	UNGG	39 MWe	1955	1959	1980
Marcoule	G3	UNGG	40 MWe	1956	1960	1984
Chinon	Chinon-A2	UNGG	210 MWe	1959	1965	1985
Brennilis	EL4	gas-heavy water	70 MWe	1962	1967	1985
Chinon	Chinon-A3	UNGG	480 MWe	1961	1966	1990
Saint-Laurent	St-Laurent-A1	UNGG	480 MWe	1963	1969	1990
Chooz	Chooz-A	PWR	310 MWe	1962	1967	1991
Saint-Laurent	St-Laurent-A2	UNGG	515 MWe	1966	1971	1992
Bugey	Bugey-1	UNGG	540 MWe	1965	1972	1994
Creys-Malville	Superphenix	RNR	1 200 MWe	1976	1986	1998
Marcoule	Phenix	RNR	130 MWe	1968	1974	2010
Fessenheim	Fessenheim-1	PWR	880 MWe	1971	1978	2020
Fessenheim	Fessenheim-2	PWR	880 MWe	1972	1978	2020

The first reactors G1, G2 and G3 are under decommissioning. They should be dismantled by the end of 2035.

For the other UNGG reactors, the six built by EDF, the decommissioning will have to be performed in a non-standard way because of the presence of graphite in the reactor pressure vessel. Initially, the dismantling of RPV-I should have been done under water but it turned out to be too complicated. EDF has changed its approach and the cutting of RPV-I is now planned to take place in air. A demonstrator has been built by EDF. The aim of this demonstrator is to define the best way to dismantle the UNGG reactors. The dismantling of Chinon A1 should start in 2032.

The dismantling of Chooz-A is currently under progress and should be finished in 2025. The dismantling of the EL4 reactor in Brennilis is ongoing.

The cutting of Superphenix reactor pressure vessel is planned to be completed in the coming years.

Phenix and Fessenheim reactors are in the decommissioning preparation phase. The schedule has not been settled yet.

5 Waste management for high level waste

France has chosen to implement a closed fuel cycle. This choice enables France to strongly reduce the toxicity and the volume of its high-level waste. The actinides and fission products, separated from uranium and plutonium at La Hague site during the reprocessing of fuel assemblies, are being vitrified.

To ensure the final disposal of this type of waste, France has decided to develop a deep geological repository in Bure, in Northeastern France (near Nancy). After 25 years of research, the project called “CIGEO” is now under licensing. The construction is planned to start in 2025 and it should be operational in 2035. After 120 years of operation, it is planned to close it permanently, and to dismantle the surface facilities.

6 French energy policy and its consequences for nuclear industry

After the Paris climate convention, France defined three goals, namely, to be carbon-neutral by 2050, to abandon fossil fuels and to be able to supply 645 TWh of electricity, which corresponds to the expected French needs in 2050.

To reach these goals, in 2018 French President Emanuel Macron requested a study to define the means of generating electricity in the future. In this study, both nuclear and non-nuclear scenarios have been taken under scrutiny. The following three scenarios involve the nuclear phase-out:

- Nuclear power is phased out by 2050: the decommissioning of the existing nuclear reactors is accelerated and the rate of development of solar, wind and marine energy is pushed to the maximum (M0)
- Very robust development of distributed renewable generation across the country driven in large part by solar. This development implies strong mobilization on the part of local actors and governments (M1).
- Very robust development of all renewable technologies, driven notably by the installation of large onshore and offshore wind farms. Focus on economic optimization and the technologies and geographic areas with the highest efficiency to allow economies of scale (M2).

Three other scenarios involve nuclear power:

- Launch of a program to build new nuclear reactors, developed in pairs on existing sites every five years starting in 2035. Robust development of renewables to offset the decommissioning of second-generation nuclear plants. (N1)
- Launch of a program calling for the faster development of new reactors (a pair every three years) from 2035 with a gradual ramp-up. Renewable energy development continues but at a slower pace than in scenarios N1 and M2. (N2)
- The generation mix is evenly split between renewables and nuclear in 2050. This implies keeping existing nuclear power plants in service for as long as possible and proactively developing a diversified mix of new nuclear (i.e. ~14 EPR + a few SMRs)

The main conclusions of the report are that the scenarios with nuclear phase-out:

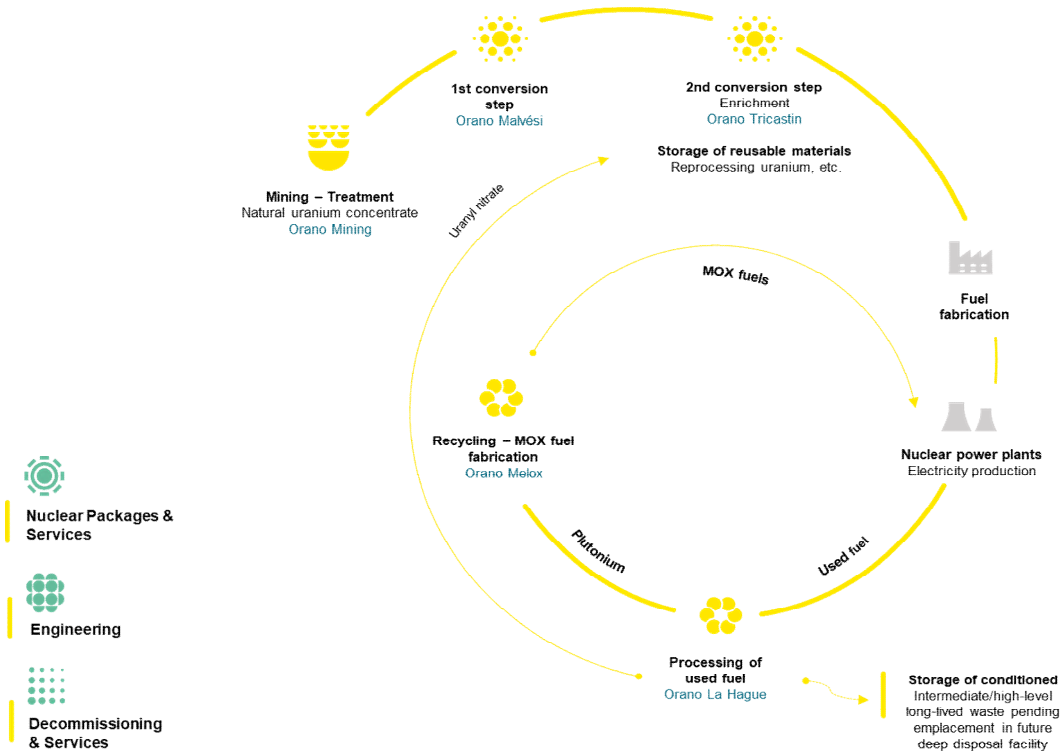
- Are more expensive
- Are riskier in terms of securing the electricity production on the necessary level. Blackouts are more likely than in scenarios with nuclear production.
- Have more negative impact on the environment and people's lifestyle

Following those conclusions and considering the reliability of nuclear electricity generation during the COVID pandemic phase, in February 2022 president Macron announced the launch of new French nuclear power generation:

- Building of 6 new reactors EPR2 (modified design of EPR for the French market, taking into account feedback from the EPR construction, less expensive than EPR, optimized)
- Starting of feasibility and siting studies for 8 more EPR2
- No more closing of NPP (except for safety reasons) but increasing their lifetime beyond 50 years
- Investing in new technologies that can help reduce waste generation

7 ORANO's role in French nuclear renaissance

ORANO, is an international leading company involved in the nuclear fuel cycle, from mining to reprocessing and recycling including engineering, nuclear transport and packages, services, and decommissioning and waste management.



Since 1976, ORANO has been a key player in the French nuclear energy sector providing services for the fuel cycle activities especially for the reprocessing of fuel assemblies keeping in sync with the French policy of a closed fuel cycle. Uranium and plutonium are separated from minor actinides and fission products in La Hague plant. Minor actinides and fission products are vitrified: thanks to this technology,

the volume of waste is reduced by 5 times and the toxicity by 10 times. The produced glass matrix is very safe and stable over a very long term and can be stored, pending its emplacement in a permanent disposal facility. Plutonium is reused to manufacture mixed oxide fuel assemblies called MOX and loaded in French nuclear reactors.

As far as the announced nuclear renaissance in France is concerned, ORANO is well prepared to support this new trend. With ORANO's main front-end facilities renewed (new conversion plant, 10-year-old enrichment plant), and its shares in different uranium mines, ORANO has all the necessary assets to be a major player.

In the fuel recycling area, ORANO together with French industrial playing is currently working on the following projects:

- in the short term, the implementation of MOX fuel assemblies in 1300 MWe PWR to sustain the recycling fuel cycle., Those reactors are not yet licensed to use MOX fuel assemblies. ORANO is providing support to EDF to reach this goal.
- in the mid-term, ORANO is contributing to a R&D program aiming at developing multi-recycling fuel for both PWRs and EPR2.
- in the long term, ORANO is involved in preparing the complete closure of fuel cycle using generation IV reactors to increase natural uranium saving and further decrease the waste volume.

These three dimensions are connected to the French president's announcements related to the reduction of waste generation.

CONCLUSION

France is going through a key phase in making decisions on the future of its nuclear electricity generation. The first decision has just been made and needs to be confirmed by the new President and its new government. Although Emmanuel Macron was re-elected as president, the parliament elections are coming up next June.

Thanks to its strong assets, ORANO feels confident about the future of the nuclear industry in France and its capacity to remain a major player.