French Radioactive Waste Management: a Sustainable Approach – 14507

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ABSTRACT

In France, EDF, operating 58 pressurised water reactors, AREVA, operating the fuel cycle facilities and Andra, managing the final waste repositories are three major players in the nuclear field. The French Atomic Energy Commission (CEA) is a major player as provider of technologies, processes and R&D in the field of waste management and is the owner and operator of nuclear facilities in France, including facilities which are in the D&D stage. The CEA is the majority shareholder of AREVA.

For the last 30 years, France has set up industrial and legislative tools, leading to an efficient radioactive waste management.The present paper deals with EDF, AREVA and Andra complementary skills covering conditioning, treatment, storage and final disposal.

The French radioactive waste regulatory framework for the management of radioactive waste and nuclear material is set by the French 2006 planning Act, in line with the European Directive. The law requires in particular the National Plan for the Management of Radioactive Waste and Material (PNGMDR).

The elaboration of the "PNGMDR" is led by the General Directorate for Energy and Climate (DGEC) / Ministry of Ecology, Sustainable Development and Energy – and the Nuclear Safety Authority (ASN), in the framework of a pluralistic working group including operators (notably EDF, AREVA and Andra), and NGOs. The document is updated every 3 years. Based on the national waste inventory, its purpose is to draw up a progress report on existing management measures of radioactive materials and waste, to make an inventory on foreseeable needs for storage and waste disposal, to indicate the necessary capacities for such installations and the duration of storage and, for the radioactive wastes for which a definitive management route does not yet exist, to determine the objectives to achieved. It establishes a strategic roadmap concerning all radioactive material and waste.

In respect with the protection of human health, safety and environment, the French strategy adopted for sustainable management of radioactive waste is as follows : limit the waste quantities and toxicity (at the generation stage or by recycling or by treatment); sort out the radioactive waste by nature and activity level in order to facilitate the treatment, conditioning and disposal ; package the radwaste as soon as it is generated ; limit the use of storage and send to disposal as soon as reasonably practicable.

Comprehensive and safe management routes are already in operation for the large majority of short-lived wastes generated both by power plants and fuel cycle facilities in service and

during decommissioning. They largely rely on the use of Andra's repositories and of the CENTRACO waste processing plant, operated by SOCODEI a subsidiary of EDF Group. Regarding the long-lived radioactive waste, the geological disposal centre is under development and will be available in 2025.

On an international level, the increased awareness of the general public and authorities of the issue of radioactive waste, combined with the dismantling of power plants, will lead certain countries to review the implementation of management solutions for their waste. Based on their know-how in France and other countries, EDF, AREVA and Andra are able to provide them with recognised technical expertise on waste management solutions.

INTRODUCTION

The reduction of the overall impact of radioactive waste has been one of the key drivers for the implementation of the French nuclear program. Interactions between the nuclear industry including EDF and AREVA, ANDRA, the administration, the competent authorities and other stakeholders including the civil society has led to a continuous evolution of the industrial facilities, practices, solutions and products to move towards waste minimization.

The outcome is the implementation of a consistent and complete scheme for the management of radioactive materials and waste, which allows tolink in an optimal manner EDF's nuclear power plants, AREVA fuel cycle facilities and ANDRA's repositories.

Used fuel recycling has been the cornerstone of the French nuclear program since its inception leading to structure the waste management according to three main streams:

- the ultimate waste stemming from the recycling of used fuel;
- the waste stemming from the plants operation;
- the waste stemming from the dismantling of facilities.

The solutions implemented for the management of these streams have been both contributing to and impacted by the French regulatory framework evolution.

40 YEARS OF REGULATORY FRAMEWORK CONSOLIDATION

Radioactive waste management began in France as early as 1969, with the creation of the first radioactive waste disposal in La Manche, near the La Hague recycling facility. In 1979, Andra, the French National Radioactive Waste Management Agency was created as part of CEA (the French Atomic Commission).

A first law was passed in 1991[1] for 15 years of research on High Level Waste. Based on the results achieved during this 15 year research period, a new Act was passed in 2006 [2] in order to define the industrial options for all radioactive waste generated in France, and especially for used fuels.

The 2006 Planning Act set up the framework:

- At the technical level, it gives a roadmap for the radioactive waste management in France

  - All the radioactive waste are recorded in the National Inventory, which gives a mapping of the wastes, with indication of their amounts, locations and radioactive characteristics.
  - The management of the radioactive waste is defined by a National Plan for radioactive materials and waste Management (PNGMDR) [3]. Its elaboration is led by the Ministry of Ecology, Sustainable Development and Energy, and by the Nuclear Safety Authority (ASN). It is prepared in the framework of a pluralistic working group including operators (notably EDF, AREVA and Andra), and NGOs. Based on the national waste inventory, its purpose is to draw up a progress report on existing management measures of radioactive materials and waste, to make an inventory on foreseeable needs for storage and waste disposal, to indicate the necessary capacities for such installations and the duration of storage and, for the radioactive wastes for which a definitive management route does not yet exist, to determine the objectives to achieved.

- At the industrial level
  - The reduction of the quantity and toxicity of radioactive waste shall be sought notably by processing used fuel and by processing and conditioning waste
  - Any radioactive material pending processing and any ultimate radioactive waste pending disposal shall be stored within especially designed and dedicated facilities
  - After storage, any ultimate radioactive waste unsuitable for disposal in surface or shallow facility due to concerns pertaining to nuclear safety shall be disposed of within a deep geological formation. The geological repository, subject to its license, would be commissioned in 2025
- At the financial level, it secures the funding of future radioactive waste management, with :
  - A tax on nuclear facilities to finance R&D on HLW management
  - The obligation to nuclear operators to dedicate assets for funding of long term management of their radioactive waste

Regarding the information given to the public, the 2006 Planning Act represents a key element for acceptance of radioactive waste management solutions and acceptance of nuclear energy : the National Plan and the National Inventory are made public every 3 years.

In France, there are 5 waste categories, classified according to their disposal solution. The classification is mainly based on the two following parameters: the level of radioactivity and the half-life resulting to the following categories : very-low-level waste (VLLW), low- and intermediate-level short-lived waste (LILW-SL), low-level long-lived waste (LLW-LL), intermediate-level long-lived waste (ILW-LL), high-level waste (HLW). Figure 1 gives an overview of the radioactive waste classification and the disposals (operating or under development) associated to each class of radioactive waste. Industrial repositories already exist in France providing definitive solutions for VLLW and LILW-SL. 90% of the total volume of radioactive waste generated each year in France is disposed of at actual facilities.

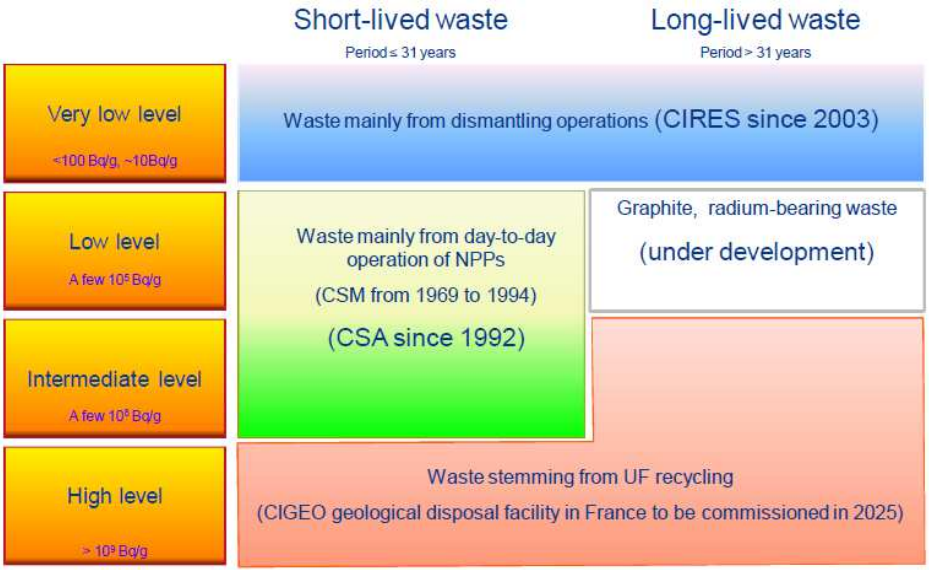

Figure 1 Overview of French radioactive waste classification

40 YEARS OF OPERATIONAL EXPERIENCE IN THE FIELD OF NUCLEAR MATERIALS & RADIOACTIVE WASTE MANAGEMENT

The French nuclear program boomed in the seventies with the commissioning of a first PWR in 1977 in Fessenheim, the commissioning of the first LWR recycling plant in 1976 (La Hague UP2-400) and the commissioning of a first repository, involving since the very beginning the three blocks of a sustainable waste management solution (Electricity generation – Fuel Cycle solutions – Waste disposal).

Since then, this program nourished from the implementation of complementary facilities, processes and practices evolution based on operational feedback and innovation, leading to the current nuclear framework.

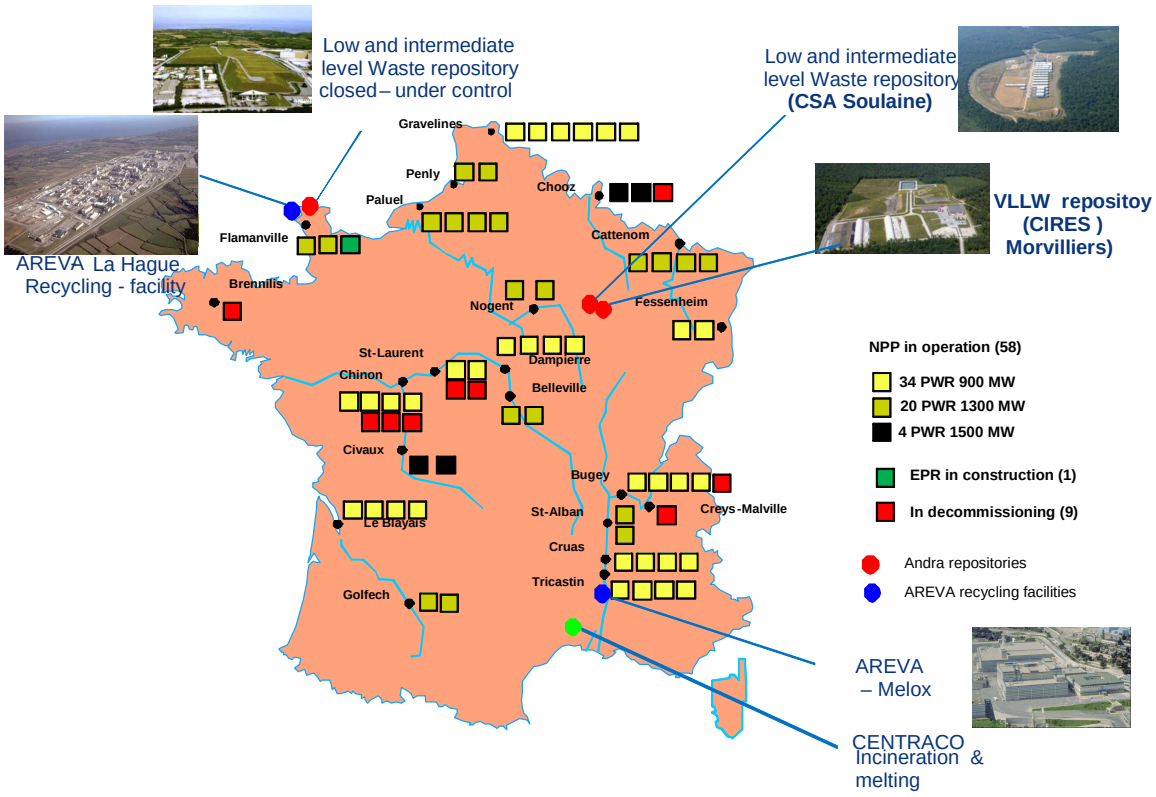

Figure 2 EDF, AREVA & ANDRA facilities in France

As illustrated in Figure 2, French nuclear facilities are as follows:

- EDF owns and operates 58 PWR NPP :
  - 34 PWR 900 MW
  - 20 PWR 1300 MW
  - 4 PWR 1500 MW
- EDF is currently building 1 EPR, under construction
- 9 NPP are under decommissioning by EDF
- EDF operates CENTRACO facilities for radioactive waste treatment
- AREVA's range of nuclear activities covers the entire fuel cycle from mining, extraction, conversion, enrichment, manufacture and recycling, to logistics and storage services. La Hague plant is dedicated to used fuel recycling and ultimate waste conditioning. AREVA operates recycled fuel fabrication plants including the MELOX plant (for MOX fabrication).
- AREVA is currently working on the dismantling of the first French recycling facilities (UP2-400 and UP1) and of the first French MOX fuel fabrication facility in Cadarache.
- ANDRA operates 3 repositories
  - 1 Low and Intermediate Level Waste repository closed – under monitoring in La Manche district, next to the La Hague AREVAs' processing plant
  - 1 Low and Intermediate Level Waste repository (CSA Soulaine)
  - 1 Low Level Waste repository (CIRES Morvilliers)

The solutions implemented by the French nuclear industry provide a comprehensive and funded solution for the waste generated by the existing fleet for its entire life, as illustrated on Figure 3.

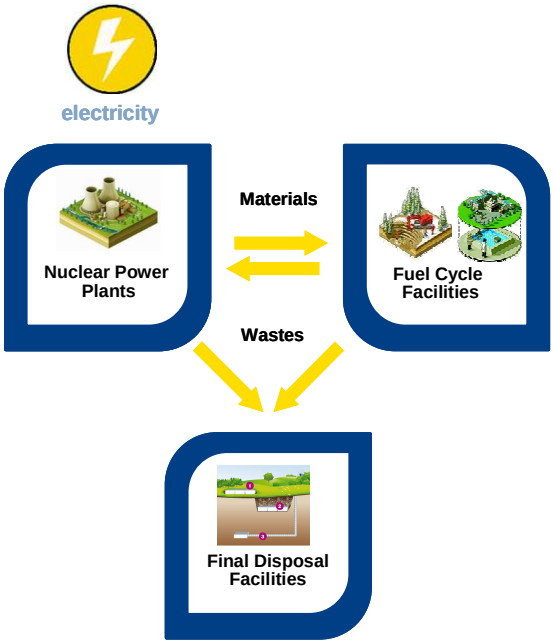

Figure 3 Nuclear materials & radioactive waste flows overview

NPP Materials and Waste management

Used fuel

As leading nuclear power plant operator in the world, EDF is also among the largest radioactive waste producers. The fleet of 58 pressurized water reactors in operation in France generates every year 1 200 tons of used nuclear fuel, from which 1 050 tons are reprocessed at AREVA's La Hague facility, giving rise to around 150 m^3 of high level waste (HLW) and 200 m^3 of intermediate level waste (ILW) per year. Recycling valuable materials (Pu and U) while minimizing the volume and long term radiotoxicity of the ultimate waste to be disposed of into the geological repository is at the heart of the overall management strategy.

Operational waste

The fleet also generates every year 10 000 to 15 000 m^3 of short-lived waste (technological, maintenance and process waste) stemming from NPPs'operation.

The strategy adopted by EDF for sustainable management of the related waste is as follows:

- To limit the waste quantities at the generation stage, by recycling or treatment ;
- To sort out the radioactive waste by nature and activity level in order to facilitate the treatment, conditioning and disposal ;
- To package the radioactive waste as soon as it is generated ;
- To limit the use of storage and send to disposal as soon as reasonably practicable.

The rationale for processing operational waste at the plants is illustrated on Figure 4.

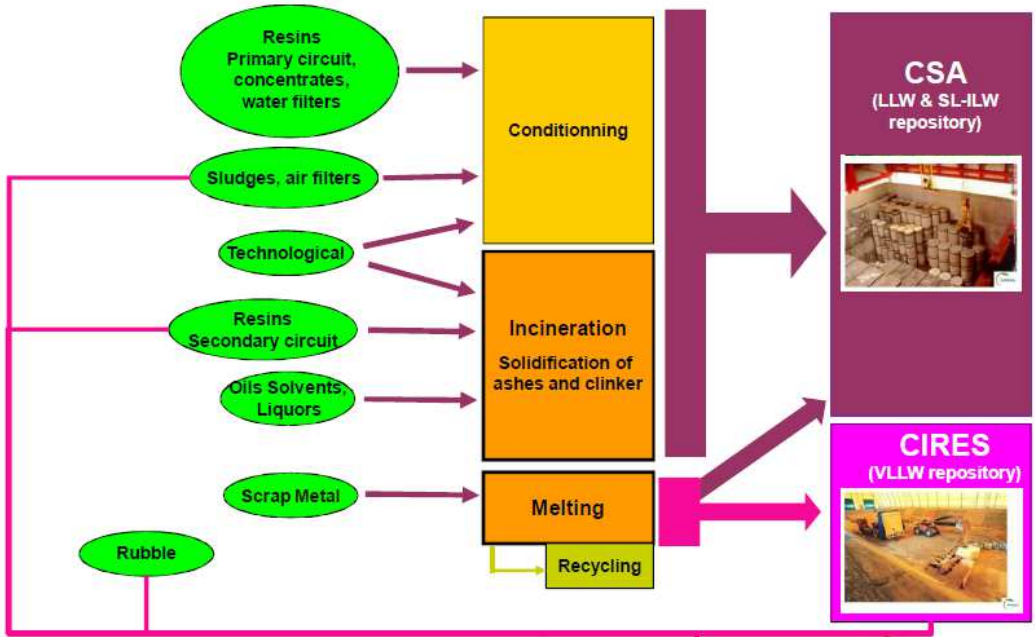

Figure 4 Radioactive waste overview

Waste treatment at CENTRACO

For waste volume reduction, a major development occurred with the commissioning in 1999 of the CENTRACO waste treatment facility, operated by SOCODEI, a 100% owned subsidiary of the EDF Group. This facility offers waste volume reduction services by incineration and metal melting: in the range from 5 to 20, and more than 90 % of its capacity is used to process EDF LLW. The CENTRACO incineration unit is designed to process short-lived LL radioactive combustible solid and liquid waste produced in nuclear installations (boots, clothing, wash-liquors). The CENTRACO melting unit has the capacity to melt and recycle scrap metal and metallic components produced in nuclear installations during routine operation, during process maintenance and during dismantling. The start-up of the CENTRACO facility also enabled the treatment of certain wastes which remained without a management route and which in certain cases were remaining in interim storage on the station sites (oil and solvents, various aqueous wastes, greasy waste)

The large majority of final waste is disposed of in the two ANDRA's surface repositories in the Aube district: the Soulaines repository for short lived LILW, commissioned in 1992, and the Morvilliers repository for VLLW commissioned in 2003.

Decommissioning waste

The decommissioning program of EDF comprises 9 shut-down reactors, planned through to the 2030s and that will generate a total amount of 180 000 tons of radioactive waste, mainly very low level waste (VLLW) and low level waste (LLW).

The role of EDF in radioactive waste management is clearly defined in the French law through the 2006 waste act, which was reinforced in 2011 with the Nuclear Waste European Directive[4]. These two legal texts clearly place the full and entire responsibility on the

industrial operators whose activities are the source of the wastes. Thus, EDF is responsible for the radioactive wastes it has generated, with no possibility to transfer the responsibility and with no limit in time: on the one hand, EDF is responsible for assuring or making sure that they are properly managed; on the other hand EDF has to secure the funding for the long term management of its wastes.

From the very outset of France's nuclear power program, EDF developed industrial-scale management of the radioactive waste produced by operation and maintenance of its 58 pressurized water reactors in service. This management process has constantly progressed thanks to feedback and experience and in line with changes in the regulations and available technologies.

Fuel cycle facilities Material and Waste management

Recycling facilities: minimizing the overall environmental footprint through used fuel recycling

40 years of improvements in waste management rules, principles and processes at La Hague plant has led to impressive reduction of the waste volumes as synthesized in Figure 5.

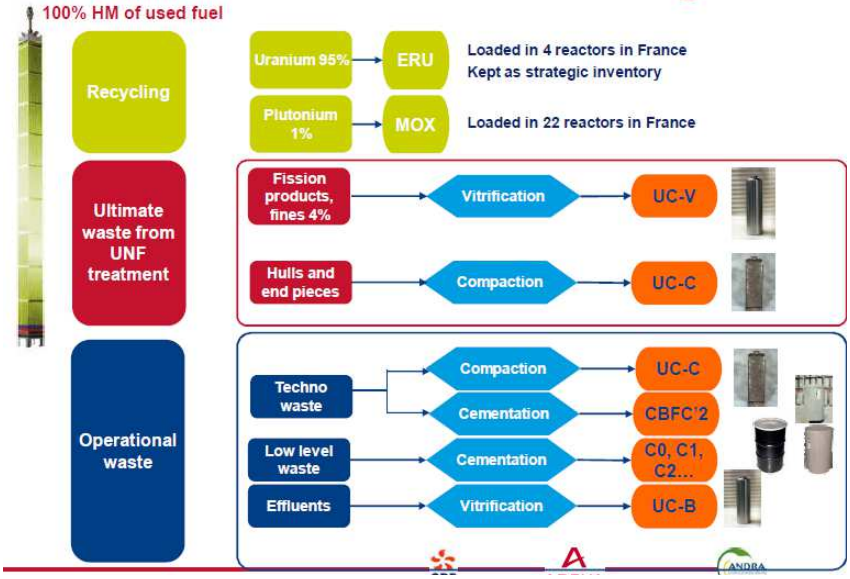

Figure 5 Reference main streams at La Hague

AREVA has implemented recycling capabilities associated with an optimized ultimate waste management with the so-called "Universal Canister" (UC) Strategy (Figure 6). This strategy based on recycling and waste conditioning standardization by using a single type of package for long lived waste, leads to important savings in terms of volume (up to 5 compared to direct disposal) and long term radiotoxicity (up to 10 compared to direct disposal). This ultimate waste consists mainly in fission products and minor actinides traces, as well as structural assembly parts. The fission products are incorporated into a stable borosilicate glass matrix and conditioned in the UC-V (Universal Canister for Vitrified waste) ensuring stability and containment during a very long period (over than 100 000 years). The structural assembly parts - hulls and end pieces – are compacted and conditioned in UC-C (Universal Canister for Compacted waste).. One of the challenges is to further reduce the ratio UC/tHM taken into account the used fuel evolution including the increase in Burn-up.

The UC strategy provides the ability to rationalize the global waste management from

reception and storage of waste to final disposal. On-site handling, transport operations, and geological disposal selection, design and construction are indeed facilitated thanks to the uniqueness of packaging with smaller volumes and reduced thermal constraints. The resulting costs are therefore lowered.

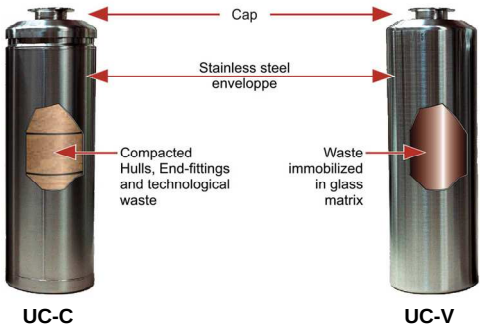

Figure 6 Universal canister

The UC strategy complements the recycling strategy in an economically sound way. Solving the waste issue has become the prime contributor to nuclear program sustainability: recycling with practical and already visible steps in the minimization of the nuclear legacy to the future generations through the UC strategy contributes to making the final waste issue solvable.

In the French case, the geological repository should have a footprint of around 15 km² taking into account that the whole used fuel inventory would be recycled. The shift in the policy from recycling to direct disposal would lead to a significant increase in the volume of HLW to be disposed of (90 000 m^3 instead of 10 000 m^3) and thus to a significant increase in the repository footprint (25 km2).

Recycling facilities: operational waste

The La Hague recycling plant operation leads also to the generation of waste including :

- solid wastes mainly consisting of gloves, work clothes, toolings, and parts originating from operation and routine maintenance in La Hague workshops

Depending on their nature and activity, they are intended either to the existing surface repositories (VLLW and LILW-SL) or the upcoming Cigéo repository for HL –ILLL waste.

For these wastes, the general approach based first on the reduction at the source consists in the optimization of the waste conditioning, at every step, from their generation to their disposal in existing or future repositories. This approach may include the conditioning in primary packaging following specific treatment including incineration (e.g. for gloves), melting (e.g. scrap metal), bitumization (e.g. for radioactive sludge), cementation (e.g. for solid waste), compaction (e.g. for technological waste) and vitrification ; the trend is towards the replacement of some of the above mentioned processes (for example bitumization) by more efficient ones.

Along with used fuel recycling, AREVA's range of nuclear activities covers the entire fuel cycle from mining, extraction, conversion, enrichment, manufacture and recycling, to logistics and storage services. The development of all these activities has been also anchored in a policy for the systematic reduction of volumes and harmfulness of the waste based upon the following general principles:

- preventing and reducing the volume and harmfulness of the waste at the source,
- implementing treatment solutions with the emphasis on reuse, recycling, elimination,
- organizing shipments in a way that minimizes waste volumes and distances shipped,
- implement waste management that does not cause harm to the environment or to public health,
- informing the public of the potential environmental impacts or health effects from waste production and management.

Recycling facilities: decommissioning waste

AREVA is currently working on the dismantling of the first French recycling facilities (UP2-400 and UP1) and of the first French MOX fuel fabrication facility in Cadarache

The first industrial recycling plant at AREVA's La Hague site, UP2 400, was shut down at the end of 2003. The dismantling operations include the clean-up of all facilities, and also the conditioning of waste, as suitable procedures were not available at the time.

This extremely large worksite, begun in 2009, should be operational for 25 years.

The dismantling of the UP1 recycling plant located at the Marcoule site started ten years ago the worksite should still last for another ten years.

A number of remotely controlled, chemical decontamination and cutting techniques were developed for this worksite. A specialist facility also enables onsite waste processing and conditioning (rubble, scrap metal, bitumen drums, etc). This reclamation project constitutes a world first for a nuclear site of this size.

Safe storage awaiting final disposal

Transition

Pending the commissioning of Cigéo, existing HLW and ILW-LL packages are already dry stored in dedicated buildings at their production site, mainly in La Hague (Manche).

Storages such as the “EEVLH”, designed for a 100 year lifetime, and commissioned in 2013 at the La Hague site (Figure 7) are therefore only blocks of a comprehensive solution for managing radioactive waste from nuclear power generation, Cigéo being the last one.

Figure 7 EEVLH facility for HLW storage

The concept used for these facilities is modular and allows toexpand gradually the overall capacity. An industrial waste management program developed jointly between Andra and operators was launched in order to plan and implement coherent industrial resources, in particular storage capacity, pending the availability of the Cigéo project, It describes the waste

inventory to be stored and then to be disposed of and defines the scheduling and forecast flows of waste packages deliveries.

DISPOSAL FACILITIES

Short lives waste: operational routes

The Manche disposal facility (CSM) is France's first disposal facility. From 1969 to 1994 it received 527,225 m^3 of low and intermediate level radioactive waste. It is currently in the monitoring phase, which will last several centuries.

The very low level waste disposal facility (CIRES) is mainly dedicated to disposal of wastes from dismantling operations. Ithas a capacity of 650,000 m3 and has been receiving very low level waste since 2003. After its final closure, expected during the 2020s,it will be monitored during a first 30 year period, which could be renewed. The CIRES as well hosts temporary storage capacities for some long lived waste from non-electronuclear activities, and waiting for a disposal solution.

The low and intermediate level waste disposal facility (CSA), in Soulaines, has a 95-hectare footprint and a capacity of 1.000.000 m3. It is dedicated to low- and intermediate-level short-lived waste. Commissioned in 1992, it took over from the Manche disposal facility, thus taking stock of the experience already acquired. After 60 years operation the facility will be monitored during about 300 years. The CSA, by design can accommodate any type and size of waste, including for example NPPs vessel heads.

High and intermediate long lived waste: the Cigéo Geological Disposal facility

High-level activity (HL) waste and intermediate-level long-lived (IL/LL) waste, both originating from electronuclear production, will be disposed of in a geological repository, as requested by law, and as internationally recognized as the reference option.

The geological repository for HL and IL/LL waste, otherwise known as the Industrial Centre for Geological Disposal (Cigéo) (Figure 8) will include surface installations connected to the underground installations designed for waste disposal.

Surface installations will be spread over two sites. The first, with a footprint of the order of 20 ha, will be located directly above the underground installations. It will include the required industrial workshops (1a) for the construction of the repository, administrative buildings and a specific stockpile area for the muck removed during the gradual excavation of the facility. A second site, located a few kilometers away with a footprint of 100 extra hectares, will include mostly the nuclear installations (1b) where radioactive waste packages will be controlled and conditioned in containers, if required, before being transferred to the underground installations. The second site will also integrate a specific stockpile area for the muck resulting from the opening of the incline.

Connecting infrastructures (2) will ensure transfers between surface and underground installations, notably for conveying staff, transferring disposal containers and worksite machinery, as well as ventilating underground installations.

Underground installations (3) will be progressively added as the operation progresses until they reach a total maximum area of about 15 km2, after about 120 years. Located at a depth of approximately 500m, those installations will consist of specific disposal areas for the different waste categories, as well as connecting drifts and technical installations.

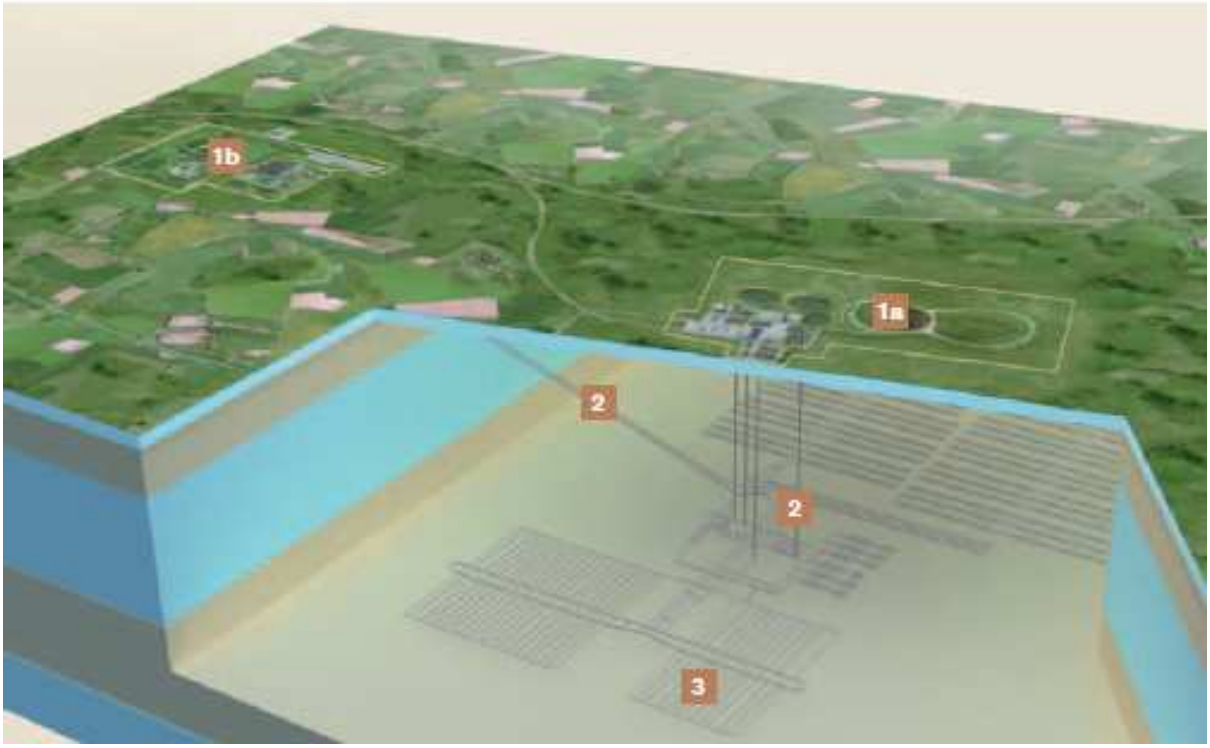

Figure 8 Cigéo project

According to the 2006 Planning Act, the Cigéo geological repository must be commissioned by 2025. After its license has been granted, construction works will begin before 2020.

CONCLUSION

Continuous improvements in NPP design, fuel management and NPP operation have helped to divide the amount of short-lived waste by a factor of 4 over the past 25 years.

Global approach for waste management, based on the complementary skills and know-how, lead us to implement, complete and safe management routes from generation to disposal for the large majority of short-lived waste generated both by power plants in service and during decommissioning, representing 90 % in volume of all the radioactive waste generated by EDF nuclear stations.

Disposals are under development for long lived radioactive waste.

The solutions implemented by the French nuclear industry provide a comprehensive and funded solution for the waste generated by the existing fleet for its entire life as illustrated on Picture 3.

EDF, as a nuclear power plants operator, AREVA, as an operator of the entire nuclear fuel cycle and in particular, as operator of the used fuel recycling plants and Andra, as the national nuclear waste agency have **complementary skills** and **know-how** and are thus able to provide any utility and nuclear operator with **recognized and proven technical expertise on waste management solutions.**

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