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Nuclear Fuel Cycle Engineering or How to Support a Sustainable Nuclear Energy Renaissance

Abstract

By recycling reusable materials into new fuels and by offering a safe and durable conditioning of ultimate waste, the closed cycle route is the most suitable approach to guarantee the sustainability of nuclear energy. This can be seen all over the world, either through clear choices in favour of the closed cycle or a renewed interest for such a policy.

France adopted this approach many years ago and has been constant in its policy ever since; therefore, adequate competences and workforce in the fuel cycle area have been constantly renewed. As part of the AREVA organization, SGN has over 40 years of experience in the design and construction of fuel cycle facilities, based in France (Marcoule and La Hague reprocessing plants, MELOX MOX fuel fabrication plant, enrichment and conversion facilities in Pierrelatte and Malvesi) and abroad (technology transfer and engineering assistance for the design and construction of the Rokkasho-Mura reprocessing plant in Japan and the MOX Fuel Fabrication Facility in the USA). Continuous assistance to the operators to optimize and keep their facilities in line with the evolving rules and constraints has ensured the integration of a wide operational experience feedback and the ability to design flexible facilities.

AREVA nuclear fuel cycle engineering teams have a strategic position at the interface of facilities operators, customers and R&D teams which gives them an overall view of the stakeholders, enabling them to build the best answer to the coming needs linked to the nuclear energy renaissance that will impact the whole nuclear fuel cycle.

Introduction

The pros and cons of used nuclear fuel reprocessing have been discussed ever since the beginning of the nuclear energy era. By reducing recourse to natural uranium sources and optimizing waste management, the closed fuel cycle approach is the best way to support a sustainable life for nuclear energy, with ecological responsibility. If this trend is confirmed in the future, industrial capacities for every step of the fuel cycle will have to be increased, from the fabrication of fuel to its recycling and ultimate waste management.

After a presentation of the main advantages of the closed fuel cycle, this paper will focus on SGN experience in design

and construction of any kind of facilities for both front end and back end of the fuel cycle, acquired since the beginning of the 1960's in France and exported abroad many times. We will explain how the engineering teams' central position at the interface of process designers, operators and customers gives them a global view of stakeholders, extremely useful to propose a global and adapted service to each customer.

Closed fuel cycle advantages

It is more and more widely accepted that nuclear power - as a CO₂-free source of power - will have a major role to play in meeting the increasing demand for energy worldwide. However, the management of nuclear waste remains one of the main concerns for the public and may constrain the expansion of nuclear power. Moreover, uranium, as a fuel resource, may not be seen as a lasting solution to energy needs.

To be sustainable, the renaissance of nuclear energy must include responsible management of its natural uranium resources and a safe and durable management of its ultimate wastes. The closed cycle policy is the only one today which perfectly fits into this scheme of sustainable development and ecological responsibility:

- By enabling the recovery and recycling of re-usable materials, thus contributing to the conservation of natural uranium sources: the recycling of plutonium into MOX fuel and of reprocessed uranium after re-enrichment provides a secured secondary source that guarantees long-term fuel supplies at a stable price and can save up to 25% of uranium needs;
- By minimizing As Low As Reasonably Achievable (ALARA) nuclear waste toxicity and volume, thus contributing to the protection of the environment of present and future generations: after treatment, the volume of high-level waste is divided by 5 and its toxicity is divided by 10. The high-level waste and the long-lived waste are conditioned into a passive form that can be safely stored pending final disposal. A geological repository can then be optimized both from a technical (compactness, retrievability) and economic point of view. Moreover, as ultimate wastes from reprocessing do not contain any significant quantity of fissile material, they are not subject to proliferation concerns.

On the international scene, the closed cycle policy is the object of renewed interest. Countries with important

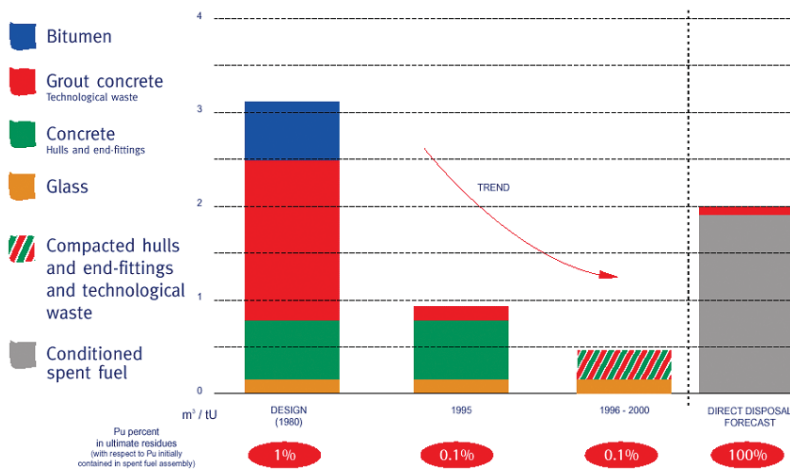


Figure 1: Evolution of the volume of final residues (high-level and long-lived waste) conditioned at UP3 plant (La Hague)

nuclear generation programs like China, Russia, India, Japan and France are clearly committed to the closed fuel cycle. And the United States, having banned reprocessing in the late 1970s, is now seriously reconsidering it as an attractive option for anchoring nuclear energy in sustainability and bringing major optimization routes for the management of its fuel cycle back end. Indeed, a closed fuel cycle strategy in the USA would eliminate the need for additional repository capacity, beyond the initial capacity at Yucca Mountain, until 2070 [1].

AREVA is committed to maintaining its involvement in the development of a nuclear industry that preserves the environment now and for future generations. Waste management optimization is a key element of AREVA's industrial strategy: through a continuous improvement approach [2], including evolution of facility design and operating feedback, the volume and the radiotoxicity of final waste from nuclear fuel reprocessing operations have been considerably reduced, as shown in Figure 1.

AREVA fuel cycle engineering experience

Through SGN, AREVA has acquired over more than 40 years a large body of experience in design and construction of fuel cycle facilities in France and worldwide. SGN has for a long time meant "Saint Gobain Nucléaire", since it was first a department of the glass factory set up to design and construct the first nuclear fuel reprocessing plant UP1 which started in 1958 in Marcoule (Rhône Valley) dedicated to GCR (gas cooled reactor) fuels. SGN was also involved in the design of the front-end facilities for uranium conversion in Malvesi. The second major reprocessing plant was the UP2 400 plant built in La Hague at the tip of the Cotentin peninsula in Normandy, which was commissioned in 1966 to treat GCR fuels and was extended to treat LWR fuels in 1976 with the start-up of a new head-end facility, HAO.

SGN's experience abroad started in the early sixties through

participation in the Eurochemic reprocessing project in Mol (Belgium). Then, SGN built the first Japanese reprocessing plant in Tokai-Mura (commissioned in 1977). At the same time, SGN (through the former USSI) was designing and building the EURODIF enrichment plant in Pierrelatte.

The decision to build two modern reprocessing plants in La Hague was taken at a time when many countries were very keen to close the fuel cycle and when France itself started a significant program which led to 58 LWR reactors in 1998. The first studies for this second generation of reprocessing plants in La Hague (UP3 then UP2 800) started in 1977.

The design of this new generation of plants was a real challenge [3] since it had to integrate many constraints:

- First commercial plants with high nominal capacities of 800 tonnes/year of LWR fuels, leading engineering teams to design many types of new continuous and reliable equipment.
- Increased safety requirements, including lower staff exposure, which meant an extensive use of remote operation, including for maintenance.
- Significantly lower releases, which meant innovations in the process.
- On line waste treatment associated with the goal of reducing as low as reasonably achievable the amount and activity of final waste.

Therefore, a large R&D program - 3.9 billion francs up to 1989 (nearly 600 million Euros) - was built associating the CEA (French Atomic Energy Commission), SGN and AREVA NC (formerly COGEMA) [4].

UP3 units were commissioned between 1986 (dry unloading facility) and 1990 (shearing and dissolution facility), and the first units of UP2 800, which were taking the place of the UP2 400 equivalent units, in 1994 (R1: head-end unit; R2: first extraction cycle) and the last ones in 2002 (ACC: hulls compaction; and R4: plutonium polishing).

In 1987, Japan Nuclear Fuel Services (JNFS) chose the reprocessing concept developed in France to be implemented in Rokkasho-Mura through a technology transfer contract (TTA - Technology Transfer Agreement); at the same time, a design and construction contract was signed with MHI and executed in partnership with five Japanese companies, namely Mitsubishi Heavy Industries, Hitachi, Toshiba, Mitsubishi Materials Corp and Sumitomo Metal Mining. Construction work started in 1993 and the first phase of tests - water tests - in 2001, followed by chemical tests in 2002, and then uranium tests in 2004. Since April 2006, hot tests have been under way using

approximately 430 tonnes of spent fuel; they have confirmed that both PWR and BWR fuels can be treated without problems and that the facilities will deliver the expected performances; SGN and AREVA NC teams are still associated with Japanese companies in achieving the active start-up of the plant [5].

The R&D of management of high-level waste has been taken into account by CEA since the first reprocessing operations with the development of the vitrification process using a hot metallic crucible. SGN has been associated with its implementation through the construction of the first pilot plant PIVER (Marcoule, 1969) then the first industrial plant AVM (Marcoule, 1978) and the two facilities of La Hague R7 (1989) and T7 (1992). In 1981 a contract was signed with BNFL for the technology transfer of the vitrification process of specific equipment for the Windscale vitrification plant which started in 1990 in Sellafield (UK).

SGN experience with fuel fabrication started with the fabrication of metallic fuel in the 1960's. The fuel cycle closure was achieved with the start-up of the MELOX plant in Marcoule in 1995. As in the treatment field, the MELOX project was a very ambitious challenge:

- First commercial plant for manufacturing MOX fuel at a high capacity.
- Very high level of automation.
- Total quality management.

As a result of the full involvement of the engineering teams, MELOX reached its original licence capacity (100 tons per year) in 1997, only two years after its start-up. Since its commissioning, MELOX has continuously evolved thanks to close relations between the operators, the engineering teams and successful R&D program:

- Implementation of a multi-design production line in 1999.
- Second capacity licence (145 tonnes per year) obtained in 2003, capacity achieved in 2005.
- Third capacity licence (195 tonnes per year) obtained in April 2007.

This technology is currently being transferred to the USA where SGN is a member of the teams building the MOX Fuel Fabrication Facility at the Savannah River Site.

JNFL has started a plan to construct a MOX fabrication plant (J-MOX) which will use MELOX Advanced Process used at MELOX plant [5] through a TTA signed with AREVA.

This year, AREVA announced its intention to invest 610 million Euros for updating its capacity to convert uranium by building new facilities (COMURHEX II project) in Malvesi and Pierrelatte; SGN is in charge of the detailed design of these facilities where start-up is planned in 2012 to reach a first nominal capacity of 15,000 tonnes of uranium per year,

with the possibility to increase it up to 21,000 tonnes of uranium per year.

SGN and AREVA NC signed in 2005 a TTA with the Russian company TENEX for the construction of a depleted uranium defluorination plant in Zelenogorsk, Siberia. This contract includes the general facility design, the supply of process equipment, the management of installation and testing and the operations and maintenance training of future operators.

AREVA is also paving the way for the future by launching the construction of the new Georges Besse II enrichment plant, which will gradually replace the existing Eurodif plant. AREVA and Urenco established the Enrichment Technology Company Ltd (ETC) as a joint venture to develop, manufacture and assemble centrifuges.

Construction of the Georges Besse II plant started in September 2006. ETC is responsible for the design, supply and startup of the centrifuge cascades. SGN is providing other engineering studies, project management and overall technical coordination for the project.

The Georges Besse II plant is a 3 billion Euros program and one of the largest industrial investments of the decade in France. It will have a production capacity of 7.5 million SWU, which may be raised to 11 million SWU as market conditions warrant. With its modular design, the new enrichment plant will ramp up gradually, ensuring a smooth transition from the existing plant to the Georges Besse II plant.

The South Unit is scheduled to produce its first SWU in the first half of 2009. The plant will be fully operational by 2018.

SGN's experience covers all the types of plants used in the fuel cycle with a wide range of production capacity: pilot plants (ATI - La Hague, RNR fuels reprocessing -1969; PIVER - Marcoule - vitrification, 1969), hot cells (CYRANO - Fontenay-aux-Roses), industrial plants (400 tonnes/year, 800 tonnes/year for reprocessing plants, 40 to 195 tonnes for MOX fabrication, 7.5 to 11 MSWU for enrichment facilities, 15,000 tonnes for conversion units). All these projects at the different steps of the fuel cycle have ensured that strong resources and competencies have been maintained in the AREVA Group for the design, construction, start-up and continuous improvements of these facilities.

Fuel cycle engineering position

Engineering teams are central in AREVA's organization offering a global service; their knowledge of the different parts of the fuel cycle associated with the experience of all the steps in the deployment of a new project is a key factor in offering a coherent and comprehensive scheme for any kind of project.

SGN has always been intensively associated with R&D teams of the CEA and has developed its own R&D competencies, particularly through its own laboratory and pilot scale facilities.

There is a major step between the demonstration of the feasibility of a process at laboratory scale and its implementation at an industrial level [4]. AREVA teams (SGN and AREVA NC) have achieved the optimization of this process through a step-by-step approach that proved its efficiency at the La Hague reprocessing plants when UP2 800 units attained their nominal capacity less than one year after their start-up. During this step-by-step approach, each actor has its own role (AREVA NC with the support of SGN specifies R&D objectives; the CEA is in charge of most of the process definition and active tests at small-scale; SGN is then in charge of industrialization and nuclearization of the process by developing mock-ups and carrying out inactive tests at pilot or full scale), but the efficiency of the approach results from close and constant interaction between the different actors:

- At the very beginning, during the scientific and technical feasibility steps, it is important to take into account the industrial constraints such as maintenance, waste management and safety requirements in selecting the appropriate process. Engineering teams are a key partner for the R&D teams, since on the one hand they will have to implement the process in the global design, and on the other hand, they will have integrated lessons learned from previous tests and operations.
- During the next steps - the design phases - engineering teams are the main actors, but R&D is still going on to validate engineering options. It is of major importance when specific, huge and "first-of-a-kind" equipment is being developed, for example the rotary dissolver in UP3 and UP2 800, which was tested at full scale with inactive fuels.
- Testing and start-up are performed by the future operator, but cooperation with engineering and R&D teams allows the best responsiveness and flexibility to solve any malfunction issue; SGN and AREVA NC (acting as operator of La Hague plants) are currently supporting JNFL teams at Rokkasho Mura during the active start-up of the plant. The results obtained are very encouraging and show the efficiency of this cooperation [5].

SGN maintains its partnership with all the operators of the facilities, contributing to the adaptation of their plants to the evolving environment, showing that the units built are very

flexible. The first kind of evolution is the adaptation of the facilities to the product to be treated or fabricated. UP2 400 was adapted to treat LWR fuels when they started to replace GCR fuels. More recently, the UP3 dissolution unit has been modified to treat RTR (research testing reactor) fuels that were formerly reprocessed in specific units of the UP1 plant [6]. Eight years of conception and qualification have been necessary to adapt the LWR dissolver to treat RTR fuels while keeping the capability to treat LWR fuels. The dissolution parameters have been defined by CEA teams, and then the technological modifications have been designed and tested at the SGN development and testing facility HRB near La Hague.

At the MELOX plant, the multi-design production line introduced in 1999 enabled the manufacture of either PWR or BWR fuels of varying cross-sections and lengths for foreign customers. The implementation of this new fabrication line in an existing and operating plant was made possible through very careful preparation and close cooperation between the operators and the engineering teams. The doubling of the capacity since the original licence also required process adaptations as well as new organization of the production.

Other types of evolution aim to adapt to new environmental constraints, such as what has been done at La Hague to improve waste treatment and reduce sea releases. In 1995, five years after UP3 start-up, thanks to the excellent performances of the extraction units, the amounts of low- and intermediate-level effluents were significantly lower than had been expected; therefore, a new strategy to manage these effluents was decided and UP3 liquid waste management was strongly modified to direct liquid waste streams to vitrification units instead of treating part of it with a co-precipitation process followed by a bituminization of the sludge. This evolution was done through a completely new management of the different streams, sorting them according to their activity and chemical composition and the adjunction of two evaporation units to concentrate the streams [7]. All these modifications have been effected without interfering with the operation of the plants.

The AREVA La Hague plant, like many other AREVA facilities, is now certified ISO 14001. Therefore this improvement policy is still going on and the engineering teams are a constant part of it. SGN is also assisting the operator with close teams to resolve minor issues on a day to day basis, allowing the facilities to achieve high rates of availability.

Close cooperation with operators allows us to integrate lessons learned all along the operation of the facilities in the design of the next generation of plants. For example, major changes were effected to improve maintenance operations between UP2 400 and UP3 designs, such as the development of specific shielded casks [8] to evacuate

pumps and other mechanical devices.

The first major plants of the fuel cycle are now in the process of decommissioning. The experience gained during these operations, where SGN is defining dismantling scenarios and coordinating operations, is also very important for the design of future plants. The entire life of the product is currently being integrated through the development of a sustainable engineering approach, eco-design, which aims to define the best product taking into account all the stakeholders during all the steps of its life: building, operation and dismantling.

Conclusion

In nuclear engineering, knowledge management is fundamental. A large part of the competencies that are needed to design and build safe, reliable and cost-effective facilities results from past experience, integration of lessons learned and continuous dialogue with other actors. Changes in nuclear policy may be very detrimental by causing severe losses of competencies and making future nuclear renaissance more difficult. The consistency of the French nuclear policy, and the resulting industrial projects that have been carried out at every step of the nuclear cycle, have led to the steady maintenance of a very high level of competencies in nuclear engineering that have been enhanced through worldwide experience. In the fuel cycle, SGN is the carrier of these competencies and represents a unique asset for the AREVA Group in its support for the nuclear renaissance throughout the world.

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