FRENCH "CYCLE IMPACT" APPROACH

S. MISSIRIAN
EDF
Saint Denis, France
Email: sophie.missirian@edf.fr

P. DEVIN
Orano
Courbevoie, France

J. M. HOORELBEKE
ANDRA
Chatenay-Malabry, France

Abstract

The "Cycle Impact" approach was launched at the end of the 1990s on the French Nuclear Safety Authority's initiative (ASN): EDF, in collaboration with its industrial French partners Orano and Andra, has to identify and anticipate actions in order to guarantee a consistent nuclear fuel cycle management in the mid-term. The impacts of fuel design, characteristics and management and nuclear reactors fleet evolutions on the whole supply chain should be studied: NPPs, front-end and back-end facilities, interim storage and logistics. The objective of the "Cycle Impact" exercise is to demonstrate that the choices made by industrial stakeholders on these evolutions, bearing in mind their interdependence and nuclear time frames, do not create unacceptable consequences regarding the entire French fuel cycle. It also allows ASN to have an overview of future regulatory requests to be examined.

After two previous exercises performed in 2000 and 2007, the "Cycle Impact" file 2016, made of 47 deliverables, coordinated by EDF in collaboration with Orano (formerly Areva, French company providing front-end, back-end and logistics services) and Andra (National Agency for Radioactive Waste Management), was submitted in June 2016. The fuel cycle consistency on a 15-years period was analyzed and forecasts until 2040 were made to ensure the absence of cliff-edge effect. Based on four scenarios of nuclear-sourced electricity production and associated fuel reprocessing-recycling strategies parameters like spent fuel pools level of occupancy and transportation casks availability had been studied. Hazard sensitivity analyses had been performed.

On request of the ASN, the file had been assessed by the French technical support organization (IRSN). An expert report including opinions and recommendations was produced and commitments were taken by the industrial actors. The report was subjected to a peer review by the Advisory Committee of experts (GP) for laboratories and plants including experts from waste, nuclear reactors and transports committees. Following the recommendations issued during the meeting of the Advisory Committee on 2018 May 25th, ASN has identified actions to be undertaken by each party in a letter on 2018 October 25th. With the goal of improving nuclear transparency, summary of the IRSN report, GP opinion and ASN stance has been published.

1. INTRODUCTION

The "Cycle Impact" approach is an initiative from the French Nuclear Safety Authority (ASN) which involves EDF and its industrial French partners Orano (formerly Areva) and Andra. Following a request from ASN, these actors submit a file providing information and analyses on the whole fuel cycle: nuclear power plants (NPP), front-end and back-end facilities, interim storage, existing and future waste disposal and logistics in France. The general objectives of this exercise are to:

— Demonstrate the consistency of the French fuel cycle in the mid-term whatever the energy policy, the choices made by industrial stakeholders, the radioactive materials and installations evolutions;
— Give ASN an overview of future regulatory requests to be examined.

2. BACKGROUND

Two “Cycle impact” files have been submitted before the last one in 2016: the first in 2000 followed by one in 2007. For both exercises, the time frame to study the robustness of the fuel cycle was a 10 years period, respectively 2000-2010 and 2007-2017.

For the 2000 file, EDF was asked to analyse the impact of a new fuel or new fuel management on the different operations of the fuel cycle. The objective was to identify the topics for which additional justifications would be needed and to anticipate authorisation requests. The consistency of the fuel cycle was demonstrated and following this first work, it was recommended to update regularly this global analyse.

The 2007 file aimed at analysing together with Areva and Andra the consistency of the fuel cycle including fuel cycle facilities and waste management following fuel design and fuel management evolutions. This consistency was demonstrated and an updated file was expected for mid-2016. The situation in 2014 showed that the hypotheses taken for the 2007 work were coherent and balanced and that the impacts of some projects delays have been controlled.

3. 2016 CYCLE IMPACT EXERCISE

3.1. Timeline

The frame of the new exercise to be submitted was sent by ASN in October 2015 and the file was delivered to ASN in June 2016. To analyse the “Cycle Impact” file and issue its stance, ASN needs a technical assessment of the work performed as well as the opinions and recommendations of a group of experts on the exercise.

Following a request of ASN, the French technical support organization (IRSN) assessed the file and the instruction implied about more of 100 questions to be answered during 2017. At this stage, commitments for future analyses have been taken by the industrial stakeholders.

In May 2018, the expert report from IRSN [1] was subjected to a peer review by the Advisory Committee of experts (GP) for laboratories and plants. The 32 members of this committee are appointed by ASN for 4 years and include experts of the field, experts from waste, nuclear reactors and transports advisory committees, members of NGOs. The GP gave its opinion and recommendations on the file to ASN.

Given all these elements, ASN published its stance in October 2018 on the “Cycle Impact” file with 15 actions to be performed by the industrial stakeholders ([2] and [3]).

3.2. Scenarios and hypotheses

In comparison with the previous exercises, the 2016 Cycle Impact file time frame was 15 years: the period studied was 2015 to 2030 and forecasts were made until 2040. The scope of the study has broadened as hazard analysis had to be included.

This exercise studied two scenarios: the current French fleet and recycling strategy and a low variation of the NPP fleet. In prevision of the energy multiyear plan, two additional variations with decreasing nuclear production were also studied on ASN request. These scenarios led to forecasts of:

- The fresh fuel to manufacture and transport;
- The spent fuel to discharge, transport, store in pools and reprocess;
- The reusable materials from reprocessing to transport, recycle, transform and store;
- The waste to manage, transport, store and dispose.

The study took into account French installations for front-end and logistics.

3.3. French fuel cycle

3.3.1. French Nuclear Power Plants fleet

The starting point of the analysis is the nuclear power plant fleet as it gives the need for fresh fuel to be delivered and spent fuel to be managed. In France, the installed nuclear capacity is 63 GWe for 58 plants (see Fig. 1). The hypothesis taken for the analysis is an annual production of 420 TWh which is a high value covering the production of the last years.

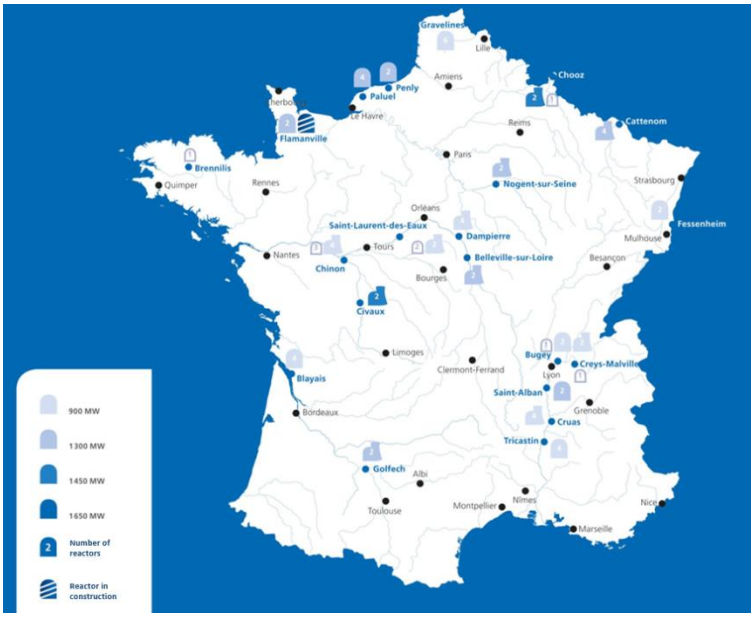

FIG. 1. Map of the French Nuclear Power Plant fleet.

Three different types of fuels are used: Enriched Natural Uranium, Enriched Reprocessed Uranium and MOX. 5 different fuel managements exist for the fleet (see Fig. 2).

During the instruction, questions were mostly asked about interim storage strategy, future fuel management evolutions and fuel in wet storage behaviour and surveillance. The answers provided did not unveil difficulties or issues impacting the fuel cycle consistency.

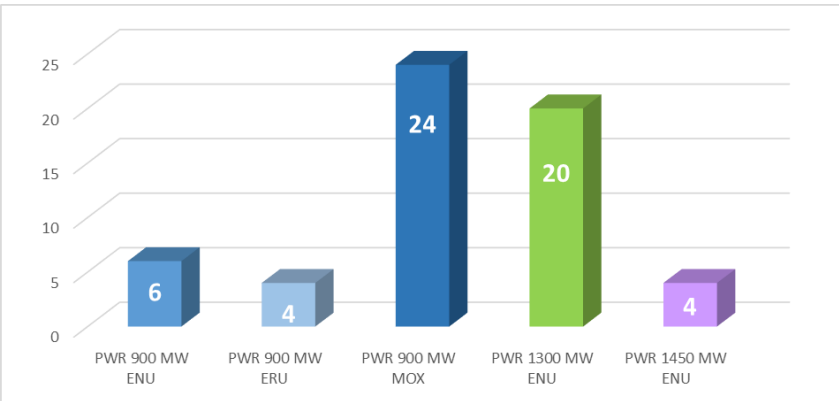

FIG. 2. Authorized number of NPP per type of fuel and fuel management.

3.3.2. Front end in France

Front end in France includes conversion (Orano Malvési [4] and Tricastin [5]), enrichment (Orano Tricastin [5]) and fuel manufacture (Framatome Romans [6]).

Orano Malvési site, near Narbonne, is the starting point of front end: it receives uranium from different mines of the whole world, Niger, Kazakhstan and Canada essentially. The process consists in the purification (dissolution in nitric acid) and the transformation of the yellow cake (concentrated uranium) in uranium fluoride four (UF4) with isoflash process which saves ammoniac and nitric acid (see Fig. 3). This is the first step of conversion. Then this form of uranium is transported by tank at Tricastin site, near Pierrelatte, for the second step of conversion to be transformed in uranium fluoride six (UF6) at Comurhex II plant. The new plant of Comhurex II (CX II) at Malvési is in operation and the new plant at Tricastin is ramping-up.

FIG. 3. Reactor with flames CX II.

On the Tricastin site (see Fig. 4), the uranium chemistry is also operated in TU5 and W plants. On TU5 plant, the uranyl nitrate, coming from Orano La Hague facility after the reprocessing uranium, is transformed in a chemical form more stable to interim storage waiting its reuse. On W plant, the uranium tails (depleted uranium) coming from enrichment, is transformed also in a chemical form more stable to interim storage waiting its reuse.

FIG. 4. The Orano Tricastin site.

Depleted uranium is used for MOX (Mix OXyde fuel) manufacture and reprocessed uranium for ERU fuel. These inventories constitute strategic reserves regarding the uranium market. Depleted uranium has also other uses like radiological protection against the ionizing rays in the interim storage of reprocessing uranium for instance.

Enrichment plant is also situated on the Tricastin site. The process was the gaseous diffusion until 2013 and GBII centrifugation (see Fig. 5) started its production progressively from the end of 2010.

FIG. 5. GB II enrichment plant.

The fuel manufacture is carried out at Romans by Framatome (formerly Areva NP). The plant firstly convert UF6 into UO2 and secondly manufacture UOx fuel assembly by a process of powder metallurgy. The plant manufactures ENU (Enriched Natural Uranium) and ERU (Enriched Reprocessed Uranium) fuel. The latter needs additional radiological shielding.

Questions during the instruction of the file by IRSN were about transports, uranium interim storage capacity essentially. It has been concluded that no difficult issue has been identified even in taking into account foreign customer of Orano.

3.3.3. Back-end

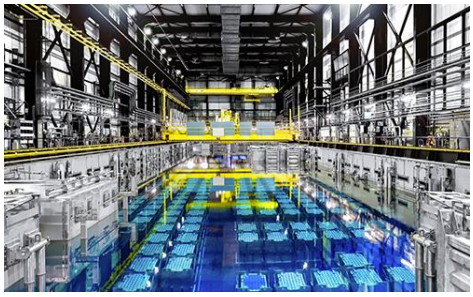

FIG. 6. Storage pool of La Hague.

Once used in nuclear power plant, ENU spent fuel is stored for cooling at site (minimum 6 months and typically 3 to 5 years). It is then transported to La Hague for reprocessing. It is before stored for cooling again (minimum 6 months and typically 3 to 5 years) in pool (see Fig. 6).

The reprocessing plant of La Hague [7] is situated in North Cotentin region in the west of France. The mechanical process (cutting spent fuel) and chemical process (dissolution by nitric acid) consists of separate metallic structure, non-soluble, fission products (4%), plutonium (1%) and reprocessed uranium (95%) as illustrated in Fig. 7.

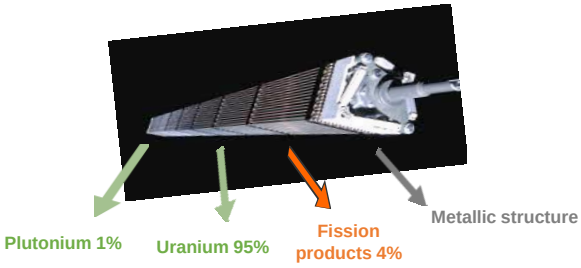

FIG. 7. Spent fuel separation.

Metallic structure is ultimate waste compacted in a standard container and fission products are vitrified in a standard container also. These wastes are 10 times less toxic without plutonium. They are stored at La Hague waiting for geological disposal.

Plutonium and reprocessed uranium (RepU) after separation are purified. RepU is transported at Tricastin to TU5 plant to be transformed in a stable form and stored waiting for a reuse to manufacture ERU fuel assembly.

Questions during instruction were about external and on-site internal transports, spent fuel pools level of occupancy, waste interim storage management pending implementation CIGEO project, operation issues, hazard analysis.

It has been concluded that no difficult issue has been identified even in taking into account foreign customer of Orano, but operation issues must be gone into.

Plutonium is recycled in a fuel called MOX, mix of depleted uranium and plutonium, manufactured at MELOX plant [8] at Marcoule in the East South of France, in the Gard department. This operation allows to save 10% of natural uranium resources.

The process of MELOX (see Fig. 8) is equivalent to Romans process: it is based on powder metallurgy equivalent to the ceramic manufacture. The process consists of different stages: uranium and plutonium powder grinding, mixing, homogenization, the powder is pressed to make pellets, introduction in a sintering furnace, pellets milling, introduction pellets in the clad to constitute a rod and at least the different rods are gathered in a structure to constitute a fuel assembly. The process is essentially automated and the maintenance is made in gloves box. The MOX fuel loading is authorized in 24 NPP 900 MW in France.

FIG. 8. Process of MELOX.

Questions during instruction were about transport, the evolution of the Pu isotopic and the consequences for operation and particularly for Radiation Protection, scrap management.

It has been concluded that no difficult issue has been identified even in taking into account foreign customer of Orano.

3.3.4. Logistics in France

The fuel cycle needs an important logistic to transport radioactive materials on the French territory between the different facilities and NPP. The logistics services in France are operated by Orano TN. The Fig. 9 below summarizes the complexity of this logistic.

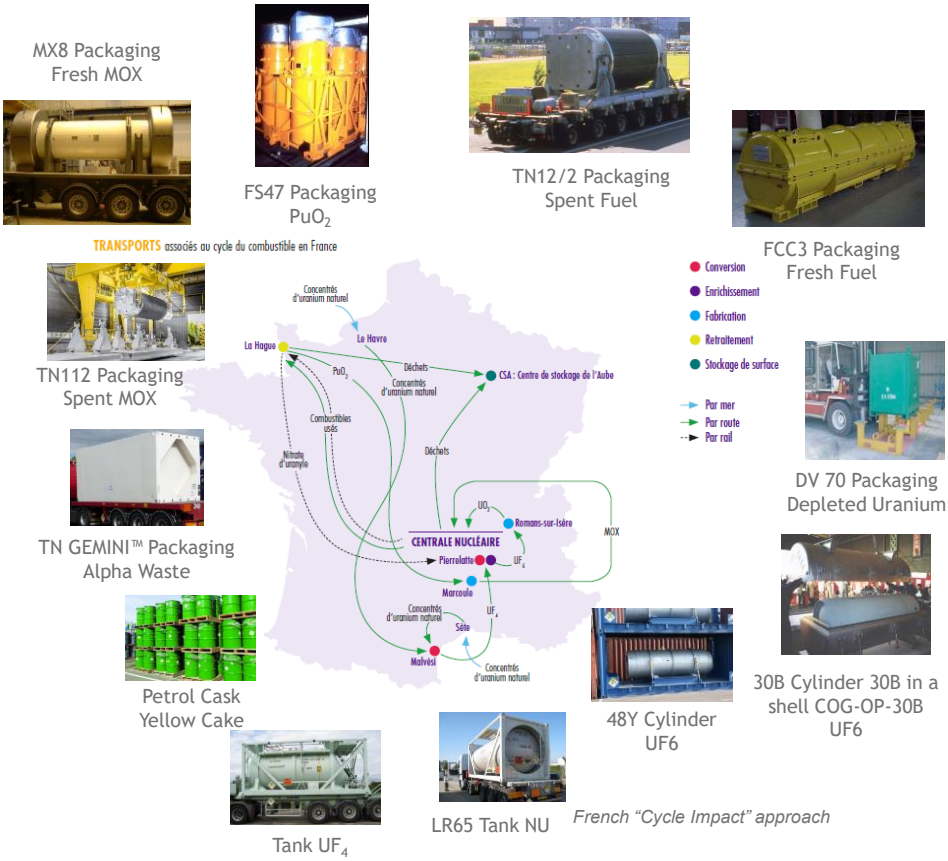

FIG. 9. Logistics services.

Questions during instruction were about the anticipation of the renewal of approval, the rate of availability of packaging according to the transport flows and according to the packaging fleet.

It has been concluded that no difficult issue has been identified even in taking into account foreign customer of Orano.

3.3.5. Waste management

In France long term management of radioactive waste has been the responsibility of the state owned Andra [9] [10].

Andra operates industrial disposal facilities on the surface for low level wastes (LLW) and very low level wastes (VLLW). Both facilities accommodate wastes generated by the operation of EDF's NPP fleet and the nuclear fuel cycle.

The operational disposal of LLW in the Centre de stockage de l'Aube (CSA) ([11] and [12]) started in 1992. Only 32% of its total capacity of 1 million m3 was filled in 2016. Therefore CSA will be capable to provide the industry for disposal services for tens of years in the future. The CSA can accommodate a wide range of waste package types which offers high flexibility. Isolation and containment are provided by robust concrete structures for centuries. Provisions are made to protect Man and environment in the longer term, mainly on the basis of a strong limitation of the content of the accepted waste in long lived radionuclides.

Located in the vicinity of CSA, Andra's Cires [13] opened in 2003 to dispose of VLLW. This opening came along with the decision of the Nuclear Regulator ASN to consider as radioactive all wastes produced in areas of nuclear facilities where a waste is or may be potentially contaminated or activated. Cires initial capacity of 650 000 m3 provides an operational availability of around 25 years. There are plans to provide additional disposal capacities and continuity in disposal service for VLLW. It can be noted that significant volumes of VLLW will arise in the future from the decommissioning of nuclear facilities. Ongoing exchanges in France aim

at exploring potential complementary management routes for VLLW in the case of a negligible radiological content.

Andra is preparing an application for the creation of a geological disposal facility in East of France, Meuse Haute-Marne area: Cigéo Project [14]. Isolation will be provided over very long periods of time by depth as well as the geodynamic stability of the selected site. A high level of containment will be provided by the host clay layer. The project will be implemented in the vicinity of the Meuse/Haute-Marne Underground research laboratory where Andra has carried out in situ characterization and demonstration since 2000. Co-disposal of intermediate level waste (ILW) and high level waste (HLW) is planned in Cigéo. Cigéo design capacity covers existing HLW and ILW in France as well as all wastes which will be produced in the next decades by the operation and decommissioning of all existing French nuclear facilities [15]. Its reference capacity is around 75 000 m3 of ILW and 10 000 m3 of vitrified HLW. Respectively 60% and 30% of this reference inventory is already produced and stored in waste producers' sites. ILW and vitrified HLW are currently produced by the operation of NPPs and the reprocessing of UOx spent fuels. ILW and vitrified HLW to be produced in the future by the reprocessing of MOx and URe fuels are also taken into account. ILW include metallic pieces of the fuel assemblies separated during reprocessing and various operational wastes. Vitrified HLW concentrate fission products and minor actinides. Specific disposal cells and areas are planned respectively for ILW and HLW to avoid any interaction. ILW will be disposed of from early stages of the operational phase while HLW will be accommodated after a few decade storage phase for thermal decrease. Cigéo operation will start with a pilot industrial phase to confirm the safety and reversibility of the facility prior to larger scale operations [16].

Finally so called "low level-long lived" waste is been produced by the front end of the fuel cycle; this includes uranium bearing waste from the conversion of yellow cake into UF4 before enrichment. A specific shallow depth disposal option has been considered along with some legacy and NORM wastes. Preliminary studied are being carried out to compare various management scenarios for this particular category of waste in order to define the most suitable industrial solutions.

FIG. 10. Surface disposal in France for LLW (CSA - left) and VLLW (CIRES - right).

FIG. 11. Cigéo Project for ILW and HLW (left) and Meuse Haute-Marne URL (right).

4. CONCLUSION AND PROSPECTS

The “Cycle Impact” exercise offers the opportunity to create a global vision of the French fuel cycle challenges. It consolidates an overview of the future French cycle while taking into account past experience and identify constraints, requirements and potential consequences to anticipate. Furthermore, it provides the opportunity for ASN to collect the opinion of an expert group on the topic. The elaboration of the file and the assessment process creates opportunities for constructive exchanges in a collaborative framework of the actors of the fuel cycle as well as IRSN and ASN.

The GP considers in its opinion published on ASN website that regarding safety and radiation protection, the impact of current and foreseen fuel management on the French fuel cycle facilities does not reveal major technical difficulty. It recommends that the industrials analyse more deeply the hazard impacts on the fuel cycle as well as the strategy definition for revamping or renewing the facilities.

In its stance, ASN asked for several actions linked to fuel management, interim storage capacity, hazard analysis and energetic mix evolutions impacts. On this last point, consequences of each energy policy plan (Programmation Pluriannuelle de l’Energie, “PPE” in French) in terms of safety and radiation protection must be analysed. It also recommends that at least a ten-year period be considered for the impact assessments of any strategic evolution of the fuel cycle so that thesae developments can be designed and implemented under appropriate conditions of safety and radiation protection.

Following the end of the 2016 exercise, the industrial stakeholders will meet ASN twice a year to follow the commitments taken and actions to perform. After a first meeting in February 2019, the industrials have started to work collectively on these analyses.

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1 Respecting the applicable measures regarding publication, especially for the purposes of conservation of safety and security and of secret of the business of the concerned industrialists, certain information considered as "sensitive" were not disclosed in the report.