NATIONAL ASSESSMENT BOARD

FOR RESEARCH AND THE STUDIES INTO THE MANAGEMENT OF RADIOACTIVE WASTE AND MATERIALS

Instituted by the Law n°2006-739 of June 28, 2006

ASSESSMENT REPORT N° 13

June 2019

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SUMMARY – CONCLUSION

The Law of 2006 provides that radioactive waste management involves industrial interim storage, disposal in geological repositories and the separation-transmutation of long-lived radioactive elements. This report assesses the state of progress of studies and research on these topics and reviews the approach to these issues in different countries with a nuclear power industry.

CIGÉO GEOLOGICAL REPOSITORY

The purpose of the Cigéo project is the design, construction and operation of a reversible geological repository for long-lived high- and intermediate-level radioactive waste (LLHLW and LLILW). It is intended that this repository will be created at a depth of 500 m in the approximately 130 m thick Callovo-Oxfordian (COx) argillite layer in Meuse-Haute Marne. In contrast to interim storage, which is inherently temporary, a repository built on solid scientific and technical principles is a long-term solution because it relies on stable properties found in nature.

The Board believes that the knowledge base acquired by Andra and its partners is robust, and favourably assesses the company's efforts in reporting and critical analysis. Cigéo's construction license application (DAC) could therefore be submitted in 2020. The Board draws attention to the extreme complexity of administrative procedures prior to the construction and commissioning of Cigéo. It recommends exploring means that allow them to be appraised together.

The Board notes that the governance principles for Cigéo are gradually being implemented thanks to the tool constituting the implementation master plan (PDE), developed under the law on reversibility. It also notes that Andra is responsible for the Cigéo project. Consequently, Andra will propose the PDE to the Government, while taking into account the advice it has received. It is therefore a matter of urgency to define how and by whom this advice will be presented to Andra for the preparation, execution and updating of the PDE. In 2017, the Board suggested that a specific body be created for this purpose. Each year, the Board will organise a hearing on the PDE.

The construction and operation of Cigéo will involve huge changes within Andra and the local industrial network. The Board recommends that these changes should ideally include all actors involved. Andra's new skills, as project owner, will have to be deployed as close as possible to the site. Andra will have to fully assume its rights and responsibilities, particularly with regard to its prime contractors and all subcontractors, and ensure the traceability and conservation of its decisions and achievements.

SEPARATION AND TRANSMUTATION

The Law of 2006 stipulates that transmutation research should be carried out within the framework of research on Generation IV reactors. The strategic approaches set out by the Multi-Annual Energy Plan (PPE) considerably push back the deployment of FNRs and aim to reduce the percentage of nuclear-generated electricity in the energy mix to 50% by 2035. This will result in the closure of a number of 900-MWe reactors before their 5^{th} ten-year inspection and will have consequences for recycling policies for reprocessed uranium (RepU) and plutonium (Pu).

As the PPE provides for continued reprocessing of spent UOx fuel, new interim storage facilities will soon be required if RepU recycling is not implemented quickly. In addition, there are now twenty-four 900-MWe reactors able to mono-recycle plutonium into MOx fuel. The closure of many of these would call into question this practice. EDF is preparing applications for a license to MOx or supply RepU to a few 1300-MWe reactors in order to continue the mono-recycling of uranium and plutonium from the reprocessing of spent UOx fuel.

The lack of FNRs to consume plutonium leads to an increase in the amount of spent MOx and, to avoid the construction of new interim storage, the PPE calls for the multi-recycling of uranium and plutonium in PWRs. This would make it necessary to deploy a fleet of second-generation EPRs and create facilities for manufacturing and reprocessing a new MOx fuel. The inventory of high-level waste would also increase more quickly. The Board questions the basis of such a strategy with regard to the management of radioactive materials and waste. Presented as a first step in controlling an FNR fuel cycle, this strategy would require significant specific investments while postponing prospects of transmutation in 4th generation reactors for a long time. The analysis of the consequences on the management of radioactive materials and waste shows that the PPE deviate significantly from the objectives of the Law of 2006.

Given the value that the transmutation of americium would have for future waste management, the Board recommends that studies be carried out within the scope of international collaborations to make up for the lack of irradiation tools in France and meet the requirements of the Law of 2006.

FUNDAMENTAL RESEARCH SUPPORTING APPLIED RESEARCH

The Astrid programme has facilitated considerable advances in all scientific and technological fields dedicated to the fourth generation, with benefits for the systems using the previous generations. The Board notes that ending the Astrid project will result in France losing its leading position, while the competitors, such as Russia and China, continue to invest in FNRs.

A new type of reactor is being discussed with the development of a preliminary draft of a low-power modular reactor (SMR). It would have passive safety and could be built by assembling prefabricated modules at the factory. The Board will follow the development of this option, that has recently appeared in the PPE, with regard to the management of radioactive materials and waste.

The Board proposes that a new R&D programme should be built, based on robust fundamental research, to meet the many challenges related to the evolution of the emerging nuclear power policy. This programme should bring together the entire scientific and technological community in a large-scale action and should attract a new generation of talent.

Regardless of the developments in the nuclear power industry, the maintenance of appropriate training programmes remains essential in ensuring the transmission of thorough knowledge of nuclear sciences and technologies. Only by maintaining skills can we guarantee safe management of the nuclear programme, associated facilities, their decommissioning at the end of their life-time and of the waste produced.

WASTE MANAGEMENT

The Board believes that low-level waste management has been well covered by the studies requested by the successive national plans (PNGMDR). Their findings provide the elements necessary to change the management of very low-level waste and prepare that of long-lived low-level waste. Nevertheless, the Board regrets that no effective solution has been identified and stresses the importance of quickly defining and securing the best options, taking into account an industrial and regulatory logic.

INTERNATIONAL PANORAMA

Geological disposal of long-lived high-level waste is the reference solution for all countries with a nuclear power industry. The different countries are not all progressing at the same rate. At present, only Finland is building a spent fuel repository.

In all the countries, there are two levels of decision-making: first, the definition of a process, selecting a site, and the preparation of a DAC; then successively, acceptance of the application, license to build, operate, and in the future close the repository.

The Board notes that each step should be achieved through a transparent and inclusive process. This will also involve any local authorities and citizens concerned (locally and nationally), safety and environmental authorities, and scientific bodies. This process of dialogue ensures a critical analysis of the concepts and technologies proposed and is a part of the evaluation. The preparations for a decision to be made by the authorities are based on this process and on expert evaluation.

The Board highlights that the decision-making processes are often very long and that it requires constant effort to avoid stagnation of the project, which could result in the burden of the waste being passed on to future generations.

INTRODUCTION

In 1991, in a first law in France on the management of radioactive waste, Parliament, conscious of the specific character and novelty of the problems posed, entrusted a 15-year assessment of the state of progress of research in this field to a National Assessment Board (CNE) made up of twelve independent and voluntary individuals. Under this law, the CNE assessments give rise to an annual report to Parliament, submitted to the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST). This first Board (CNE 1) generated a total of 13 reports between 1991 and 2006.

In June 2006, a second law on the management of radioactive materials and waste confirmed the existence and role of the Board, which became the current CNE 2, and this document constitutes its 13th report to Parliament.

The Board evaluates current research and makes recommendations to assist decision-making by public authorities.

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This year, the Board (see Appendix I) held 11 one-day hearings, generally bringing together around sixty people representing all the actors in the sector. It also held 7 closed hearings and made several visits (see Appendices I to V). For this 13th report, it has taken account of documents submitted up to 1 May 2019 (see Appendix VI).

As in previous years, the Board has devoted a large part of its work to the analysis and evaluation of research and studies on the Cigéo project being conducted by the National Radioactive Waste Management Agency (Andra). Application of the Law of 2006 expressly provides that long-lived high-level and intermediate-level waste should be stored in "deep geological repositories". Andra is thus currently preparing the construction license application (DAC) for an underground repository at a depth of 500 m in a clay formation that is more than 100 m thick and is located at the border of the Meuse and Haute Marne.

The Laws of 1991 and 2006 also recommend that research be conducted on the separation and then transmutation of long-lived radioactive elements present in the waste in order to reduce long-term radiotoxicity. This report makes an initial assessment of the innovative results obtained from the Astrid fast neutron reactor (FNR) project, which was supervised by the CEA. The Board has noted that the CEA cannot carry out this project as it was defined in 2010. For the future, it is planning a technological monitoring programme dedicated to the fourth generation and research into separation and transmutation as part of international collaborations.

The Board also assesses the management of all radioactive waste, regardless of its level of activity. The decommissioning of many nuclear facilities could produce large quantities of low and very low radioactivity waste in France. Its long-term management must be planned

In all countries confronted with the problem of managing waste downstream of the nuclear power cycle, the deep geological repository is considered the reference solution for long-lived high-level and intermediate-level waste, as pointed out in the 2014 OPECST report. The Board has benefited from input from its foreign members to provide a review of progress in studies and research carried out in the main nuclear countries for the disposal of this waste.

CHAPTER I: CIGÉO

The purpose of the Cigéo project, by application of the Law of June 2006, is to design and build a reversible geological repository for long-lived high-level and intermediate-level radioactive waste (LLHLW and LLILW) as part of the French industrial waste management programme (PIGD). This repository should be created at a depth of 500 m in the 130 m-thick Callovo-Oxfordian (COx) argillite formation in Meuse - Haute-Marne. This project is the result of studies and research carried out over a period of more than twenty years, especially in the underground laboratory at Bure, which demonstrated the excellent capacity of the COx formation to isolate the waste and then sustainably confine the radionuclides it contains.

At present, the Board believes that the knowledge base acquired by Andra is robust, due to very large scientific and technical effort that has borne fruit. In particular, it appreciates the efforts currently being made to summarise and carry out critical analyses.

The site's suitability as a geological barrier has been demonstrated and repository design options have been established. The elements required for the Cigéo regulatory process to proceed will be gathered for the DAC. There is still potential for progress and the deepening of some knowledge will make developments possible, thanks to the principle of reversibility. The industrial pilot phase (Phipil) will provide the opportunity to progress in this direction.

Assisted by the system project manager, namely the Gaiya group (Technip-Ingérop), Andra, as prime contractor, carried out the initial preliminary design of Cigéo up until June 2015. After a project review commissioned by the Directorate-General for Energy and Climate (DGEC), the project entered the detailed preliminary design phase, which will close with the submission of the construction license application (DAC). To prepare for filing of the DAC, Andra has developed a safety options dossier (DOS) which gave rise to various analyses, in particular by the Board and the ASN. Andra is currently working to integrate different opinions in its detailed preliminary design with the aim of filing the DAC in 2020.

This chapter details the scientific and technical advances presented by Andra this year.

1.1 FROM CIGÉO'S DESIGN TO ITS REALISATION

1.1.1 Important milestones – the declaration of public utility (DUP) and the construction license application (DAC)

As with all industrial projects, the Cigéo project is subject to a series of regulatory procedures with the aim of allowing public authorities to manage the realisation of the project and to control its impact. These procedures result in three different types of administrative authorisations being issued:

- statements of general interest intended to manage the effects on private interests including expropriations;
- construction permits regulating the modifications made by the works on the project's urban environment or landscape;
- operating permits regulating potential environmental damage during the life of the project.

These authorisations are granted on condition of three main principles:

- that the issuance of one license does not prejudge the issuance of the others;
- that the environmental assessment is comprehensive for all license applications;
- that the environmental assessment, while remaining global, must be progressively updated in sequence with the license applications.

In the case of Cigéo, the regulatory procedure will start with a public enquiry, which should result in the declaration of public unity (DUP). The DUP is a prerequisite to ensure Cigéo is valued at the national level and to provide the necessary regulatory framework for the advancement of the project. It will facilitate the land management by providing the justification for the necessary expropriations. It will play an initiating role in obtaining authorisation for operations that may be carried out before obtaining the construction license decree. These operations notably affect preliminary works such as new drilling, preventive archaeology and networks development (electricity, water, railway lines).

The Cigéo DUP will be based on a global impact study. It will focus on operations connected to the construction of the repository carried out under the management of Andra, as well as operations connected to infrastructure not under the management of Andra.

A preparatory version of the file was established at the end of 2018 and is currently being reviewed both internally and externally before it is finalised in the second quarter of 2019. Andra plans to submit the file after the public debate on the National Plan for the Management of Radioactive Waste and Materials (PNGMDR) held in April 2019, directed by the National Commission for Public Debate (CNDP). During the DUP review process Andra will submit applications for preliminary work permits, for which a commitment is expected in 2020 after the DUP has been obtained.

Construction permit applications (building permit, renovation permit) and the construction license application (DAC) for the Cigéo as an INB (basic nuclear facility) will be subject to obtaining the DUP. Since the issuance of one license does not prejudge the issuance of the following licenses, Andra plans to first submit the DAC, and then proceed with the various applications for building permits during the review process of the DAC. Each of these applications will also be subject to public inquiries during the review process by State services.

The DAC will make up an essential element of the procedure, as it must lead to the project’s construction license decree. The documents to be submitted for the DAC are governed by a regulatory framework (Decree 2007-1557) currently being developed and which will take into account the specificities of Cigéo. The file will therefore include the documents relating to any future INBs and alongside any additional documents.

Decree 2007-1557 requires thirteen documents for an INB. The main documents are as follows:

- the preliminary safety report covering the operational and post-closure phases;
- the operational and post-operational risk assessment study;
- the master plan for the operation of Cigéo;
- the decommissioning, closure and monitoring plan;
- the impact study.

According to the stipulations of Article13 of Decree 2007-1557, these documents are to be submitted to public enquiry, with the exception of the preliminary safety report.

Cigéo has specific features that differ from a standard INB. The reversibility law dictates a significant development of the decree.

To address this, the DAC file will have to cover:

- the progress of the construction of Cigéo involving construction stage sequencing;
- the adaptability of the design to incorporate potential technological advances and possible changes in the reference inventory;
- the flexibility of the operation to adapt to different rates of disposal and closure of the project;
- the capacity to recover packages that have already been stored.

Additional documents will include preliminary specifications for package acceptance, the development plan for the disposal facility, and documents detailing modifications made to options that have already received an opinion from the relevant authorities.

These different regulatory documents will be supported by technical documentation useful for the review process, entering into three categories:

- the scientific and technological programming of the development plan for the disposal facility;
- the files justifying the design options supporting the preliminary safety report;
- the scientific and technological knowledge base justifying knowledge of the site and the packages to support the design and the demonstration of safety.

The construction license application (DAC) should be consolidated by the end of 2019 and submitted in 2020. A public enquiry of the DAC is then expected to take place in 2022.

Finally, it should be noted that each construction and renovation on the site (surface buildings, etc.), or off site (electrical connection, water supply, road deviations, railway line reinforcement, etc.) shall be subject to various permit applications depending on the public utility declarations.

The Board draws attention to the extreme complexity of the administrative procedure prior to the construction and implementation of Cigéo.

A backlog in obtaining the permits required and the associated procedures is likely to lead to significant delays in the realisation of the disposal facility. An excessive delay could lead to a loss of momentum for project actors and even to a gradual loss of skills.

The Board recommends exploring means that would allow diverse procedures to be coordinated and appraised together.

1.1.2 Progress made towards submitting the DAC

Recent advances in the configuration of Cigéo have been made in order to respond to the opinions expressed during the DOS review process.

The review of the DOS by the ASN/IRSN and its analysis by the Board have led to the submission of requests by the evaluators and to commitments from Andra, including the following three points:

- the justification of the favourable properties of COx from the point of view of the geometric characteristics of the constituents of the repository and the thermo-hydro-mechanical (THM) behaviour of the rock;
- the justification for the design choices that have an impact on the architectural layout of the repository;
- the justification of the technological feasibility of repository components (HLW and LLILW cells).

The Board has analysed the responses and commitments of Andra. Details of this analysis are provided in chapter 1 of Appendix VII. The resulting recommendations are listed below.

Andra has demonstrated the technical feasibility of a 112-m long HLW cell following three-step sequencing: excavating the bare hole, putting in place a lining consisting of an assembly of semi-rigid steel elements and then filling the annular space with a cement-type material.

The Board notes that Andra currently has a robust design for the construction of HLW cells. For the DAC, Andra must now demonstrate that the technology developed is capable of realising 150 m long cells, as planned for the HLW1/2 areas in the reference configuration.

With regard to the production of LLILW shafts and cells, the Board considers that Andra has a body of scientific and technical knowledge that is large enough to enable it to size the structures according to the operating life requirements of the repository. It requests to be shown that the technological choices to be made for the DAC based on the models will result in integrated solutions in terms of the thermo-hydro-mechanical behaviour of the structures and the rock mass.

In addition, it recommends that efforts be continued to characterise the hydro-mechanical properties of the damaged zone in the silt-carbonate unit because it is in this unit that the seals of the surface-underground connections will be made.

1.2 HYDROGEN MANAGEMENT

In the past, Andra and its scientific advisors have drawn attention to the ATEX (explosive atmosphere) risk resulting from the release of hydrogen by some components present in Cigéo during its operation and after its closure.

Andra has characterised potential sources of hydrogen and proposed design options or specifications aiming to manage the ATEX risk. In terms of operational risk, studies have focused on:

- equipment such as batteries being charged, which are managed following the standard provisions in the industry;
- the design and methods of using LLILW cells and the definition of acceptable characteristics for any packages emitting hydrogen by radiolysis that will be stored there;

- the design of a device for monitoring and inerting the atmosphere inside the HLW cells after their closure when hydrogen generation by anoxic corrosion of the steel is likely to occur.

A description of the different devices designed by Andra is provided in chapter 2 of Appendix VII.

The Board believes that Andra has successfully demonstrated that it can control the ATEX risk for the LLILW areas. The mitigation method is based on evacuating the hydrogen, which keeps concentrations outside of the risk zone, with wide margins for redundant devices and safety. In addition, Andra has shown that if the ATEX zone were reached, the blast would not have an impact on the structure of the containers, allowing them to be handled. It notes that Andra demonstrated in its 2009 file the absence of impact of a blast on the civil engineering of the facilities and on the rock.

As for HLW cells, the Board is closely following the ongoing research into the design developments for hydrogen risk control in the operational phase. Andra has proposed a new design based on active monitoring and renewal of cell atmospheres.

However, the Board draws attention to the complexity of the device envisioned. It recommends properly identifying whether or not a possible increase in ATEX safety would impair the other functions required in the cell.

Taking into account the active devices' risk of failure, particularly when they are deployed on a large scale, the Board recommends focusing efforts on passive devices and on demonstrating their efficiency. Given that the ATEX risk is particularly present during an eventual reopening of a cell, the Board invites Andra to reflect on the methods and techniques that should be put in place in the event of this operation being necessary.

The estimate of source terms after operation throughout the whole of the repository forms the basis for the hydrogen management. It is based on the compatibility of the source terms (types of packages) and knowledge of correctly identified process (anoxic corrosion and radiolysis). The source terms may then be transformed into hydrogen production logs in order to feed hydrogen transfer simulations.

The THM calculations therefore include the hydrogen production depending on the age of the packages and the progress of the resaturation phases. The calculations may quantify the different flows surrounding the disposal. They show that diffusion to the COx is the main means of hydrogen migration. In addition, the impact of hydrogen production on the pressures and constraints is quantified. It is taken into account in the calculations to size the structure.

The calculations being made aim to reduce uncertainties. On the one hand, they come from the design choices to be finalised (in particular steel mass and developed surface), on the other hand, they come from the quantification of chemical processes: corrosion kinetics for the production of hydrogen; chemical reactions with the COx for its consumption.

The Board confirms that Andra has an effective modelling tool to predict the consequences of hydrogen release on the thermo-hydro-mechanical behaviour in the repository after its closure. It recommends that Andra properly identifies the uncertainties associated with these simulations and analyses the residual risk linked to these uncertainties.

1.3 THE CASE OF BITUMEN WASTE

The Board has repeatedly warned of the potential difficulties for the geological disposal of packages coated in bitumen sludge. Noting in its November 2012 report no. 6 that the knowledge available did not make it possible to make a definitive statement on the behaviour in the event of a fire involving the bituminized packages in disposal, it recommended not planning to use them for the first phase of the disposal operation. It required a full-scale demonstration by December 2014, together with a safety analysis of the disposal behaviour of the primary package and its container. The producers and Andra have gradually provided elements in response to this issue, in particular on the external fire resistance of repository packages containing bitumen waste. In 2018, ASN/IRSN analyses highlighted the risk of fire linked to exothermic reactions that may occur when temperatures of certain bitumen packages increase, which may in fact lead to a thermal runaway and therefore a fire inside the repository package. Therefore, it was recommended that industrial solutions for the neutralisation of the reactivity of bitumen-coated packages be studied or that design options for their disposal that would preclude any risk of fire spreading be considered. The Permanent Waste Group (Group of experts on waste appointed by the French safety authority) reiterated these recommendations in its May 2017 statement.

The current approach followed by Andra and the producers is to examine both types of questioning. Therefore, two pathways have been defined: a first involving a feasibility study of the neutralisation, and a second focusing on developing the design of Cigéo to allow receipt of bitumen waste packages in their current state in LLILW cells. Any processing of the packages will engender releases and the production of new types of radioactive waste to be conditioned and stored.

The Board highlighted issues about bitumen waste as early as 1997, and did so again in 2012. In its 2018 report, it recommended an international commission be created to examine the issues more closely. This recommendation was followed through, and an international review team has been in place since summer 2018 at the request of the government. Its work is actively ongoing and the conclusions are expected by summer 2019. The Board will be called by the OPECST to give an opinion on the report that will conclude the review. For this purpose, it has been attending the review team's meetings as an observer.

1.4 DISPOSAL OF SPENT FUEL

Spent fuel is part of the Cigéo reserve inventory. It is classified as a nuclear material and not as waste. This situation is likely to be changed as the Multi-Annual Energy Plan (PPE) evolves. The Management has recommended carrying out research into the disposal of spent fuel.

Spent fuel assemblies that have left the pools adjoining the French reactors are stored in large pools at the La Hague site for at least 5 years while waiting to be reprocessed. There are currently 7,500 tonnes of spent fuel (UOx and MOx) stored, 7,000 of which belong to EDF. The Cigéo research, design and file preparation efforts, in particular as regards the DAC, are a priority for the reference inventory. Nonetheless, EDF has already started work on the evolution of spent fuel in disposal, in partnership with CEA and Andra. The work carried out is based on several points:

- the behaviour of spent fuel (UOx and MOx) in disposal conditions: this involves determining the source term as well as possible, namely the nature and quantity of radionuclides released by the fuel assemblies as a function of time and disposal conditions. Two mechanisms are being studied: the instantaneous release fraction (IRF) and then the release by leaching of the irradiated oxide matrix. Experiments and simulations still need to be carried out to better quantify these mechanisms in the context of the Cigéo repository.
- the thermo-hydro-mechanical (THM) design of Cigéo: the calculations performed show that a disposal configuration can be found for which the maximum temperature in the COx remains below the criterion of 90°C and also that the mechanical criterion guaranteeing the absence of hydraulic fracturing of the rock is respected. The THM criterion would therefore be verified.
- the impact on the long-term safety of Cigéo: a model is being created to simulate the release and transport of radionuclides from spent fuel within the repository structure and in the COx.

The conclusions of these studies and research are not required for the DAC as the spent fuel is listed in the reserve inventory. On the other hand, Andra has ensured that the design of Cigéo is compatible with the handling of spent fuel containers in its infrastructure, in accordance with the concept of adaptability that characterises the design of the structure.

The Board recommends that studies into the possibility of disposing of spent UOx and MOx fuel in Cigéo are carried forward.

1.5 DOCUMENT DATABASE

Andra has integrated its information management in a centralised approach integrating a digital model and a data manager – the Building Information Model (BIM).

The database aims to gather all the information relating to the project. The data, which are heterogeneous in nature, relate to environment recognition data, the monitoring of all the sensors that are implanted there, the sizing calculations, the traceability of the identified safety criteria, and also the design plans and the realisation progress. Therefore, it relies on a structuring of formats and on interoperable software. This interoperability is essential to be able to automatically update the entire chain when data is modified or newly introduced.

This database is based on a principle of collaborative work: all project stakeholders must be able to question the parts that concern them and add to the database with their contributions (data production or realisation progress). This collaborative work must be monitored and controlled by Andra.

In 2018, Andra demonstrated the progress of its digital model project with an operational prototype of the LLILW package handling area between the shafts and the repository area. When finished, all elements of Cigéo will be integrated into this digital model. This model is a visualisation aid, to monitor the progress of the project, to test the compatibility of all the components and objects of the structure, and to communicate outside of the project. It also has a role to play in simulating operating phases, particularly to train the staff who will operate Cigéo.

The database must be accessible and up to date throughout Cigeo's entire operating life and must ensure complete traceability of all integrated data. The Board draws attention to the need to ensure that accessibility and interoperability are maintained *throughout Cigeo's operation and monitoring, taking into account evolutions in digital formats and standards.*

This building of information in a digital model (BIM) should not exempt Andra from storing data on other durable media.

1.6 THE ORGANISATION AROUND CIGÉO AND REGIONAL BENEFITS

1.6.1 Governance

The Law of 25 July 2016 stipulates that in order to “guarantee citizen participation throughout the entre life cycle [of Cigéo], the National Agency for Radioactive Waste Management should develop an operational master plan [PDE] and update it every 5 years, in consultation with all stakeholders and the public”. In April 2016, Andra proposed a first version of the PDE within the scope of the DOS that would allow future generations to access the knowledge base that led to the design choices and, if necessary, allow them to evolve.

In its report 11 of 2017, and following the Law of 2016, the Board warned of the importance of a mechanism to concretely and effectively embody the principles of reversibility, which are defined in such a way as to allow the possibility of an evolution of the decisions taken, in particular with regard to the adaptations deemed necessary during the construction of the structure, in consultation with the stakeholders and the public. Since then, the Board has recommended putting in place a specific body responsible for conducting consultations at regular intervals, taking stock of developments deemed desirable and communicating them to Andra.

This approach involves specifying the major principles and stakes involved in defining a governance for Cigéo that dictates the process and temporality of the consultation; a new version of this chapter of the PDE on Governance will be attached to the DAC. During the initial discussions with Andra, all stakeholders in the PDE confirmed their willingness to participate in drafting the chapter on governance.

At present, the principles have been identified and the Andra has been given the responsibility for preparing the PDE and will have to ensure:

- the identification and implementation of pluralistic bodies to give their opinions during decision-making processes;
- continuous exchanges in addition to regular meetings and visibility of significant decision phases;
- that the recommendations and continuous exchanges in addition to regular meetings are taken into account;
- that the Cigéo reversibility principle is respected to allow for technical, societal and economic progress.

The industrial pilot phase (Phipil) will be a way of testing and developing the governance mechanisms.

The Board notes that the governance principles for Cigéo are gradually being implemented thanks to the tool that constitutes the operational master plan.

In this context, it points out that at the end of the consultation process, it will be Andra, which is responsible for the implementation of the Cigéo project, that, taking into account the opinions received, proposes the Cigéo operational master plan for the next 5 years to the Government.

In view of Andra's responsibilities, the Board believes that the bodies that will advise Andra on the preparation, implementation and updating of the PDE need to be defined as a matter of urgency.

In 2017, the Board proposed that a specific body be created for this purpose.

Each year, the Board will organise a hearing on the PDE.

1.6.2 Regional benefits

In addition to the intrinsic qualities of the site, the creation of the underground laboratory in Meuse-Haute Marne required goodwill from the local authorities towards the idea of hosting this structure. In fact, since the Law of 15 July 1982 on guidance and programming for research and technological development, the legislator has envisaged supportive measures and proposed the creation of a public interest group (GIP) to implement them. The Law of 30 December 1991 on research into the management of radioactive waste mentions, in article 12, the possibility of creating a GIP in order to carry out supportive actions and to manage equipment so as to encourage and facilitate the installation of each laboratory.

Consequently, the "Objectif Meuse" and "Haute-Marne" GIPs were created by inter-ministerial decrees on 20 May and 16 August 2000, respectively. They were renewed by inter-ministerial decrees on 9 May 2007 to take into account the changes brought about by the Law of 28 June 2006 on the sustainable management of radioactive materials and waste.

Both GIPs are responsible for implementing supportive measures in aid of Andra's and the Cigéo project's underground research laboratory.

Their role is to:

- manage the equipment to encourage and facilitate the installation and operation of the laboratory or of a potential repository centre;
- carry out spatial planning and economic development actions within the two departments concerned;
- support training initiatives and actions promoting the development, improvement and diffusion of scientific and technological knowledge.

Details on how these GIPs work are provided in chapter 3 of Appendix VII.

The Board recognises and encourages economic support initiatives in the territory by all actors concerned. It highlights the importance of training initiatives to be able to anticipate the skills that will be required due to the deployment of the project.

The Board recommends strengthening support for local businesses, in particular for access to public procurement procedures. This support must also focus on training in using and appropriating the culture associated with the Building Information Model (BIM). Otherwise, some companies would have to overcome difficult barriers to access the tenders.

1.6.3 Feedback from major civil engineering works

Cigéo will not be an ordinary project as it will share a basic nuclear facility between surface buildings and major underground facilities, and will also have an exceptional construction and operation duration. Andra conducted an analysis of major civil engineering works in order to establish a database of feedback and define a good practices guide. Although the projects considered are different from Cigéo's, the analysis of the problems encountered and the solutions implemented illuminates various organisational points. Several lessons are particularly relevant for a project like Cigéo.

Sharing information between different actors is essential. This requires a system for centralised collection of all the information relating to the project and its execution and rigorous exchange and reporting mechanisms. All actors must have access to the information they require and participate in a warning chain for the detection of anomalies. The project organisation must include a process for handling deviations from the reference configuration, integrated into the site logistics.

One factor for success is the commitment of all the actors to a business project. An extended enterprise organisation (or corporate club) enables better sharing of values and a commitment from all stakeholders: culture of safety, adherence to anomaly detection chains, integration in the site logistics.

As the project is logically moving from a design phase to an implementation phase, Andra is planning significant adaptation of its business lines and skills to ensure its role as project owner. This development must be anticipated by precisely identifying future needs by drawing both on willing internal resources and on recruiting new staff. As a first estimate, Andra plans to increase its workforce by about 200 people. Just as Andra was able to do with the Aube surface disposal centre, it will have to strategically choose the skills it must keep in-house and those it will strengthen by subcontracting.

Finally, in accordance with public procurement procedures, the organisation of purchases must take into account the industrial network, and in particular the local network. This organisation must make it possible to secure the supply of equipment required for the project and to ensure the long-term maintenance of the equipment delivered. The realization of Cigéo is in this sense an opportunity to develop a local industrial network, fostered by the size and the expected duration of the project.

The Board notes that the construction and operation of Cigéo will involve a huge change within Andra and the local industrial network. It recommends that:

- *this change takes an approach that encourages the commitment and involvement of all actors concerned with the construction and operation of the repository;*

- *Andra should properly define the prerogatives, the limits of responsibilities and the supervision methods of the project owner, its project managers and all subcontractors;*

- *Andra's new technical skills will have to be deployed as close as possible to the site;*

- *Andra should maintain the traceability of its decisions and undertakings.*

The analysis of feedback from industrial experiences also points to the crucial importance of properly identifying the requirements before the realisation: changes in the design during the realisation at best cause significant delays, and at worse incompatibilities. The stability of the benchmark, shared with the control authorities, is thus essential to ensure sufficient maturity from the start of the project.

The Board again highlights the upmost importance of stabilising the inventory of waste to be stored and the design of the structure in a reference configuration, to be able to review the file without undue delay and with the most complete databases possible.

This need for stabilisation is not at odds with the reversibility of the project. On the basis of a stabilised design, adaptability should make it possible to regularly re-examine certain components of the structure, in particular to be able to integrate technologies developed in long-term R&D studies. These modifications, which will be evaluated and then approved by the authorities, and their integration methods, will be discussed during the reversibility reviews.

1.7 SUMMARY OF CIGÉO COSTS

The reference costing for Cigéo, determined by the ministerial decree of 2016, is €25 billion$_{2011}$. This is currently under review, and will be finalised in 2020, at the end of the detailed preliminary design. As the initial costing announced by Andra in 2014 for the period 2016-2156 was €33.8 billion$_{2011}$, Andra had to make a substantial cost reduction, without this having any impact on safety, security and reversibility, principles that remain non-negotiable.

Like safety and security, reversibility is a fundamental principle in the construction of Cigéo defined by the Law of July 2016.

This principle is applied using governance tools (improved knowledge, transparency, ASN monitoring), as well as project management tools for realising a structure that provides the expected functions, even if these functions change over time. The constraints to the implementation arising from issues of progressiveness, adaptability, flexibility and recoverability all generate costs that it is no use identifying within the overall cost at the filing stage of the DAC. On the other hand, within the scope of updating the PDE, the costs of various options that conform to the reversibility principle can be compared.

The basic principle of Andra's attempt to reduce costs involves splitting the possible savings into two groups.

The first group includes cost reductions that can be scientifically and technically demonstrated from the start or during the process of reviewing the DAC without amending its schedule.

The second group, defined by Andra as opportunities, includes other possible cost optimisations. These include long-term cost reductions, i.e. reductions made after 2060.

The scientifically and technically demonstrable cost reductions amount to approximately €4.75 billion. The optimisation of the design and configuration of the underground facilities would result in a saving of €4.5 billion, the nuclear surface building would give a saving of €50 million, and finally conventional surface facilities, transversal facilities and preliminary layouts would provide €200 million.

Post-DAC opportunities could amount to a reduction in costs of €600-700 million in the short term, and over €500 million in the long term.

Compared to the initial cost reduction revisions already presented in 2017, these scientifically and technically demonstrable cost reductions are higher. They were estimated at €4.3 billion. This shows a continued effort to manage costs.

There are currently two working groups in place; one working on costing (structure, unit costs, methods, etc.), and the other on staffing (including assessment of operational and maintenance costs). The producers are involved in this work.

For the DAC file, the cost estimations are based on a reference configuration that is restricted to scientifically and technically demonstrable optimisations during the detailed preliminary design phase. The resulting cost will be established on the basis of short-term technical optimisations (mainly project management), using the most likely unit costs and purchasing costs, and the personnel costs required for this configuration. These cost reductions more specifically relate to the technical optimisation of LLILW cells and areas, which provide the most significant saving (€2.4 billion), the optimisation of HLW0 and HLW1/2 cells and areas, which will reduce the cost €1.5 billion, and the optimisation of nuclear and surface buildings that could reach €0.5 billion.

Even though the DAC file must understandably be prioritised by Andra and the logic of incremental cost must be maintained (i.e. the cost calculated as the works are carried out), the optimisation choices that will be made in the short-term may affect the long-term costs. The link between short-term and long-term savings does not seem to be clearly expressed.

The Board recommends ensuring that the costing is carried out in accordance with the principles inherent to reversibility, the conditions of which are defined by the law. In addition, the Board draws attention to the fact that incremental costing logic could lead to a short-term reduction in costs to the detriment of opportunities to reduce costs in the long term. It requests that this practice be justified.

On the other hand, the PPE may lead to changes to the inventory and the type of waste, which will have repercussions on the disposal costs.

Therefore, Andra must take this into account. This will provide an opportunity to test the robustness of the cost estimation methodology.

CHAPTER II: SEPARATION & TRANSMUTATION

In its report no. 12 of June 2018, the Board highlighted the uncertainties in the future of nuclear energy and the lack of visibility surrounding the strategy that legal actors and research organisations will have to implement in order to respond to the guidelines of the law on the ecological transition for green growth (TECV Act). Today, while the new guidelines have not yet been completely set out in detail, these are recommended in the framework of the Multi-Annual Energy Plan (PPE) and the Board is in the process of analysing, in the context of the 2006 Law, their consequences on the nuclear material used and the waste produced by the nuclear power cycle.

The studies are backed up by fundamental research where the key actors involved include the CEA, the CNRS and universities (see Appendix VIII).

2.1 TOWARDS A NEW CONFIGURATION FOR THE NUCLEAR POWER SYSTEM

The TECV Act calls for a reduction in the levels of nuclear-generated electricity in the energy mix, which should reach 50% in 2035. In the version submitted for consultation, the PPE requires that the first reactors to be closed between 2025 and 2035 will be 900-MWe reactors before their 5th ten-year inspection. Some of these, currently MOxed, will be closed and the use of Pu will be compensated by MOxing some 1300-MWe reactors. The implementation of next-generation EPRs is envisaged to maintain electricity production at the level necessary to ensure security of supply in a context of energy transition and to sustain the industrial network.

The energy transition will require a set of fundamental and applied research, presented in chapter IV.

2.2 MODIFICATIONS PROPOSED FOR THE FUEL CYCLE

The closure of a significant number of 900 MWe reactor units by 2035 has consequences for recycling policies for reprocessed uranium (RepU) and plutonium, as practiced by EDF. Today, only the 900-MWe reactors are authorised by ASN to be “MOxed”. In the PPE, the government stated that it intends to pursue the strategy of processing and recycling uranium and plutonium at least until the 2040s. Therefore, the current fuel cycle must be adjusted in order to avoid too great an accumulation of recoverable nuclear materials: RepU stored by Orano in the form of uranium oxide and plutonium present in spent UOx fuel, first stored in cooling pools attached to reactors (BK Pools), then in the Orano reprocessing plant pools at the La Hague site.

Furthermore, EDF, Orano and CEA have confirmed to the Board that the option of putting in place 4th generation fast-neutron reactors remains the long-term reference option as this technology alone makes it possible to both consume depleted uranium and to multi-recycle Pu, while reducing the radiotoxicity of the waste. According to EDF and Orano, the abundance on the market and the current low cost of natural uranium lead to this option only being considered in the long term, when the EPRs have to be replaced (if the deployment of an intermediate fleet were to be decided on, as mentioned in the PPE).

Given the uncertainties surrounding France's energy resources, the Board notes that this strategy is a short-term vision for the management of materials subject to geopolitical uncertainties and therefore fragile. In fact, it risks undermining France's energy independence.

2.3 CONSEQUENCES ON THE CYCLE

2.3.1 On reprocessed uranium (RepU)

Spent fuel from PWRs still contains 95% uranium, which is separated during reprocessing. The RepU produced in this way may be re-enriched to produce enriched reprocessed uranium fuel (ERU) for use in Cruas's 900-MWe reactors. The loading of this type of fuel was halted by EDF in 2013 for economic reasons but it is expected that it will resume in 2023 in order to stabilise the stock of RepU while using spent fuel materials from PWR reactors in operation. The first reactor units that will be loaded at Cruas will not be enough to stabilise the stock of RepU, which will continue to increase. This is why EDF also plans to use several 1300-MWe reactor units to recycle the RepU around the year 2030. Recycling ERU leads to savings of around 10% in natural uranium.

The Board highlights that over 30,000 tonnes of RepU are already stored in Tricastin and that new interim storage facilities will soon be required if RepU recycling is not implemented quickly.

Will the license applications to the ASN be submitted early enough for the 1300-MWe reactors to begin consuming ERU before saturation of RepU interim storage facilities?

2.3.2 On plutonium

According to the PPE, the use of plutonium as an energetic material relies on several successive phases: the recycling of Pu in the form of MOx fuel, then the recycling of MOx in EPRs while waiting for recycling in FNRs. This new strategy raises a great deal of questions for each phase.

The strategy of mono-recycling Pu in the form of MOx fuel implicates 24 900-MWe reactors. The closure of several of these reactors would call into question this strategy. For this reason, EDF is preparing a license application to "MOx" the 1300-MWe reactors in order to continue recycling Pu, which would result in a saving of natural uranium import of around 10% per year.

Given the scope of the studies to be carried out into MOxing the 1300-MWe reactors, and the ASN's review deadline for this plutonium recycling option, will the R&D of the various organisations be able to provide complete documentation in the time envisaged by the manufacturers?

What are the consequences of putting in place this new strategy across the whole nuclear power cycle?

The authorisation for MOxing the 1300-MWe reactors and replacing PWR reactors with EPRs, which are MOxed by design, would permit mono-recycling of U and Pu as carried out at present. Nevertheless, this leads to the continued interim storage of spent MOx, the quantities of which would be continuously increasing due to the lack of FNRs to consume them.

This is why EDF is considering a new multi-recycling strategy for U and Pu that would only involve new-generation EPRs. This multi-recycling of Pu has already been briefly studied in the past for PWRs and was rejected by EDF for various reasons (cost, unproven industrial feasibility, enrichment of waste in minor actinides, safety of the cycle and reactors, etc.). This technological option, which is being considered again today, will require the development of a new MOx fuel (CORAIL or MIX). Additional studies and significant means are required to demonstrate its industrial feasibility, which will not necessarily be directly transferable to the FNR system. These will have several objectives:

- Demonstrate the economic and technological value of the multi-recycling of U and Pu in EPRs awaiting an FNR system;
- Master the production of CORAIL fuel or MIX fuel and their reprocessing on an industrial scale;
- Manage the increase of the production of minor actinides: what will their isotopic composition be? what will the impact of this increase be on reprocessing?
- Manage the plutonium isotopic degradation, which will require a new specific production method for the fuel: how many cycles will be foreseen?
- Control the reactivity and safety of the reactor core;
- Prepare the adaptation of La Hague and Melox, which will have to be automated to ensure radiation protection;
- Assess the consequences on the type, duration, toxicity and quantities of waste produced. While MOxing the 1300-MWe reactors does not change the type of waste produced by the system, the implementation of CORAIL fuel or MIX fuel necessary for the multi-recycling of Pu leads to a new waste that is much richer in minor actinides than that produced after mono-recycling UOx.

This complex strategy of multi-recycling U and Pu in EPRs will result in significant changes in the Pu isotopic composition and will involve the adaptation of fuel production and reprocessing facilities. Furthermore, the limited number of cycles, in the absence of FNRs, could lead to an increase in interim storage of spent MOx while increasing the inventory of high-level waste.

The Board is looking into the value of such a strategy, presented as a first step in mastering a FNR fuel cycle, which would require significant specific investments.

The Board notes that this course of action departs from the objectives of the Law of 2006.

2.4 CLOSURE OF THE CYCLE

Therefore, it appears that, without calling into question the recycling of U and Pu in the short and medium term, which keeps the plants operational, the option of using the plutonium associated with depleted uranium in an FNR is pushed back to a much later date.

The Board considers that the Astrid programme has already facilitated considerable advances in all scientific and technological fields contributing to the implementation of FNRs. An overall assessment of the Astrid studies will be produced at the end of 2019. The Board will assess this.

The Board is questioning the ability of nuclear stakeholders to maintain and develop expertise and skills to avoid losing the accomplishments made by implementing Rapsodie, Phénix and Superphénix and those made by developing ASTRID, in the absence of a motivating project by 2050-2060.

The transmission of thorough knowledge concerning the reactors, the separation and the fuel cycle, safety, radiation protection, etc. will be essential in safely managing the entire nuclear power system, whatever its future, until its final closure.

The Board regrets that ending the Astrid project will result in France losing its leading position, while the competitors, such as Russia and China, continue to invest in FNRs.

2.5 TRANSMUTATION OF MINOR ACTINIDES

The study of the transmutation of minor actinides is stipulated in the Law of 2006. This research on the transmutation of actinides was assessed in reports 11 and 12.

Experiments that have been carried out in recent decades involved:

- the separation of minor actinides downstream of spent UOx fuel processing, either separated into groups (AM = Am+Np+Cm) or isolated;
- the irradiation of needles containing minor actinides in reactors including HFRs (Petten), HBWR (Halden), ATR (INL) and Phénix (Marcoule) with different media (oxide, inert matrix, etc.).

The post-irradiation examinations of the latest experiments are still in progress. These define a conditioning matrix suitable for the transmutation of minor actinides and provide an initial assessment of fission transmutation rates.

New initiatives proposed by the CEA include:

- studies of drafts for the FNR-Na system (simulation and experimental platforms to qualify the innovative components);
- technological monitoring of other Gen IV reactor systems, including molten salt reactors (MSRs), which have potential in the transmutation of actinides. R&D will be required to remove the many technological obstacles associated with this system.

The Board notes that both on a global scale, as well as in France, the number of studies on minor actinides is decreasing. It is essential to consolidate the cooperation network that the CEA has built with a multi-annual experimental programme. The Board remind again about the current lack of fast neutron spectrum irradiation tools and dedicated experimental platforms in France. Against this background, it is important to strengthen international collaborations.

Given the value that the transmutation of americium would have for future waste management, the Board recommends that studies be carried out to develop the skills acquired in order to meet the requirements of the Law of 2006.

Recently, a new approach has come to light. This would use a new-generation power laser to produce 14-MeV neutrons through a fusion reaction. These neutrons would be injected into a molten salt reactor to transmute actinides. However, major scientific and technological challenges still need to be overcome:

- realising a power laser requiring innovative technology, which is only in the early stages of development;
- developing a new nuclear sector based on the use of a molten salt reactor, while there is still no prototype, nor an industrial network at international level;
- setting-up an online-industrial process for the chemical separation of long-lived fission products and minor actinides.

At the current stage of knowledge, the scale of scientific, technological and industrial developments is such that it is not realistic to set any deadline for the eventual industrial implementation of this approach.

Furthermore, it should be noted that reprocessing existing glasses containing nuclear waste would be neither economically nor technologically feasible.

CHAPTER III: WASTE MANAGEMENT

3.1 GENERAL OVERVIEW

Studies undertaken for the recovery and conditioning of historical waste (SLLILW, LLILW, LLLLW) still in bulk at La Hague or Marcoule, are continuing: these relate to radioactive waste from the CEA or Orano (see report no. 12, Appendix XVII). Given the scale of the operations and the uncertainties regarding the provision of the heavy resources needed simply to recover the waste, the schedules run over the next two decades. The recovery and conditioning of liquid effluences and some irradiated or spent fuels from the CEA still need to be defined (reprocessing or waste for Cigéo).

Among the different types of waste (VLLW/VVLLW, SLLILW, LLLLW, LLILW and HLW, uranium conversion treatment residues from Malvési), the VLLW operational system is coming under question and the LLLLW system is being defined. Waste packages for the LLILW and HLW systems are destined for Cigéo.

In its previous reports, the Board analysed the results of the studies concerning the management of VVLLW, VLLW and LLLLW waste, as well as that of the specific uranium waste from Malvési (uranium conversion treatment residues). These studies have been ongoing for several years. They mobilise all the institutional and industrial stakeholders involved in the nuclear system: ASN, IRSN, CEA, EDF, Orano and in particular Andra, which is responsible for the management of all waste except that from Malvési.

The IRSN is leading a study into the harmfulness of radioactive materials and waste (Article 1 of the PNGMDR Decree of 23 February 2017). This question is at the heart of societal debates concerning low-level waste and it requires a specific approach. Harmfulness (or dangerousness or toxicity) reflects the capacity to cause adverse effects on the health or survival of living organisms. For radioactive waste, the effects may be radiological or chemical in nature. In order to take into account the diversity of waste, the IRSN has proposed a ranking of the harmfulness of waste (divided into 132 families and 6 categories) and materials (10 categories and 27 subcategories). The criteria selected are radiological exposures (indicators: dose and effective dose) and chemotoxicity (several indicators) for 4 exposure scenarios for an individual.

Every 3 years, the PNGMDR anticipates any future problems in the management of VLLW and requests studies to prepare a change in current practices, or even in the strategy itself.

Thanks to the operation of Cires, Andra has excellent feedback concerning the management of VLLW. However, when it comes to LLLLW, no strategy has yet been adopted, whether for radiferous, graphites or bitumens; moreover, the inventories have not been stabilised. Andra is currently characterising a potential clay site close to Cires and the CSA, which could accommodate a second VLLW repository and an LLLLW repository.

On the Malvési site, Orano is looking into the possibility of SCR type disposal (sub-surface disposal with an engineered barrier system or cover) of uranium waste. Some of the LLILW bitumen waste from the CEA or Orano could be downgraded to LLLLW.

3.2 VLLW

The prospective VLLW production inventory (and other waste categories) has been consolidated for the next 50 years. Thus, 45% of the VLLW would be metallic, of which 9% is homogeneous batches consisting of steam generator envelopes and GB diffusers (from the George Besse 1 enrichment plant), and the rest being made up of various different types of waste and by land and rubble. A small part of this waste could be incinerated. In total, the VLLW accounts for approximately 2 million m^3. If the current centralised management of VLLW continues, this would lead to saturation of Cires by 2028.

The uncertainties in the inventory do not relate to metal VLLWs but to soils and rubble. These are estimated based on feedback from EDF, CEA and Orano decommissioning sites (research reactors and workshops). The feedback shows that, when the initial state of the sites is known and the objective to be achieved is also well defined, the uncertainties are at 10% to 30%. The differences between the quantities forecast and the quantities produced are due to changes in the clean-up scenarios (conservation of structures or complete demolition with or without decontamination of soils and subsoils). The definition of the final state determines the volume of waste and demonstrations are necessary to establish that there are no environmental risks when a complete clean-up is not involved, as most often recommended by the ASN (return to grass).

The preliminary studies into a new management relate to: the extension (almost achieved) of the capacity of Cires (from 650,000 to 900,000 m^3), the opening of a new VLLW repository, the fusion and recovery of 200,000 m^3 of homogeneous batches of metals, or even those of other VVLLW metals, and decentralised disposal in situ for VLLW with activity at the limit of detection. The possible recovery of VLLW will depend on the definition of release thresholds

For the management of VLLW, it is still necessary to specify the methods used to control and trace materials that could be returned to the public domain or stored in situ.

Their management must also take into account the current economic and environmental constraints. There are three important parameters involved in technological and economic optimisation: conditioning of waste in packages, transport and disposal of packages.

When it comes to the environment, efforts should be made to assess the potential impacts (local and global) of disposal options (centralised or decentralised). The method used for life cycle analysis (LCA) has been applied to conventional waste and Andra is assessing how to adapt it to VLLW to take into account its specific features: long-term impacts, societal requirements and regulatory constraints. An initial study shows that a multimodal rail/road design would reduce the environmental impact of transporting VLLW to Cires by 30%. However, this mode of transportation cannot be generalised as some sites are located far from the railway. The environmental impact of road transport still needs to be assessed in more detail.

No less than 12 articles of the PNGMDR decree of 23 February 2017 relate to adjustments to be made in the VLLW system so that it can be included in the general framework of waste processing as defined by the TECV Act. The transcript in the French environmental code requires reducing, reusing, recycling and recovering energy from waste, and eliminating it. Changes in the management of VLLW, such as crushing rubble, incineration and densification that would allow a possible saving of the volume of disposal in Cires are, for the moment, not being considered by Andra.

Multi-criteria analysis shows that the “incineration” and “disposal” scenarios are ultimately the same for all aspects other than environmental criteria. It makes sense to compare both scenarios on an environmental level. To achieve an increase in disposal volume, incineration generates greenhouse gases (GHGs), potentially radioactive fine particles and chemical substances.

With regard to metallic VLLW, fusion provides a clear gain in volumes to be stored (reduction factor greater than 6). If fusion is followed by the recovery of metals, the reduction factor of the volume to be stored is 20. It should also be noted that fusion-recovery provides a saving in terms of raw materials and is fully in line with the guidelines stipulated in the TECV Act.

It is in the event of a change in the regulations (release threshold) that a significant reduction in VLLW production from clean-up and decommissioning can be achieved. The majority of future VLLW will come from the decommissioning of the reactor fleet (400,000 t including 265,000 t metal); a large part of this non-metallic VLLW intended for Cires could then be downgraded as it would not require any radiation protection measures. Orano is examining the feasibility/profitability of a metal recovery system based on a fusion/decontamination facility (arc furnace) on a greater scale than simply relying on fusion of the EDF steam generators and Orano GB diffusers. This study could be supported by the future investment programme. The arc furnace has some specific advantages because it would be able to process all metals by accepting large parts without special preparation, separating chemical impurities, maintain radionuclides and dust in the slag and finally homogenise the composition of recoverable metals.

Beyond what is already envisaged by EDF in the framework of the Cyclelife initiative (see report no 12), another example of recycling and recovery (which has been retained by Andra) involves the reduction of the volumes of VLLW to be stored at Cires, which is the aim of the Orcade project (2017-2021) for the recovery of the metal core of Phénix electrical cables (conventional cables 17.5 t, VLLW 25.4 t and SLLILW 3.5 t) and Marcoule's Atelier Pilote (conventional cables 135 t).

3.3 LLLW

The category of LLLLW falls under a default definition: it is long-lived waste that cannot be stored on the surface but is not intended for Cigéo deep disposal in an approach proportionate to its radiotoxicity. Its inventory is expanding.

The characterisation of a potential site at which to implement a sub-surface repository at Vendeuvre-Soulaines (in the Community of Communes of Soulaines, CCS) began in 2013. An area of 10 km^2 with suitable properties has been identified. It consists of a homogeneous layer of teguline clays (suitable for the manufacture of tiles) of the lower and middle Albian, with a thickness from 20 to 80 m, flush or under quaternary cover, and resting on a layer of 10 m of green sands of the Upper Aptian. These sands contain an aquifer that may be a local water resource. They are located on the eastern edge of the regional aquifer system of Albien; a hydraulic connection between them and the exploited sandy facies of the centre of the Paris Basin is unlikely, according to Andra. Tegulin clay has a permeability of 10^{-10} to 10^{-11} m/s. Its retention properties of radionuclides are comparable to those of Callovo-Oxfordian clay.

Andra's recent efforts have focused on the analysis of construction techniques to identify the best available techniques based on the feedback from the realisation of various underground structures. Andra favours access to disposal cells directly from open structures.

The PNGMDR expects an industrial management plan for LLLLW in 2019.

The SCR and SCI disposal concepts (sub-surface disposal with or without an engineered barrier system) studied by Andra take into account the period of radioelements to be stored. During a first phase (a thousand to several thousand years) corresponding to a slow evolution of the disposal, the analysis can be conducted according to safety criteria such as: isolation, then confinement of radionuclides and toxic substances, exhalations limitations, etc. established to limit the radiological impacts considering several scenarios. Beyond this phase (comparable according to Andra to an operating phase), disposal erosion should not have any impact during the release of residual radionuclides.

The new initiatives proposed are as follows:

- it is no longer a question of accommodating all LLLLW on the same site considering that the typology of this waste is heterogeneous, while some producers (including formerly

Solvay and CEA) are targeting on a reclassification of some of their waste as VLLW given their level of radioactivity;

- a safety approach and waste management methods proportionate to the risk associated with each of the three LLLLW waste families (radiferous, graphite, and bitumen).

The Board stresses the importance of quickly securing all LLLLW management chains, taking into account an industrial and regulatory logic. One could start with the simplest to implement.

When the studies being conducted by Andra to establish the feasibility of the disposal of each LLLLW system are completed, the Board will analyse the conclusions made and their relevance, taking into account the lifespan of this waste, the associated radioactivity, its chemical harmfulness, and the impact of erosion that will affect the site over time.

3.4 CONCLUSIONS AND RECOMMENDATIONS

The Board believes that low-level waste management has been well covered by the numerous studies requested by the successive PNGMDRs. Their findings provide the elements necessary to progress the management of VLLW and prepare for that of LLLLW. The Board is disappointed that an effective solution has not yet been identified.

To optimise the management of VLLW according to its harmfulness, the Board recommends establishing a more operational methodology based on the indicators developed by the IRSN.

The Board appreciates the quality of the studies brought to its attention; however, it notes that economic factors play an important role in almost all of the conclusions. This may hinder the enhancement of the technological options that may be envisaged. The Board recommends establishing a balanced programme that makes it possible to go as far as establishing draft studies for each waste management option envisaged in order to shed light on the possible choices through technical considerations.

Finally, it wants to be presented with the progress of studies each year, avoiding any detailed history of VLLW and LLLLW waste management, which is now well known.

CHAPTER IV: FUNDAMENTAL RESEARCH SUPPORTING APPLIED RESEARCH

Fundamental research and R&D focus on progress related to the current fleet, Gen IV fast neutron reactors, the fuel cycle and the evolution of associated facilities. Appendix VIII reviews the activities of the CEA, CNRS, EDF and Orano since report no. 12 of June 2018.

4.1 R&D SUPPORTING THE CURRENT FLEET

4.1.1 SMRs

The current fleet of reactors and cycle facilities will develop in line with the TECV Act and the PPE.

A new type of reactor is also being discussed with the development of a preliminary draft of a low-power modular reactor (SMR). It would have passive safety and could be built by assembling prefabricated modules at the factory. In the context of the energy transition, this type of reactor would target an international market by offering a permanent, flexible power source (as opposed to intermittent energy sources) that can meet local needs.

The Board notes that France is behind compared to the international competition. It will be following with interest the development of research to fill this gap.

The Board wonders about the legal and practical management of radioactive waste produced by an internationally distributed fleet of SMRs.

The Board regrets that the PPE will lead to the dispersal of resources to the detriment of Gen IV research as provided for by the 2006 Law.

4.1.2 Reprocessing procedures

Continued R&D has made it possible to test new processes for dissolving high-Pu fuels. The use of mono-amides to reprocess spent fuel significantly improves the performance of current processes.

4.1.3 Nuclear Waste in a Glass matrix

R&D studies have added to the information on the degradation of irradiated glass by water. Experiments conducted on industrial glass extracted in 1994 show that there are no effects on the initial rate of deterioration (V_0) but there is an effect on the residual velocity, which remains much lower than V_0 even though it may increase by a factor of 10 with the cumulation of alpha dose. Experiments are being planned to understand these deviations. However, this increase has no impact on the safety analysis based on the initial velocity (see Appendix VIII).

The Board believes that these new results on nuclear glass confirm that this matrix provides good guarantees of radionuclide confinement. It recommends continuing the experiments on industrial glass to understand the contribution of glasses to safety margins.

4.2 ASTRID AND GEN IV FNRS.

The Astrid programme as defined in 2010 will be brought to a close in 2019. It developed in the context of numerous European and international collaborations and has been supported by substantial human and financial resources for a decade.

The CEA has presented a first review of this programme to the Board. The final review is due to be finalised at the end of 2019. The achievements of the Astrid programme are very innovative. In Appendix VIII, the Board presents a first review of research focusing on the following topics:

- FNR fuel assembly;
- materials for Gen IV reactors;
- recycling Pu and separation and transmutation.

The Board highlights that the Astrid programme has facilitated considerable advances in all scientific and technological fields dedicated to Gen IV, with benefits for the Gen II and III systems.

The Board would like to draw attention to the consequences of putting on hold a R&D programme into FNRs. Just some ten years ago, France was a forerunner, but today it is seeing its skills deployed in FNRs decreasing, following the decline in its commitment to research. If we plan to deploy a fleet of FNRs even at the end of the century, we must maintain skills levels as well as training material and a scientific attractiveness that will allow future experts to emerge.

The Board asks the CEA to outline the actions that would enable it to ensure the maintenance of skills in FNRs for a period exceeding a generation.

4.3 FUNDAMENTAL RESEARCH

4.3.1 CEA-DEN

The developments in separation processes and irradiation experiments for transmutation have been strongly supported by fundamental research at the CEA.

This fundamental research, which is experimental, theoretical and numerical, (Appendix VIII) covers:

- the multi-scale behaviour of irradiated metallic materials;
- the development of the microstructure of fuel pellets;
- the behaviour of Pu and other actinides in the cycle;
- sonochemistry to accelerate the dissolution of Pu oxide;
- the separation and modelling of species in solution and in interphases.

The Board positively appreciates the progress made. However, it is questioning the future of fundamental research on the fuel cycle within the CEA DEN. The reduction of resources risks calling into question CEA's leadership in the acquisition of knowledge as well as in national and international collaborations.

4.3.2 CNRS and universities

At the start of 2018, the CNRS (IN2P3 and INC) created the Research Group (GDR SCINEE, Nuclear Sciences for Energy and the Environment).

The CNRS also decided to relaunch the NEEDS programme in 2020 with the aim of studying the fundamental mechanisms/processes and the acquisition of basic data of interest for nuclear energy under three main themes:

- reactors and energy transition;
- waste, characterisation and disposal;
- resources, environment and territories.

The themes of NEEDS and the Research Group comprehensively cover both upstream and downstream of the cycle. Together with the CEA, NEEDS brings together nuclear industrial actors (EDF, Orano, Andra, etc.) and the academic community (CNRS and universities). Strong links have been established between national laboratories and major instruments such as Soleil.

These studies address the important problem of the ubiquitous presence of radionuclides in the environment and their potential impacts on living systems. In the final analysis, the behaviour of radionuclides in the environment can only be properly predicted if the physicochemical forms in which they are involved are known. This is why the speciation of radionuclides is at the heart of numerous GDR SCINEE studies.

4.3.3 Soleil

Soleil's (CEA DEN and DAM) Mars (Multi-Analyses on Radioactive Samples) resource is available to the scientific community for X-ray characterisation of radioactive samples.

It is a remarkable tool. The CEA and CNRS have presented to the Board several of the first diffraction spectra ever obtained on a sample 1 mm long and 50 microns thick taken from an irradiated rod in a Gravelines PWR (5 years of irradiation, 23 years of cooling). These studies are the first of their kind and make it possible to obtain information on the bonds between the different atoms within the irradiated fuel.

4.4 CONCLUSION

The Board positively appreciates the advances made in understanding the behaviour of materials under the influence of irradiation and the phenomena involved in the fuel cycle.

The Board would like CEA-DEN to present it with a hierarchy of objectives and related programmes, which clearly shows the strategy it intends to follow in the coming years.

To meet the many challenges related to the new nuclear power strategy, the Board recommends launching a national initiative comprising a strong fundamental research aspect. This initiative, aimed at involving the entire scientific and technological community in major research and training activities, should mobilise young talents. It would contribute to transmitting and consolidating French expertise.

CHAPTER V: INTERNATIONAL PANORAMA

5.1 INTRODUCTION

This chapter presents the latest developments at an international level concerning the disposal of radioactive waste, and briefly describes the various aspects of the decision-making process. The role in the decision-making process of authorities responsible for safety, planning and environmental protection, as well as elected local, regional and national political representatives is essential.

The decision-making process is participative in the countries with the most advanced disposal programmes.

Appendix IX gives an overview of the main trends in the development of nuclear power programmes around the world. Appendix X presents an international overview of nuclear power programmes, while Appendix XI describes the Belgian procedures for obtaining a creation and operation license for a nuclear waste disposal facility, as well as some highlights of the year 2018.

5.2 DECISION-MAKING STAGES

Decision-making can be split into two main stages:

- decisions on the process, implementation procedures and preparation of a license application to build a repository (pre-application);
- decisions relating to the approval of the application for a license to build, operate and close a repository (post-application).

a) Pre-application

A feature common to most national deep geological repository implementation programmes – such as Cigéo in the case of France – is the definition of stepwise procedures for site selection and concept development. A general framework is provided by the government, which brings together the safety and security authorities and those responsible for environmental protection. It is then up to a dedicated responsible body to implement the programme.

This body may be formed by the government, as is the case for France and the UK, for example, or by the electricity companies that operate nuclear plants, as is the case in Finland (Posiva) and Sweden (SKB).

The level of detail required by the political and public authorities may vary from one country to another. In the case of Finland and Sweden, for example, the requirements for the site selection process are fairly general. The authorities undertake a general review of the procedures proposed by the responsible body (Posiva and SKB), but allow the body a certain flexibility to proceed according to their own plans.

In France, parliament has played a key role in the defining the elements making up the programme for managing waste and the associated responsibilities for its implementation.

In the UK, the government recently dedicated several years to the creation and consultation of documents (2014 white paper, 2017 community consultation, etc.) that define the selection process for the site that was launched by the operator RWM Ltd at the start of 2019.

The need for elected officials and local citizens to participate in the preliminary process for preparing decisions, particularly in terms of site selection, is now emphasised in most countries. However, the modalities of this participation may vary: consultations, consultative referendums, veto rights conferred on local elected representatives, etc.

b) Post-application

Once the application for the construction of a repository has been filed, the decision-making process generally follows similar procedures in the different countries. The application is examined in detail by the relevant authorities covering safety, environment and planning. These authorities advise on the acceptability of construction and operation and formulate requirements for the project. The final decision is made by the government. In certain cases, such as in Sweden and Finland, this is done with the agreement of local authorities. In the UK, a local support survey is required and the result must be positive in order to obtain a construction license.

Country specificities and contextual elements are briefly described below.

5.3 BELGIUM

The long decision-making process for the long-term management of radioactive waste is illustrated for two cases: surface disposal for short-lived or low-level waste, and geological disposal for intermediate or high-level radioactive waste.

5.3.1 The case of surface disposal for short-lived low-level or intermediate-level waste

Between 1960 and 1982, Belgium participated in international operations of low-level radioactive waste immersion in the North Atlantic (coordinated by the OECD/NEA for Germany, Belgium, France, the United Kingdom and the Netherlands). It definitively put an end to this practice in 1983. The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (Ondraf/Niras), which was created in 1980 and is responsible for the safe and sustainable management of radioactive waste in Belgium, has since constructed facilities to temporarily store Category A waste (LLW and ILW) that has not been stored at producer sites.

In 1998, the Belgian government decided that a definitive solution should be developed for Category A waste. The focus was on the existing nuclear zones but applications were open to all interested municipalities.

In collaboration with university research units, Ondraf has developed a partnership concept in which representative samples of the local population are invited to develop their own projects with Ondraf. Four municipalities that already had nuclear facilities (Dessel, Mol in Flanders, Fleurus and Farciennes in Wallonia) came forward. After five years of studies and extensive work, the partnerships have resulted in five technical drafts for surface and deep disposal. Four of these, developed in Dessel and Mol, were approved by the relevant municipal authorities in 2005. In 2006, the government decided to place Category A waste in a surface repository in Dessel, on the basis of the preliminary draft developed by this partnership.

In 2013, Ondraf then applied for authorisation to create the nuclear facility for this disposal at the Federal Agency for Nuclear Control (AFCN). The AFCN analysed the proposed file and checked whether this future facility would guarantee the safety of the population, the environment and the workers in the short, medium and long term.

It put around 300 questions to Ondraf. In 2019, Ondraf submitted its amended safety file to the AFCN, which will send it to its scientific board for appraisal. If everything goes to plan, the license could be approved by mid-2020. The first waste will then be stored in the facilities in 2024.

The Board notes that the participative approach in Belgium, building on partnerships from the start of the project, has led to a progressive, reversible and democratic decision-making process and has undoubtedly paved the way to better acceptance of the disposal project at a local level.

5.3.2 The case of geological disposal for intermediate-level or high-level waste

In 1974, one year before the first Belgian reactors began operating, the Belgian Nuclear Energy Research Centre (SCK•CEN) decided to initiate design studies for a geological repository for Category B and C waste (LLILW and HLW) and start looking into site selection. The geological studies, confirmed by several drillings, showed that below the SCK•CEN site in Mol, there is a layer of clay known as 'Boom' clay (poorly indurated, plastic, thickness 100 m, centre ~ 250 m below the surface), which made it possible to construct an underground laboratory on the site to study the properties of clay as the host rock of such a disposal site. The construction of the laboratory began in 1980, the year Ondraf was created. Since 1995, the underground laboratory has been operated by EURIDICE (an economic interest group made up of SCK•CEN and Ondraf).

Between 2011 and 2018, Ondraf submitted several "national policy" proposals to its trusteeship, all based on a geological disposal solution within national territory. While the initial proposals included a host formation (poorly indurated clays), the latest proposal is limited to the geological disposal solution, without specifying the host rock.

Ondraf stated that "*this policy decision is also needed to estimate the costs of long-term management. Postponing the decision will only increase costs: the maintenance of the current interim waste storage site is expensive, not to mention the risk of having to build new interim storage buildings if the solution does not materialise. If we want to avoid leaving future generations with the waste burden we are now producing, a short-term political decision is needed. The future disposal project must receive public support. This is why ONDRAF wants to launch a societal pathway as soon as the policy decision is made.*"

However, at present no policy relating to geological disposal has been clearly drawn up in Belgium.

5.3.3 The "creation and operation" license for a nuclear waste disposal facility – procedures

A detailed description of the procedures in place in Belgium can be found in Appendix XI.

A creation and operation license for a nuclear waste disposal facility requires a procedure at the Belgian federal level that, depending on the level of risk of the facilities concerned, requires different opinions at other levels (municipal, provincial, or even European level in case of potential cross-border impact).

We should note the important role assigned to a scientific board, appointed by the Government and independent of the AFCN, whose opinion is binding if it is negative

5.4 CANADA

Three repository projects have been publicly announced in Canada. They are driven by three different operators:

- Ontario Power Generation (OPG): plans to store long-lived low-level and intermediate-level waste near the Bruce Nuclear Generating Station at Kincardine, Ontario;

- the Nuclear Waste Management Organization (NWMO) is looking for a site to store all spent fuel and high-level radioactive waste in Canada;
- the Canada Nuclear Laboratories (CNL): this entity proposes sub-surface disposal of up to 1 million m^3 of low-level waste inherited from research, exploitation and decommissioning, mainly on the site of the National Laboratory of Chalk River in Ottawa.

5.4.1 Deep disposal for long-lived low-level and intermediate-level waste - OPG

The deep geological repository for low-level and intermediate-level radioactive waste will be located adjacent to OPG's waste management facility at the Bruce Nuclear Generating Station. The facilities will manage approximately 200,000 m^3 from nuclear power plants owned or operated by OPG in Ontario. The proposal is to situate the facility approximately 680 m below the surface in low-permeability limestone and under a 200 m thick layer of shale.

The project began in 2001 when the municipality of Kincardine asked OPG to initiate preliminary discussions on the long-term management of low-level and intermediate-level waste. At the end of 2005, the regulatory approval process was initiated with the submission of the disposal project description after a long preparatory phase including an independent assessment study, negotiation of an agreement with the local authority, and a local authority survey that revealed strong support for the realisation of the project.

In 2006, this procedure led to a preliminary declaration relating to the environmental impact study for such a project.

In 2007, the Minister of the Environment requested a further review of this impact study and tasked this to a commission composed of members of the Canadian Environmental Assessment Agency and the Canadian Nuclear Safety Board. Three documents were submitted to this Board in April 2011: the environmental impact study, the preliminary safety report and several additional documents providing perspective on the subjects of safety, security and environmental protection. In February 2012, the Board launched the public enquiry period. After 15 months of assessing the documents submitted to the public enquiry, the Board announced that a four-week-long public discussion would be held on the project. In May 2015, the Board concluded that the Kincardine site proposed by OPG represented a technically acceptable solution for the long-term management of low-level and intermediate-level radioactive waste and recommended that this project be followed up. However, the project was also met with opposition, both from elected officials and citizens at a local and national level, extending as far as the Great Lakes region of the US.

OPG was asked to add studies of alternative solutions to its file, as well as an impact study on the cumulative effects associated with disposal on the same site of spent fuel and high-level waste as proposed by NMWO.

For this reason, the authorisation schedule for the project remains uncertain.

OPG estimates that it will take five to seven years to both obtain the green light from the administration and carry out the necessary work (site preparation and construction of the repository) before hoping to send the first packages of waste.

5.4.2 Disposal for spent nuclear fuel – NWMO

Since 2010, the NWMO has been involved in a multi-year (local authority-driven) site search campaign, where Canada's spent nuclear fuel could be safely contained and isolated in deep geological repositories. The government has approved the principle of such a multi-barrier disposal facility. The process for selecting such a site has been the subject of an extensive consultation over two years. This participative process has made it possible to gather ideas, feedback and the best advice from a wide representative sample of Canadians. In this way, the citizens have been able to give their opinion on what such an (open, transparent, fair and inclusive) consultation should include in order to be able to make a satisfactory decision.

The process is led by the local authority. It is designed, above all, to ensure that the selected site is safe, can be secured and is hosted by a fully informed and willing local community. This process must also adhere to the highest scientific, professional and ethical standards.

The safety and relevance of any potential site will be gauged by a series of scientific, technical and societal assessments, which will progressively become more detailed.

The selection process requires the support of local authorities in the region concerned, i.e. they must be willing to initiate and implement it. Potentially interested local authorities are encouraged to initiate a process of study and engagement that includes First Nations and Métis local authorities, as well as surrounding municipalities. The project will only move forward if the interested communities, the First Nations and Métis local authorities and neighbouring municipalities work together to implement it.

Local authority support for the project was extensive, with almost 21 authorities expressing interest. The NWMO has selected five site proposals for more detailed studies. All of these sites are in Ontario, where most Canadian nuclear reactors are located.

The current plan states that one of the sites will be selected for the disposal project by 2023. Exploratory geological studies, including deep drilling, have recently been initiated on some of the proposed sites. Design studies are also under way, incorporating the technological option based on encapsulating spent fuel in copper containers for disposal in crystalline rock. A study laboratory on multi-barrier systems (container + bentonite) has been set up north of Toronto.

5.4.3 Near-surface disposal of low-level waste – CNL

The installation of a sub-surface disposal facility is a planned on the Chalk River National Laboratories (CRL) site. The CRL site is located in Renfrew County, Ontario, on the shore of the Ottawa River, approximately 200 km northwest of Ottawa.

The sub-surface disposal facility is expected to be operational in about fifty years; the proposed concept is based on a modular artificial mound composed of multiple disposal cells, each composed of:

- ground coverings at the base of each cell and a definitive cover;
- leachate collection and leak detection systems;
- environmental monitoring systems.

The Canadian Nuclear Laboratories have submitted a request for a review of the project to also allow the disposal of some intermediate-level waste, in addition to low-level and mixed waste. All waste to be stored will have to meet package acceptance criteria and thus contribute to the implementation of long-term disposal and operational requirements.

CNL has provided a draft environmental impact study and public hearings have taken place, and it is currently preparing responses to comments received.

5.5 SPAIN

The Spanish nuclear power programme is based on an open cycle.

Final deep geological disposal is planned for spent fuel elements. However, at this stage there is no exploratory programme for selecting a site for such disposal.

The interim solution approved in 2011 consists of constructing a temporary centralised storage facility (TCR), in addition to the three existing individual temporary storage facilities located at nuclear power plants in operation. The TCR site has already been selected and is located in Villar de Cañas, 140 km southeast of Madrid. The Spanish Council of Ministers approved the official start of the project on 30 December 2011.

The project was progressing well and an application for official project authorisation had been sent to the Spanish Nuclear Safety Council (CSN) by ENRESA, the company responsible for radioactive waste in Spain. However, at the end of 2018, the Ministry for Ecological Transition requested that the CSN temporarily suspend the decision on licensing the project.

The Ministry is currently reassessing the general situation, including the possibility of extending the lifespan of some power plants until 2025-2035. A detailed economic study to assess this possible lifespan extension is currently being carried out by the private owners of the nuclear power plants. The aim of this is to estimate the economic profitability of the investments required for the extension with regard to the expected revenues associated with the additional production of electricity.

5.6 FINLAND

In Finland, the process of installing a disposal facility was completed 20 years ago, when a site near the Olkiluoto nuclear power plant was selected with the agreement of the municipality of Eurajoki.

The disposal concept is based on Swedish KBS3 technology (disposal of spent fuel encapsulated in copper containers in crystalline rock). A construction permit – the first in the world for a spent fuel repository – was issued in 2015. Construction works are now well under way, with approximately 7 km of tunnels already excavated. The drilling of the shaft for the sending of encapsulated irradiated fuel containers down to the disposal area is under way.

A full-scale level 1 test module using electric heating elements to simulate the waste heat of spent fuel is being installed in a disposal tunnel set aside for observation as part of a multilateral cooperation project (known as FISST – Full-scale In-situ System Test) in order to:

- prove that the definitive disposal process works in practice (from the supply chain to the in-situ transfer of containers);
- prove that the initial state (as predefined) can be achieved by satisfying the safety requirements in force;
- produce the first feedback on the evolution of the disposal.

In this way, the FISST project will provide assurance that the disposal can be carried out by means of a technical and scientific demonstration under realistic conditions and in a real disposal facility.

Having been approved by the STUK (the Finnish Nuclear Safety Authority), preparations are also under way for the construction of the central tunnel (nuclear classified).

Alongside the underground works, the construction of the encapsulation plant has also begun. The excavation and blasting works for the foundations have been completed. The detailed designs and contract attribution are being developed. The main system providers have already been selected.

The transfer of the first container containing real spent fuel could start in the mid-2020s.

5.7 UNITED KINGDOM

The three most advanced countries in the world in terms of deep geological disposal are Finland, Sweden and France. In these countries, sites have already been selected and the associated construction applications have been approved (Finland), submitted and assessed awaiting a final decision (Sweden) or are at the point of being submitted (France). However, the nuclear power programmes and corresponding waste inventories differ greatly between these three countries, with France presenting a specific case compared to Finland and Sweden, where the situations are relatively similar.

The French programme is actually much more extensive and complex as it involves both civil and military applications. Furthermore, it includes many research reactors, various pilot facilities for fast neutron reactors and has a partially closed cycle (spent fuel is reprocessed).

For these reasons, the country with strategic issues the closest to those posed for the French programme is the United Kingdom. The country (which also has nuclear weapons) has a long nuclear history and a variety of nuclear facilities and activities similar to situation in France.

Therefore, it is of interest to describe the situation and ongoing projects in the UK in more detail, especially as the British government has very recently launched a new site selection programme for the implementation of a deep geological repository.

5.7.1 Waste inventory

Since the 1940s, the UK has been accumulating a substantial quantity of radioactive waste from civil and military nuclear activities. This quantity is expected to increase over the next century, as existing nuclear facilities are decommissioned, while new nuclear plants, planned by the government, will be progressively commissioned and, in turn, produce new waste. Although there are already disposal possibilities for low-level radioactive waste (such as LLW waste stored in the county of Cumbria), there is currently no solution in the UK for LLLLW and HLW.

The total volume of waste conditioned to be stored is currently estimated to be 750,000 m^3. This includes historic waste, which is already in temporary storage, decommissioning waste destined for geological disposal, as well as the waste that will result from the new nuclear programme.

The main categories of waste included in the total conditioned volume of 750,000 m^3 are:

- high-level waste, HLW (nuclear glass): 10,000 m^3,
- intermediate-level waste, ILW: 460,000 m^3,
- long-lived low-level waste, LLLLW: 11,000 m^3,
- plutonium, Pu: 620 m^3,
- spent fuel: 68,000 m^3,
- depleted or low-enriched uranium: 190,000 m^3, currently stored at around 30 sites, but primarily at surface level in Sellafield, Cumbria.

5.7.2 Previous attempts to implement disposal facilities

In the UK, several attempts have already been made to implement geological disposal facilities for HLW. In the 1980s and 90s, initial efforts focused on selecting a site for medium-level waste instead, using a top-down approach, entirely behind closed doors. This led to a license application to create an underground facility for the characterisation of rock close to Sellafield. The application was rejected during the appeal process in 1997.

Meanwhile, Nirex (the organisation responsible for disposal facilities before the creation of the public entity Radioactive Waste Management (RWM), which is now responsible for the management of radioactive waste) became the direct property of the government. In 2005, the works had already cost over £500 million, not including interest. A large part of this spending went on the drilling campaigns and studies.

A second attempt to identify appropriate sites was made from 2008 to 2013, following the methodology described in the White Paper “Managing Radioactive Waste Safely” on the safe and sustainable management of radioactive waste. To do this, local authorities had to proactively volunteer to participate and lead consultations to foster local support to host the disposal. A rigid framework required them to complete each decision-making stage in a predetermined order. In practice, this placed local politicians in a very delicate position, while preventing both the project leader (RWM) and the government from reacting to the wishes of the communities concerned. The process was ended in January 2013 after one of the three local authorities for Cumbria decided not to move to the next decision-making stage. In addition to the almost £100 million already spent by RWM, the UK government funded all the work of local authorities related to this exploratory process. In total, the direct cost reached £4.2 million.

It should be noted that implementing a geological disposal facility is essential for the authorisation of any new nuclear power plants in the UK. This has been clearly indicated in the requirements relating to future licensing decisions that the incumbent secretary of state will have to make regarding new nuclear power plants.

In addition, geological disposal is essential to the aim of the Nuclear Decommissioning Authority, which involves cleaning up end-of-life facilities and managing historic waste. HLW is currently stored in interim facilities at a number of agreed nuclear sites (the largest being at Sellafield).

When developing the current waste management programme, the UK government made the following recommendations:

"These wastes can be managed safely in the short-term in these interim surface stores, however, it is widely recognised that this is not a sustainable long-term solution. Continued surface storage represents a major and enduring liability, requiring constant monitoring and management of risk with sustained investment in renewal of storage buildings and repackaging of wastes for an extremely long period of time. As long as the waste is retained in surface storage it will remain vulnerable to environmental events and human interference. Given the length of time this material will remain hazardous it is not credible to rely on suitably qualified, motivated and funded human intervention to protect against climate change, sea-level rise, terrorist threats, and other conflict. If the UK is to continue being a respected, leading member of international nuclear energy bodies such as the International Atomic Energy Agency and Nuclear Energy Agency it needs to match this basic requirement to be able to manage and dispose safely of its own radioactive waste. This is a national infrastructure project with a local focus, and one that will only occur where there is a willing host community. Any community entering the siting process and forming a community partnership will receive annual investment of up to £1 million, rising to £2.5 million as the process progresses over 15-20 years. For the community that hosts the facility, there will be the benefit of the creation of a significant number of jobs."

RWM is implementing a consensus-based approach.

It gives local authorities and RWM a permanent right to withdraw from the project.

The planned conditions required to guarantee the success of such an approach are as follows:

- to have attracted a number of local authorities (around 10) in the implementation process;
- to have identified, assessed and compared a number of candidate sites (around 5);
- to recommend the characterisation (in particular by drilling) of at least two sites.

RWM is now ready to study different geological formations, including hard crystalline rocks and clay formations. The cooperation with SKB (Sweden) and Andra is an undeniable asset for the project to be able to share knowledge on specific disposal concepts and best practices (or scientific foundations) relating to safety and security.

5.8 SWEDEN

5.8.1 Spent nuclear fuel disposal

The site for the Swedish geological repository for spent nuclear fuel was selected in 2009 by SKB (the Swedish Nuclear Fuel and Waste Management Company). This site is located close to the Forsmark nuclear power plant, in the municipality of Östhammar.

In 2011, SKB submitted its building permit applications for the disposal facility, in accordance with the Nuclear Activities Act and the Environmental Code.

At the start of 2018, after an in-depth assessment, the radiation safety authority “SSM” recommended that the government approve the application from SKB. After 6 weeks of public hearing, the Environmental Court recommended that the government request additional information from SKB on five particular aspects of the behaviour of copper containers in disposal conditions. Since then, SKB has prepared a response to this request and documents were submitted to the government at the start of April 2019.

The content of the file includes:

- responses to all questions raised by the Court in its recommendation to the government;
- the comparison between results obtained on the behaviour of containers during experiments carried out on the surface and those from evolution simulations of those containers in disposal conditions;
- the estimated radiological consequences of the very hypothetical case of premature container failure.

The SKB documentation is based on the results from a certain number of new experiments, calculations and model analyses, as well as feedback that is already available.

The results have been compiled in around twenty scientific reports and publications. A summary report draws the main conclusions on the specific issues related to the sustainability of containers and their key role for the safety of post-closure disposal.

All the reports have been externally peer reviewed to ensure technical and scientific rigour.

The new reports confirm SKB's earlier findings regarding the durability of copper containers in the disposal environment. Using the method proposed by SKB, they show that disposal of spent fuel in Forsmark meets the long-term safety requirements after closure.

The documentation also includes the required specifications regarding compliance to the permitted operating conditions in the Swedish Environmental Code, a clearer description of the area (both above and below ground) dedicated to spent fuel disposal operations, and finally the responses to the other documents and communications submitted.

The Ministry for the Environment will now continue to review a government decision. As a result, the final disposal authorisation process will continue unhindered at this stage. The government is expected to seek the opinion of the Radiation Safety Authority (SSM), as well as the opinion of all those who participated in the public discussion held in autumn 2018, on the basis of documents provided by SKB. The Environmental Court should not be called on again as it has already fulfilled its role in the decision-making process. The government is expected to make a decision by 2020. However, the construction permit cannot be granted if the municipality of Östhammar exercises its veto.

Alongside the finalisation of the licensing process, SKB is preparing to start construction work for the Forsmark repository and the encapsulation plant in Oskarshamn, planned for 2022 and 2024 respectively, with the first commissioning around 2030.

5.8.2 Extension of underground “SFR” disposal for low-level waste

In 2014, SKB has applied for a license to expand low-level waste disposal at Forsmark, mainly for waste arising from the decommissioning of nuclear power plants. The Radiation Safety Authority has recommended that the application be approved and the Environment Court plans to hold a new public hearing session in autumn 2019. The extension will consist of 6 new disposal caverns planned at a depth of 100 to 150 m. The building works are due to start in 2023 and operation in 2029.

5.8.3 Disposal for long-lived low-level waste, “SFL”

A final disposal solution will be required for long – lived low-level waste from the Swedish system. Inventory estimation, development of dedicated technological concepts and safety assessments are all under way. The required capacity is fairly limited as it will involve about 10,000 m^3 of conditioned waste. SFL should be constructed at a depth of 300 to 500 m. The site has not yet been selected and the construction is planned for after 2030.

5.9 CONCLUSION

The Board notes that for all the countries developing nuclear waste disposal facilities their success lies in a transparent and participative process. Locally and nationally, this process involves the local authorities and citizens concerned, the safety and environmental authorities, and the scientific bodies. This dialogue contributes to the assessment of the concepts and technologies proposed. It is on this basis that a rational decision-making principle can be set up, through dialogue and mutual respect among the stakeholders, to implement a comprehensive and sustainable strategy for radioactive waste management.

The Board highlights that the decision-making processes are often very long and that it is necessary to be persistent to avoid the project stagnating, which could result in the burden of the waste being passed on to future generations.

APPENDIX I: COMPOSITION OF THE NATIONAL ASSESSMENT BOARD

Jean-Claude DUPLESSY – Chairman of the National Assessment Board – Member of the French Academy of Sciences – Emeritus Research Director at the CNRS.

Anna CRETI – University Professor, Université Paris Dauphine, Senior Research Fellow, Department of Economics, Ecole Polytechnique External Affiliate, University of California Environment, Energy and Economics, Berkeley and Santa Barbara.

Frank DECONINCK – Emeritus Professor at Vrije Universiteit Brussel – Honorary Chairman of the Belgian Nuclear Energy Research Centre in Mol, Belgium.

Pierre DEMEULENAERE – Professor of Sociology, Sorbonne University.

Robert GUILLAUMONT – Member of the French Academy of Sciences – Member of the French Academy of Technologies – Honorary Professor at the Université Paris Sud Orsay.

Vincent LAGNEAU – Professor of Hydrogeology and Geochemistry at the Institut Mines Télécom - Director of the Geosciences Centre at MINES Paris Tech.

Maurice LAURENT – Honorary Director of the Parliamentary Office for Evaluation of Scientific and Technological Options.

Emmanuel LEDOUX – Invited expert on the National Assessment Board – Honorary Research Director at the Paris School of Mines.

Mickaële LE RAVALEC – Head of the Georesources department, Geosciences Division, at IFPEN.

Maurice LEROY – Vice-chairman of the National Assessment Board – Associate Member of the French National Academy of Pharmacy – Honorary professor - European School of Chemistry, Polymers and Materials in Strasbourg.

José Luis MARTINEZ – Research Director at the CSIC (Institute of Materials Science, Madrid, Spain). Official representative of Spain on the European Strategy Forum on Research Infrastructures (ESFRI, European Commission), responsible for the strategic group in Physics and Engineering.

Gilles PIJAUDIER-CABOT – Vice-Chairman of the National Assessment Board, Professor of Civil Engineering, Executive Director of E2S, Université de Pau et des Pays de l'Adour – Senior Member of the Institut Universitaire de France.

Claes THEGERSTRÖM – Emeritus Chief Executive Officer of SKB (Swedish company in charge of managing nuclear fuel and waste) – Member of the Royal Swedish Academy of Engineering Sciences.

APPENDIX II: BOARD ACTIVITY

Since the publication of its previous report in June 2018, the Board has presented its report No. 12 to OPECST and to the relevant ministerial departments. A delegation from the Board visited Joinville on 11 October 2018 to present its report to members of the CLIS (local information and monitoring committee) at the Bure laboratory (see Appendix III).

The Board adopted the same working method as in previous years. It conducted 11 day-long hearings (see Appendix IV) and 6 closed half-day hearings including one on bitumen waste management with Andra, the CEA and the producers, all held in Paris, in addition to a certain number of supplementary meetings with parties concerned by the law. The Board members, all volunteers, heard 123 people from Andra and the CEA, as well as from French and foreign academic institutions and industrial organisations (see Appendix V). These hearings brought together around sixty people on average, in particular representatives of the Nuclear Safety Authority, Orano, EDF, the Institute for Radiological Protection and Nuclear Safety and the central administration.

The Board devoted two days to a visit to the La Hague Centre in Cherbourg and half a day to visiting the ICEDA, Bugey Plant – EDF (Appendix III).

To prepare this report, the Board held a pre-seminar of 2 and a half days during its visit to the ICEDA Centre (EDF). It also held numerous internal meetings, including a five-day residential seminar. The list of documents that it received from the organisations attending hearings is provided in Appendix VI.

APPENDIX III: BOARD PRESENTATIONS AND VISITS

Board hearings

23 June 2018:	Presentation of report No. 12 to OPECST
11 October 2018:	Presentation of report No. 12 to the Clis

Board visits

12 and 14 February 2019:	Orano – Visit to the La Hague plant
3 April 2019 – afternoon:	EDF – Visit to ICEDA – Bugey plant

APPENDIX IV: HEARINGS HELD BY THE BOARD

PUBLIC HEARINGS

18 October 2018:	Andra – Response to scientific and technical points listed following the review and analysis of the DOS file: progress point
14 November 2018:	CEA – Management of plutonium and minor actinides: current cycle, prospectives and associated research
15 November 2018:	Andra – What are the perspectives for the industrial management of low-level and very low-level waste?
5 December 2018:	CEA – Fundamental research and upstream research in the nuclear field: CEA and CNRS studies
6 December 2018:	Andra – The environmental and economic impact of Cigéo
9 January 2019:	CEA – Nuclear materials
10 January 2019:	Andra – The industrial and technical development of Cigéo: from design to incremental realisation
6 February 2019:	CEA – International overview of nuclear activities
7 February 2019:	Andra – Hydrogen management in the different life stages of Cigéo
13 March 2019:	Andra – Governance, the DUP and the technical and economic aspects/costs of Cigéo
14 March 2019:	CEA – Future reactors and associated fuel cycles

CLOSED HEARINGS

19 September 2018 – morning:	EDF
19 September 2018 – afternoon:	Andra
20 September 2018 – morning:	CNRS
20 September 2020 – afternoon:	Orano
17 October 2018:	Restricted Andra & CEA hearing on the topic of “bitumen waste management”
5 December 2019:	CEA Chief Executive Officer

APPENDIX V: LIST OF PEOPLE HEARD BY THE BOARD

NEA

IRACANE Daniel
PAILLÈRE Henri

ANDRA

ABADIE Pierre-Marie
ARMAND Gilles
BAUER Corinne
BÉRARD Émilie
BOSGIRAUD Jean-Michel
BUMBIELER Frédéric
CALSYN Laurent
CAMPS Guillaume
CRUSSET Didier
DOUHARD Séverine
DJIZANNE Hippolyte
GÉRARD Fanny
HONORÉ Delphine
HOORELBEKE Jean-Michel
KRIEGER Jean-Marie
LASSABATÈRE Thierry
LANE Eric
LAUNEAU Frédéric
LE FAILLER Nathalie
LEMAITRE-XAVIER Elsa
LEVERD Pascal
MAZOYER David
NORTURE Anne
PASTEAU Antoine
PASQUIER Cécile
PÉPIN Guillaume
PLAS Frédéric
POIROT Nicolas
POISSON Richard
QUENTEL Julie
RABARDY Myriam
ROBINET Jean-Charles
SEYEDI Darius
SCHUMACHER Stephan
TALANDIER Jean
THABET Soraya
TORRES Patrice
VINSOT Agnès
VITEL Manon
VOINIS Sylvie
VU Minh Ngoc
WENDLING Jacques
YVEN Béatrice
ZGHONDI Jad

ARIANE GROUP

CLAR Philippe

A3I

VIAND Alain

CEA

ABONNEAU Eric
ADVOCAT Thierry
BÉCHADE Jean-Luc
BERTOLUS Marjorie
BERTRAND Murielle
BOURG Stéphane
BLANC-TRANCHANT Patrick
BOUCHET Bertrand
BRIEULLE Pascale
CAPDEVILA Jean-Marc
CAVATA Christian
CHABERT Christine
CHAIX Pascal
CHAPELOT Philippe
DELAYE Jean-Marc
DEVICTOR Nicolas
DUBUISSON Philippe
FERRY Cécile
FIRON Muriel
FRIZON Fabien
GALLAIS-DURING Annelise
GALLO Danielle
GORBATCHEV Alexandre
GUILBAUD Philippe
HANUS Éric
JACQ François
GORGUE Vincent
JOURDA Paul
JÉGOU Christophe
LAZAR-SURY Anne
LORRETTE Christophe
MASKROT Hicham
MAZAUDIER Fabrice
MIGUIRDITCHIAN Manuel
MOUTIER Gilles
PEUGET Sylvain
PUSSIEUX Thierry
RIBIS Joël
SARRADE Stéphane
SAUDER Cédric
SOREL Christian

CEA (cont.)

SORNIN Denis
STOHR Philippe
TOURON Emmanuel
TRIBET Magaly

CNRS - IN2P3

BILLEBAUD Annick
DAVID Sylvain
DOLIGEZ Xavier
PETIT Antoin
SCHUHL Alain
SUZUKI Tomo

EDF

BENOIT Géraldine
BUTTIN Jérémy
GIRAUD Olivier
ISNARD Luc
LAUGIER Frédéric
PAYS Michel
ROBERT-MOUGIN Denis
SABATIER Alain
QUINNEZ Bruno

ORANO

AUGÉ Morgane
BARTAGNON Olivier
GAGNER Laurent
JACQ Patrick
LAMOUROUX Christine
LEBRUN Marc
PALOMAR Loïc
ROMARY Jean-Michel
SENENTZ Gérald
ZILBER Marine

Prefecture of Meuse-Haute-Marne

LERAITRE Philippe
MASSON Jean
VARNUSSON Mélanie

SOLEIL

SOLARI Pier Lorenzo

APPENDIX VI: LIST OF DOCUMENTS SUBMITTED TO THE BOARD IN 2018-2019

ANDRA

- Scientific and technical activity report – 2017.
- Submerged radioactive waste – Thematic dossier from the National Inventory of Radioactive Materials and Waste – 2018.
- National Inventory of Radioactive Materials and Waste – 2018.
- National Inventory of Radioactive Materials and Waste – Essentials – 2018.
- National Inventory of Radioactive Materials and Waste – Essentials – 2019.

CEA

- Annual report – The CEA at the heart of major future challenges – 2017.

IRSN

- “Impact cycle 2016” file.

APPENDIX VII: SPECIFIC POINTS RELATING TO THE CIGÉO PROJECT

VII.1 ADVANCES FOR THE PURPOSE OF SUBMITTING THE CIGÉO DAC

Recent advances in the configuration of Cigéo have been made in order to respond to the opinions expressed during the DOS review process.

The review of the DOS by the ASN/IRSN and its analysis by the Board have led to the submission of requests by the evaluators and to commitments from Andra, including the following three points:

- the justification of the favourable properties of COx from the point of view of the geometric characteristics of the constituents of the repository and the thermo-hydro-mechanical (THM) behaviour of the rock;
- the justification for the design choices that have an impact on the architectural elements of the repository;
- the justification of the technological feasibility of repository components (HLW and LLILW cells).

Consolidation of geometric characteristics of Callovo-Oxfordian clay and carbonated Oxfordian clay

Andra is committed to several areas as part of the DOS review.

- Improving knowledge of the geometry of the presumed flexure affecting the geological layers north of the Zira, which may have an influence on the depth and thickness of COx. For this purpose, Andra has reprocessed the 3D seismic data by refining the static correction. The new results do not confirm the presence of flexure within COx, which however remains visible in the underlying triassic formations. The geometry of COx, especially its dip, would therefore not be influenced by this structural feature. Andra will also move forward with a new drilling campaign at the end of 2019 to allow direct blocking of the 3D seismic block.
- Improving the representation of the porous horizons of Oxfordian clay in the hydrogeological model. This adjustment leads to overall results identical to those presented in the DOS. A comparison of the model with new hydraulic load data will be possible after the next drilling campaign.

THM characterisation and modelling

The thermal dimensioning of the cells and disposal areas for exothermic HLW waste is intended to preserve the favourable confining properties of the COx by ensuring that the temperature of the environment surrounding the waste remains in the range of the known behaviours and that the rock does not fracture under the influence of fluid overpressures. The comments made by the assessors after the DOS validate the hydro-thermo-mechanical modelling adopted by Andra but recommend reducing the Zira-wide uncertainties of key parameters such as the permeability and rigidity of COx and consolidating the envelope character of the failure criterion. For this purpose, Andra has designed additional laboratory experiments to consolidate the results obtained on the test specimen and is currently implementing an underground laboratory experiment on a HLW cell model designed to reproduce the THM evolution of a few cubic meters of rock up to an intentional fracturing. The results will be available for the DAC.

At the same time, Andra is progressing with an improvement to the THM models by comparing different approaches such as the thermo-poro-elasto-damageable model, the thermo-poro-visco-elastic model and by developing tools capable of simulating the consequences of fracturing. The current conclusion is that the thermo-poro-elastic model is an envelope of the phenomena feared. Cross-comparisons of codes are practiced internationally as part of the DECOVALEX 2019 project. Finally, Andra conducted sensitivity tests of the THM response to the medium at the COx scale, which confirms that the dominant parameters are permeability and stiffness (Young's modulus) of COx and that the refinement of cutting parameters on the vertical COx has little influence.

Repository architecture

In terms of progress of the DOS, Andra has designed the disposal architecture within Zira, prioritising the following configuration options:

- a grouping at the bottom of the bases of the surface-bottom connections to limit the hydraulic gradients within the structure;
- an arrangement following a blind mode of the disposal areas;
- a disposal plan to maximise the clay care at all points;
- long cells in order to limit edge effects and boost vertical diffusive transfer by COx;
- effective sealing of surface-bottom connections.

In order to confirm the relevance of its choices for the DAC, Andra committed to carrying out an analysis of the advantages and disadvantages of various other options.

The technological feasibility of HLW cells and their behaviour (corrosion, mechanical, hydraulic, gas)

Concerning the HLW cells, the recommendations from the DOS were that for the DAC Andra should present a cell design based on knowledge obtained by full-scale tests in the underground laboratory and the technical elements to control the hydrogen risk and monitor the atmosphere inside the cells.

For the DOS, Andra has demonstrated, based on the understanding of COx mechanics, its ability to produce cells of at least 100 m in length oriented along the major horizontal principal stress. The current construction method provides for the installation of a lining consisting of a semi-rigid assembly of steel elements. The use of a filling material on the upper surface of the lining to limit the gaps and to reduce the corrosion phenomena of the steel, has subsequently necessitated an evolution of the concept in order to ensure a better centring of the lining to obtain a homogeneous distribution of the filling. Andra has demonstrated the technical feasibility of a 112-m cell realised according to the following sequencing: excavating the bare hole, putting in place a lining and then filling the annular space. For the DAC, Andra must now demonstrate that the technology developed can realise 150 m long cells, planned for the HLW1/2 areas in the reference configuration.

Alongside this technological feasibility study for the cells, Andra is preparing a measuring and monitoring programme for their thermo-mechanical and chemical (THMC) behaviour. This programme, which must produce the first results before the DAC, relates to:

- the external instrumentation of optical fiber cable lining to monitor its thermo-mechanical behaviour;
- the qualification of sensors for the monitoring of chemical parameters (gases, corrosion, samples) within the cell;

- the validation of a process to inert the atmosphere.

After the filing of the DAC, it is planned to test this equipment on a surface test bench and on a test cell representative of the HL0 concept in the underground laboratory.

LLILW shafts and cells (feasibility, mechanical strength)

For the DOS, Andra acquired extensive experience in the underground laboratory in excavating large diameter shafts (up to 9 m) using different methods (impact ripper or tunnelling machine) and comprising different modes of support/coating. The use of different excavation methods is required to be able to adapt to the different geometries of the underground shaft delineation. Studies have shown that it is possible to construct structures oriented according to the major or minor horizontal stress, the latter configuration offering more difficult conditions for realisation. They have also shown the value of integrating compressible elements into the retaining wall to limit loading on the structures, generated by the convergence of the rock mass, whatever the method of excavation. For the DAC, Andra must now consolidate the methods up to an industrial qualification, especially as regards the laying of compressible materials. After filing the DAC, Andra plans to build an LLILW cell demonstrator of about 9.65 m in diameter in an underground laboratory using the traditional method using an impact ripper. The dimensions of the underground laboratory do not make it possible to use a tunnel boring machine of sufficient diameter. Andra will also study the behaviour specific to shaft junctions.

This technological programme is accompanied by a scientific programme, which following the DOS aims to improve the understanding of the mechanical behaviour of the rock in connection with the excavation method and that of the role of the damaged area (EDZ). The main newly gathered results relate to:

- the lack of scale effect on the type of the fracturing in the damaged area and on the rate of deformation of the structures between the 5-m diameter shafts and those of 9-m;
- the finding of self-clogging of the fractures under the effect of hydration in the clay unit (CU) of COx. However, this phenomenon is less apparent or does not occur in the silt-carbonate unit (SCU) at the top of the COx.

VII.2 HYDROGEN MANAGEMENT IN CIGÉO

Hydrogen management during operation

The identification of hydrogen sources in Cigéo makes it possible to take preventive measures against ATEX (EXplosive ATmoshere) risks.

Equipment

The batteries in some equipment may be potential sources of hydrogen. The associated risk management is part of the standard regulations within the industry. It is based on ATEX risk zoning, the setting up of protected dedicated premises equipped with detectors for recharging batteries and the use of safety valves.

LLILW areas

Radiolysis in some LLILW containing hydrogenated materials also generates hydrogen. A high number of packages in a confined space makes it necessary to take into account ATEX risks.

Hydrogen emissions are subject to a producer acceptance specification, with a limit of 40 L H_2/package/year for the majority of packages, and up to 120 or 300 L H_2/package/year for a limited number of packages subject to specific processing.

The resistance of containers has been laboratory-tested. The long-term release of H_2 is simulated by directly injecting He into different types of containers (screwed or keyed). The surface gas flow and the internal pressure are measured. Tests have shown that the properties of the containers allow most of the injected H_2 to escape without increasing pressure. The overpressure is negligible (less than 0.004 bar with an equivalent flow rate pushed to 90,000 l H_2/package/year), which excludes any damage to packages. During these tests, the equivalent composition in the package remained very far below the ATEX risk threshold. 0.06% of the lower explosive limit for screwed packages at 100 L/year, 11% for keyed packages.

Trials have also been carried out to test the containers' resistance to damage in the case of an internal explosion. To do this, a mixture of air and H_2 was artificially injected into the container in order to create maximum reactivity conditions. With the characteristics of hydrogen, the energy released remained low: the internal temperature rose to 260°C, then fell very quickly (50°C in 1 minute, initial temperature in 30 minutes), the overpressure is limited (5 bar and return to initial pressure in 3 seconds). The released gas (water vapour) dissipated through the container-lid interface and condensed. After the test, the gas flows removed the binder between the container body and its lid; however, the body and the lid retained their integrity, which makes it possible to envisage a normal handling process for the recovery.

The repository is designed to release gases. A specific device is provided to eliminate gases produced in the case of immobilisation in the fume hoods. In the LLILW cell, gases are released through ventilation. Aeraulic calculations show the absence of a point of local accumulation between the containers: the dimensioning of the flow rates is well beyond the needs, with a margin of safety of three orders of magnitude regarding the ATEX risk (H_2 content <0.003% for a lower explosive limit (LEL) of 4%)

The resilience of the ventilation has received special attention: redundancy (blowers and extraction fans), segregation of this equipment, design for earthquake resistance, emergency power supply. Finally, in case of failure, the design of the natural ventilation and the distribution of the packages according to their emissions ensure 100 days' maintenance below the ATEX risk (75% of the lower explosive limit). This time period allows enough time to intervene to restore ventilation before reaching the risk zone.

HLW areas

For HLW cells, corrosion of lining steels and containers under anoxic conditions produces hydrogen. These conditions are fulfilled after closure of the cell, which is isolated from the atmosphere of the shafts and after consumption of the residual oxygen by near-field oxidation reactions. The hydrogen produced under these conditions, in the absence of oxygen, does not lead to specific ATEX risks. The risk occurs when it is mixed with oxygen from the shafts when the gas concentration exceeds 4.5% oxygen. This can happen as a one-off event when the cells are opened to retrieve packages, or in a diffuse manner by migration of gas between the cell and the shaft through the closure devices or the EDZ.

To mitigate this risk, Andra first relies on passive constructive measures. Injection of annular filler material decreases the void volumes available for gas accumulation. The tightness of the cell head is reinforced by the installation of a waterproofing membrane around the docking mass. Finally, the diffusion through the rock between the cell and the shaft is limited by the injection of clogging material into the rock near the cell head.

Andra is currently studying a design development of HLW cells with active devices to ensure an oxygen content of less than 1% in the cell. The device is based firstly on gas sampling probes behind the cell head, and secondly on the nitrogen purge of the cell. This is a significant development: the lining would thus incorporate in the upper part a guide for several casings designed to inject nitrogen into the bottom of the cell and allow a return of the gas taken at different points. The nitrogen needed for the purge would be produced in a specialised unit probably installed in Cigeo. The complete design of the device, its implementation and associated instrumentation in the detailed preliminary design will be ready for the filing of the DAC. After the DAC is filed, tests are planned in the underground laboratory to study the feasibility and on the surface test bench for the entire device.

Hydrogen management after operation

The estimate of source terms after operation throughout the whole of the repository forms the basis for the hydrogen management. It is based on the compatibility of the source terms (types of packages) and knowledge of correctly identified process (anoxic corrosion and radiolysis). The source terms may then be transformed into hydrogen production logs in order to feed digital hydrogen transfer simulations.

The THM calculations therefore include hydrogen production depending on the age of the packages and on how far the restoration phases have progressed. The calculations may quantify the different flows surrounding the disposal. They show that diffusion to the COx is the main means of hydrogen migration. In addition, the impact of hydrogen production on the pressures and constraints is quantified. It is taken into account in the calculations to size the structure.

The calculations being made aim to reduce uncertainties. On the one hand, they come from the design choices to be finalised (in particular steel mass and developed surface), on the other hand they come from processes (corrosion kinetics for gas production; chemical reactions with COx for its consumption).

VII.3 REGIONAL BENEFITS OF CIGÉO

The creation of the underground laboratory in Meuse-Haute Marne has required regional authorities to volunteer to host this structure, undependably from the quality of the subsoil. In fact, since the Law of 15 July 1982 on guidance and programming for research and technological development, the legislator has envisaged supportive measures and proposed the creation of a public interest group (GIP) to implement them. The Law of 30 December 1991 on research into the management of radioactive waste mentions, in article 12, the possibility of creating a GIP in order to carry out supportive actions and to manage equipment so as to encourage and facilitate the installation of each laboratory.

Consequently, the “Objectif Meuse” and “Haute-Marne” GIPs were created by interministerial decrees on 20 May and 16 August 2000, respectively. They were renewed by inter-ministerial decrees on 9 May 2007 (modified on 29 June 2007 for the “Haute Marne” GIP to correct an error in the name of the municipalities) to take into account the changes brought about by the Law of 28 June 2006 on the sustainable management of radioactive materials and waste.

Both GIPs are responsible for implementing supportive measures in aid of Andra’s and the Cigéo project’s underground research laboratory.

Their role is to:

- manage the equipment to encourage and facilitate the installation and operation of the laboratory or of a possible repository centre;
- carry out spatial planning and economic development actions within the limits of the two departments concerned;
- support training initiatives and actions promoting the development, improvement and diffusion of scientific and technological knowledge.

To this end, they benefit from the additional tax on basic nuclear installations, which is made up of a technological diffusion endowment and a support grant. Their action respectively covers all the departments of the Meuse and Haute-Marne, but some territories, close to the underground laboratory of Bure, are also entitled to receive special support; they are part of the local area.

In 2018, the financing agreed by the “Objectif Meuse” GIP was approximately €30 million. Particular attention was paid to the local area, which benefited from 84% of aid.

In 2018, the financing agreed by the “Haute-Marne” GIP was approximately €29 million. Since the creation of this GIP, almost all of the financing has been distributed in the form of grants, i.e. financial aid that does not need to be repaid: about 1/3 is allocated to businesses and innovation, another 1/3 to equipment and services to the population and 1/5 to networks (road access, water and sanitation, digital, etc.). In 2018, 63% of the funding put in place was for the local area, which represents 41% of the population of the Haute-Marne department.

It is difficult to assess the influence of this funding on the economic fabric of these two departments. No figures are available to estimate the returns on investment or the number of jobs created or preserved. Alongside the actions carried out by the GIPs, EDF, CEA and Orano are also working for local economic development by creating facilities and helping local businesses to specialise to better meet the demands of nuclear operators. Figures provided by Andra show 1773 jobs created or sustained between 2006 and 2014 thanks to these different actions. This should significantly increase during the transition to the construction phase, with the creation of direct and indirect jobs.

The principles of economic support for the territory by Andra are today structured around the presence of the underground laboratory. Together with the levers already mentioned, they are based on a local anchoring of activities: local purchasing policy, reception of demonstrators on the territory (for example demonstrator of the ramp implemented by POMA in Froncles in Haute-Marne). A policy of supporting local initiatives is also implemented by Andra and the producers. The CEA is accompanying and structuring innovative technological and industrial activities in the local area, with the creation of Parc'Innov de Bure-Saudron.

A diagnosis for the forward-looking management of regional employment and skills was conducted with all stakeholders, particularly in relation to the needs and opportunities generated by Cigéo. Andra contributes to training through apprenticeships and continuing education, as well as partnerships with vocational high schools in the region.

APPENDIX VIII: STUDIES AND R&D IN THE CONTEXT OF THE CURRENT NUCLEAR POWER STRATEGY

The studies and R&D carried out by CEA, EDF, Orano and CNRS, presented to the Board this year, have had various different objectives but for the most part they have been part of the Astrid programme. The Board is assessing them all and stresses that the research conducted for Gen IV also has implications for the current system. These studies benefit from fundamental research; this should therefore be maintained at the highest level.

ASTRID AND ASSOCIATED GEN IV PROGRAMMES

The deployment of an FNR fleet is now only been considered for the end of this century. As a result of this, the Astrid programme has been significantly scaled back. The CEA has presented a review of the Astrid Programme to the Board. The final review "End of Agreement File" is expected for the end of 2019. Furthermore, the TECV Act will lead to the reduction of the number of reactors in the current system and to changes to their management. It is in this context that the Board is assessing the research.

Scenarios

In its previous reports, the Board has established scenario studies for the transition from the current fleet to an FNR fleet. The scenario exercises are based on calculation codes that can be activated to shed a light on different strategic paths for the cycle and to test the sensitivity of the results to the hypotheses: power of the fleet, lifetime of the reactors, availability of the facilities of the cycle. Article 51 of the PNGMDR decree of 23 February 2017 (PNGMDR 2016-2018) asked waste producers (CEA, EDF, Framatome, Orano) to complete the previous studies (Pu, U, minor actinides inventories at different stages of the scenario, industrial constraints, renewal of cycle installations), and to confirm with Andra the impact on the management of waste destined for deep disposal for each option. The study shows that PWR multi-recycling leads to an accumulation of minor actinides in the cycle and, more specifically, to a higher level of use of Cigéo.

The CNRS is studying scenarios for managing the evolution of the nuclear power generation fleet using a different methodology to the CEA. It involves optimising the achievement of an objective by playing on the possibilities offered by a fleet, for example a PWR fleet or a mixed PWR/FNR fleet. The method examines an almost infinite number of trajectories defined by sets of hypotheses to derive the scenario or scenarios likely to achieve the objective. The hypotheses of the trajectories continue to change as long as the objective is not reached. The CNRS CLASS code makes it possible to explore many trajectories but takes many hours of calculation. For example, to stabilise the amount of Pu in a PWR or PWR/FNR fleet, the power of which reduces the analysis by 10,000 trajectories, makes it possible to define the proportions of MOxed PWRs or the number of FNRs in relation to the PWRs and to quantify other characteristics of the proposed mix.

FNR fuel assembly

MOx fuel assembly is the basic object of the core of an FNR. This is a complex object. The CEA, EDF and Orano have been studying the production of a fuel assembly for the Astrid reactor for 10 years. The Board has analysed the continuous and innovative progress the CEA has made on the development of mixed oxide, the manufacture of pellets, their cladding and installation of the needles in hexagonal tubes. The aim of the CEA was to control all the parameters of fuel production: to predict the characteristics of the mixed oxide (microstructure, granulometry, flowability, etc.), pellets (density, etc.), cladding and hexagonal tubes, and to develop the tools used for their industrial production. The CEA will then have a complete scientific computing tool.

Materials for Gen IV reactors

The CEA presented the Board with a review of the R&D on fuel cladding materials and structure of Gen IV FNR, sodium-cooled (SFR) or gas-cooled (GFR and VHTR). These materials must be able to resist 1) high temperatures in normal operation: 350-550°C for SFR, 600-1200°C for GFR and 400-1100°C for VHTR, but also in incidental or accidental situations at temperatures up to 2000°C; 2) at irradiations up to 150 dpa; 3) at coolant pressures of 70 bar for GFR and VHTR.

For Astrid type FNRs, the phenomena feared are the thermal creep of the hexagonal tube and stainless-steel cladding. This results in irreversible deformations. For some years, it has been known that Fe-C-Cr-W-Ti type steels in which nanoparticles of $Y_2Ti_2O_7$ are precipitated do not exhibit this phenomenon, at least up to 160 dpa (ODS steels). The oxides block the movements of dislocations. The CEA already has experience in the laboratory manufacturing of 9 and 14% ODS Cr steels and FNR cladding (tubes 0.5 mm thick, 1 cm in diameter and 2.5 m long). Their microscopic and macroscopic characterisation shows that samples irradiated at high temperatures have a good mechanical resistance. This is due to the behaviour of chromium at the grain boundaries. Given the reorientation of the Astrid project, this programme is no longer a priority.

Silicon carbide (SiC) is known to be the most effective material at high temperatures (1000 to 2000°C) and under radiation, in terms of resistance to oxidation and thermal resistance but, like all ceramics, it is fragile and subject to a loss of conductivity in function to the temperature. Its use in the nuclear industry requires it to be used in composite form, for example SiC fibres coated with an SiC or SiC fibre-metal matrix. To manufacture the objects, SiC-fibre is braided around a Ta tube to make the cladding. The mechanical strength and the resistance to neutron irradiation (120 dpa) or sealing (using a metal lining) by helium under pressure and the volatile fission products must be studied and modelled. Similarly, the study of oxidation of SiC by O_2 or H_2O vapour (or that of its behaviour with respect to sodium and fuel) must be completed. The CEA participates in the European research programme Matisse dedicated to this research and it is planning a collaboration with the USA (ORNL).

Recycling Pu and S&T

It is known that the Purex process must be adapted to separate U and Pu from Pu-rich fuels such as PWR MOx or spent FNR MOx. Since 2013, the CEA has been developing a new process based on the extraction of U (VI) and Pu (IV) by a monoamide in an organic phase and their aqueous phase desextraction in one cycle by a simple modification of the nitric acid content. In 2017, the CEA filed a patent for the Pu and U separation of a simulated nitric solution of spent UOx fuel (involving a mixture of 2 monoamides) and another patent involving only one monoamide. In 2018, the CEA conducted a pilot test on a simulated PWR MOx solution (Pu / (U + Pu) = 10% with this process and selected 5 new molecules combining a good viscosity, a good load factor of U + Pu and good selectivity. The CEA is also perfecting mixer-settlers and pulse columns.

As for the other experiments, the processes have been modelled. The CEA aims to establish the technical feasibility and then extrapolate to an industrial level.

The Gen IV initiative revived R&D in the area of separation of U, Pu, minor actinides and fission products from spent UOx/MOx fuel. The first stage relates to recycling Pu and U, which has only reached industrial levels in the case of PWR UOx fuel. The second involves the separation of minor actinides in the laboratory. France, the US and Japan have all developed different processes, and, in the context of Europe, many countries have been involved in programmes from the 7th FPRD, including SACSESS. In Europe, under pressure from France, all processes have now been converged towards hydrometallurgy. The use of mono-amide or di-amide type extractant molecules associated with other complexing molecules makes it possible to separate and reach the desired decontamination factors. The OECD has just published a state of the art on knowledge of the subject.

On a global scale, as well as in France, studies on minor actinides are decreasing. Only collaborations will be able to maintain a minimum of studies focusing on the separation of americium. This is why Europe has recently launched the Geniors Horizon 2020 project (2017-2021): 24 partners and 11 countries, in collaboration with the US Department of Energy, with a budget of €7.5 million over 5 years. The aim is to revisit the processes that have already been studied, but at laboratory level. There are no tests planned on real solutions.

CEA's activity in terms of transmutation consists of examining samples of americium-charged covers (U/Am/O oxides) irradiated for one year in the HFR between 2011 and 2012 (Marios analytical experiment, 4 mini-needles and 6 discs with different porosity). Marios makes it possible to obtain transmutation and fission rates and to characterise helium behaviour as a function of the microstructure (porosity, etc.) and temperature. Other samples were irradiated (Diamino analytical experiment in Osiris), semi-integral experiments Marine and Sphere.

The first examinations show that it is preferable for the U/Am/O oxide to have open porosity to prevent swelling. The theoretical and measured values of the transmutation rates are in excellent agreement.

Eleven European countries have submitted the Transmeets programme to the European Union to continue examining samples irradiated by the CEA and to improve/develop codes for the design and qualification of transmutation fuels on the basis of all the results of previous programmes. Transmeets is part of the SNETP platform and has the EERA-JPNM label. The decision to launch Transmeets is expected to be made at the end of 2019.

R&D SUPPORTING THE CURRENT CYCLE

La Hague

The TCP (specific fuel processing) facility under construction at La Hague upstream of UP2 800 aims to increase the capacity of the plant to reprocess civil and military MOx fuel that is rich in Pu, or assemblies of experimental reactors. It should be operational by 2026. Its functions are to shear the assemblies and dissolve the fuel (750 tMLi over 30 years). Regarding the dissolution of insoluble Pu (IV), the CEA is closely studying an Ag^{2+} oxidation process produced in situ in nitric acid.

Manufacture of UOx and MOx fuel assemblies

The CEA, EDF and Framatome are very involved in the development of innovative cladding (chromium-plated cladding or that using ceramic materials) for PWR UOx and MOx fuels. This cladding could enhance safety in event of an accident. The CEA has a pilot plant that produces this cladding: weaving around a SiC-fibre Ta tube (then infiltrated by SiC vapour deposition), internal coating of the same material on Ta (programme on fuel known as E-ATF). The Ta tube ensures seal tightness, the weave ensures external mechanical and chemical protection, and the SiC inner lining ensures chemical protection for the fuel. There are a number of developments in progress.

Some European programmes on the subject have been launched under the H2020 initiative, including irradiations in reactors of samples or fuel-filled rods. The CEA estimates are at level 4 or 5 on the TRL scale.

In addition, the CEA is developing innovative processes for additive manufacturing (AM) to produce complex metal parts of reactors of varying sizes (Samanta platform in Saclay). The thicknesses successively added by fusion range from 15 microns to 15 mm depending on the equipment. The R&D that accompanies these undertakings relates to optimising and controlling the parameters (size of the powder grains, speed of the deposits, quality control, etc.) that condition the microstructure of the metal and its resistance to irradiation.

Nuclear glass

The temporal physicochemical characterisation of nuclear glass and the study of its behaviour in the presence of various aqueous solutions (in the laboratory or in situ) has led to a solid body of knowledge that has been taken into account in the safety analyses looking into disposing it geologically. However, the fundamental mechanisms of radiolysis phenomena are not all known. Nuclear glass is subjected to considerable dose rates and will incorporate no less significant doses before being leached. The maximum cumulated dose for which aged glass will retain the properties on which the long-term modelling of its behaviour is based should be known. At present, no measurements have been made on an industrial glass.

The CEA presented a state of the art on auto-radiolysis of nuclear glass samples based on recent experiments (2014-2018) and the results of more than 20 years of research on R7T7 glass.

The self-irradiation of the glass by beta and gamma radiation modifies the electronic interactions, while the alpha radiations produce helium and recoil nuclei, which create gaps. The separate effects of electronic and nuclear dose rates on glass properties (structure and reactivity) have never been quantified.

The CEA presented a series of results from experiments with doped glass ($^{239,\ 238}Pu$, ^{241}Am, ^{244}Cm), irradiated with beams of electrons or ions (He, Au, Kr) or with ions (He, ^{7}Li) produced in situ in a reactor in ^{10}B ($^{10}B\ (n,\alpha)^{7}Li$) doped glass. These results confirm that nuclear glass is particularly resistant to dose accumulation with saturation effects. From a certain threshold dose (2 to 3 GGy for α β γ), its properties (decreasing hardness, increasing density, increasing toughness, microstructure, coordination change of boron and other elements, redox chemical modification, defects which increase, etc.) do not vary much anymore. An internal anneal occurs when the stored energy reaches 100 J/g (around 10^{18} α/g, i.e. a nuclear dose evaluated at 40 MGy). It is the nuclear dose that controls the microstructural state. The vitreous state is maintained after stabilisation doses. The solubility of He can reach up to 3 atomic% before the appearance of bubbles, a limit that is far from being reached in glass in disposal. The more chemically complex the glass is (type R7T7, for example) the less the effects can be seen.

Atomistic modelling by standard molecular dynamics of the effects of collisions between recoil nuclei and the atoms of the glass makes it possible to statistically predict the changes of position of the atoms and consequently the structure of the disturbed glass. The CEA has conducted simulations on a three-component glass (SiO_2, B_2O_3, Na_2O) and found the experimental variations in the macroscopic properties of glass (density, hardness, toughness) and the saturation effects, which are related to the nuclear dose.

The alteration of nuclear glass by water has been studied for a long time and phenomenological models are available to account for it. There are several alteration rate ranges that can be measured by releasing boron in solution. Schematically, the initial V_0 velocity (micrometre/day) corresponds to the leaching of the glass when the vitreous network begins to hydrolyse on the surface. It decreases rapidly and stabilises at a residual value V_r (nanometre/year) when the surface is covered with hydrated silicates. The CEA has studied the effects of α, β, γ dose rates and cumulative doses on V_0 and V_r velocities from doped glass or external irradiations, using non-radioactive glass as controls. All results show that there are no effects on V_0. The velocity V_r is insensitive to the dose rates at least up to 3,500 Gy/h in α and 10,000 Gy/h in β, γ. It increases by a factor of 3 with the cumulation of alpha dose up to 15 MGy (10^{18} α/g) and stabilises above this, and is insensitive to the cumulation of β, γ dose, at least up to 0.5 GGy. These data cover the conditions of a glass in disposal conditions. More measurements are being made to cover other leaching conditions and dose accumulation ranges.

In January 1994, Cogéma carried out two sample-taking activities on a glass casting in the T7 facility. 13 g of powdered glass were leached in 130 ml of pure water at 90°C, all in a stainless-steel reactor under argon atmosphere. Under these experimental conditions, the velocity V_r is higher (by a factor of 10) than for an inactive glass of the same composition (Scores 1 experiment). Although this increase has no impact on the safety analysis based on the initial velocity V_0, in 2015 the Scores 2 experiment was started to understand this as yet unexplained discrepancy. The experiments will continue until 2023.

FUNDAMENTAL RESEARCH

CEA-DEN

The developments in separation processes and irradiation experiments for transmutation have been strongly supported by fundamental research at the CEA

Several examples of simulations under development based on previous studies have been presented to the Board: multi-scale behaviour of irradiated metallic materials, evolution of the micro-structure of fuel pellets, behaviour of Pu and other actinides in the cycle, sonochemistry of nuclear solutions.

The multi-scale/multi-physics model developed by CEA and EDF to simulate the effects of irradiation of metallic materials by neutrons is appropriate and is close to achieving the modelling of a macroscopic sample. The modelling of the evolution of the properties of the oxides of actinides must be continued as the phenomena induced by the fission and the nuclear reactions are numerous. The modelling of the change of the mechanical properties of the pellets in function to the evolution of the microstructure is still far from being understood, even on UO_2.

In terms of separation, the modelling of species in solution and in interphases progresses by means of combining many experimental and theoretical techniques. The simulation of processes from characterisations at the molecular level is a long-term task. An extremely high number of collaborations are involved.

The sonochemistry is well developed at Marcoule (ICSM). Acoustic cavitation bubbles are microreactors (high temperature and high pressure) that generate free radicals that are effective for developing oxidative reactions (under oxygen) or reducing reactions (under Ar). A great deal of progress has been made in the physico-chemistry in bubbles and this can be simulated for ultrasonic waves from 16k Hz to 1MHz under different atmospheres. Sonolysis can facilitate the dissolution of solids, such as the oxides of actinides, or produce unstable oxidation levels of actinides without adding chemical reagents to the medium, thus avoiding secondary phenomena such as corrosion. This high reactivity potential is being studied in several areas of the fuel cycle where many solid-liquid or liquid-liquid heterogeneous systems can be found. The simulation aims to identify applications such as the reductive dissolution of Pu (IV).

CNRS and universities

The CNRS decided to relaunch the NEEDS programme in 2020 with the aim of studying the fundamental mechanisms/processes and acquiring basic data of interest for nuclear energy under three main themes: reactors and energy transition; waste characterisation and disposal; and resources, environment and territories.

Furthermore, at the start of 2018, the CNRS (IN2P3 and INC) created the Research Group SCINEE (Nuclear Science for Energy and the Environment). The four themes of the research group are: nuclear systems and scenarios, fuel cycle, materials under stress and environmental radiochemistry, radioecology. It gathers together and gives visibility to studies from the academic scientific community working in the nuclear field. It calls on large laboratories and major instruments such as Soleil. This reorganisation should favour collaborations in order to respond to calls for tenders. This research group coexists with other CNRS programmes such as the IN2P3 Master Projects (disposal, irradiation).

The presence of radionuclides in the environment is ubiquitous and raises questions as to their potential impacts on living systems. In the final analysis, the behaviour of radionuclides in the environment can only be properly predicted if the physicochemical forms in which they are involved are known. This is why the speciation of radionuclides is at the heart of numerous theme

4 SCINEE reserach group studies. Several domains are covered: comparisons of man-made (mining zone) and natural areas (Mercantour), Pu (colloids) and U (mixed carbonate with Ca) in seawater and Pu/U (metalloprotein complexes) in marine organisms (sea urchins), complexation of actinides by biological ligands.

Fundamental research has also resulted in the acquisition of key scientific knowledge for the design of deep geological disposal. Research efforts will have to continue and must continue during the construction of Cigéo. Subatech (CNRS and IN2P3) is involved in the study of major physicochemical issues, particularly within the context of European projects (see EURAD project). As part of this, Subatech contributes to developing 3D simulations of disposal by increasing the complexity of the systems and components taken into account (components envisaged for Cigéo, for example). Subatech is also involved in the integrated Carbon 14 study led by Andra and Orano.

Soleil

Soleil's (CEA DEN and DAM) Mars (Multi-Analyses on Radioactive Samples) resource is available to the scientific community for X-ray characterisation (absorption, fluorescence, diffusion and diffraction in the range 3.5 to 35 KeV) of radioactive samples (soon up to 18 GBq). It is a remarkable tool. The X-ray frequency range permits the characterisation of the actinides and the main fission products. The CEA and CNRS have presented several recent results to the Board, including the first diffraction spectra on a 1 mm sample taken from a radius of the cut of an irradiated needle in a Gravelines PWR of a thickness of 50 microns (5 years of irradiation, 23 years of cooling).

CONCLUSION

The discontinuation of the Astrid programme has a direct impact on the future of R&D for the CEA DEN and nuclear engineering. While future R&D programmes are not fully defined, it will also have consequences for R&D conducted by other organisations.

The Board believes that a new R&D programme, supported by strong fundamental research, is now to be put together to address the many challenges of this new strategy and to involve the entire scientific and technological community in a major effort.

APPENDIX IX: OVERVIEW OF THE MAIN TRENDS IN THE DEVELOPMENT OF NUCLEAR POWER PROGRAMMES AROUND THE WORLD

The CEA hearing of 6 February dedicated to an international overview of nuclear activities clearly shows the rising power in Asia.

China is developing its own designs and seeking to conquer the international market (see the HPR 1000 project in the UK); it opts for a closed fuel cycle.

Russia maintains an ambitious national programme and a strong industrial network, covering all key technologies (PWR, FNR, fuel cycle), it has a very aggressive (integrated) export offer both in terms of reactors and services for the fuel cycle; it is developing an option for multi-recycling MOx (REMIX process) for its foreign customers.

As public support for nuclear weakens in some Asian countries (Japan, South Korea), they are increasingly turning to export or the development of essential expertise in clean-up and decommissioning (special case of South Korea in phase-out).

The United States relies on the DoE and the NRC to promote innovation (nuclear in competition with gas), simplify licensing, involve the regulator as early as possible in the development of new concepts (pre-licensing), develop public-private partnerships to finance R&D (not forgetting start-ups) and open national laboratories to the private sector (GAIN initiative) so that it can access the experimental facilities required to qualify the new concepts; Americans are trying to stay in the game by focusing on niche markets and opting for smaller reactors (SMR, micro-reactors) that open up new market opportunities (co-generation, industrial heat for different industries, etc.).

In the wake of Brexit, the UK is attempting to regroup expertise and restart its nuclear power programme by relying on short-term projects (EPR, HPR 1000) contracted with foreign partners, and in the longer term on development backed by public-private partnerships that are subject to calls for interest that are more focused on small reactors (SMR and AMR (Advanced Modular Reactors)), particularly to manage its Pu stocks.

The situation in Sweden and Finland is detailed in report no. 11.

Europe is losing ground and has many anti-nuclear countries, and at least tries to maintain security expertise and coordinate R&D activities dedicated to C&D and waste management through technological platforms (or consortia) that establish a common road map and manage the calls for projects and the sharing of funding by delegation (objective for the Commission: save money by avoiding duplication). We should note the adoption by the European Commission in 2011 of a directive on the management of spent fuel and waste, which was the subject of a first assessment showing significant disparities in the documents produced, with difficulties in defining the phase after closure of the geological disposal of waste (for those investigating this option);

In this context, the multilateral initiatives that are supported by EURATOM (SNETP technology platform, EURATOM-fission component of the H2020 programme, various joint programming projects of the “European Joint Program” type with, for example, the JOPRAD project dedicated to geological disposal, etc.), the NEA (GIF, IFNEC, MDEP, NI2050, etc.) or the IAEA (INPRO, etc.) are of paramount importance in order to share R&D efforts and to harmonise methodological references or good practices, particularly in terms of safety, radiation protection and waste management.

The NEA has set itself the objective, for example, of rallying efforts to further knowledge (explicit or implicit, see activities of the Nuclear Data Bank), to identify the technological options that make it possible to optimise costs, or to share best practices in terms of innovation (see Nuclear Innovation 2050) and pre-licensing of new designs proposed (short-term SMR type advanced reactors, or longer-term 4th generation reactors, see the activities of the WGSAR). The rise of the theme of decommissioning led to the establishment of a dedicated committee at the NEA.

It should be noted that 162 reactors have been shut down across the world. Some countries have a significant feedback programme (USA, Korea, UK, Germany, France, Japan, Lithuania, etc.), which is supported to a greater or lesser extent depending on the country (USA DoE programme of $6,600 billion). Cost optimisation is essential, and feedback must be pooled internationally as soon as possible by creating networks.

The European “Share” programme submitted to the Commission in 2018 (probably accepted in June 2019) aims to pool feedback and good practices for C&D (standardisation, a road map for the next 10-15 years, provision of new technologies, etc.). The launch of a European consortium also involving the EPRI is being reviewed. The ELINDER relates to training. The INSIDER programme is used to characterise facilities to be decommissioned.

France has undisputable assets in this domain. The CSFN (Strategic Committee of the Nuclear Sector) produced a report on the international market outlooks. CSFN and GIFEN (French industrial nuclear energy grouping) aim to structure the French sector around this theme, as well as on the technological offer for export of nuclear reactors (development of an SMR concept, World Nuclear Exhibition held every 2 years in Paris inspired by the event organised at Le Bourget for the aerospace industry, etc.). It should also be noted that, in cooperation with Orano and Veolia as part of the Demeterres project, the CEA has developed a decontamination (“flotation foam”) process that has been successfully tested in Japan on several hundred kilograms of earth from the Fukushima region.

APPENDIX X: INTERNATIONAL OVERVIEW OF NUCLEAR POWER PROGRAMMES

The CEA has presented a strategy to the Board for the development of reactors and associated fuel cycles for the main countries producing nuclear electricity. In this appendix, the Board examines the main elements characterising these countries in relation to the situation in France.

CHINA

The strategy of a closed cycle and deep geological disposal was reaffirmed last year in a bill. Three companies are currently managing a fleet of 45 reactors (58 GWe by 2020, or 4% of the electricity mix): CNNC, CHN and the State Power Investment Corporation.

Twelve reactors are under construction and 30 are being planned (120 GWe by 2030).

China is testing all technologies (GEN II, III and IV) and power ranges: CANDU, PWR (including VVER, AP1000, EPR and SMR, etc.), FNR, HTR, MSR (TMSR project), and appropriating them, developing Chinese brand concepts and positioning itself on the export market (see project in the United Kingdom).

The 13th five-year plan (2015-2020) provides for the construction of GEN III reactors of Chinese (CAP 1400, Hualong 1) and foreign (AP 1000) design, without explicitly mentioning the commissioning of the Taishan EPRs.

After coming into possession of an experimental FNR of Russian design (CEFR, 20 MWe), China has been developing its own programme with a 600-MWe demonstrator (CFR-600) then a 1000-MWe commercial reactor (CFR-1000).

Similarly, China relies on Tsinghua University, which operates a small German-designed 10-MWe HTR reactor to develop a 600-MWe demonstrator (reactor under construction).

The spent fuel is stored in pools on site at the plants (for 10 to 20 years), all near the sea cost, as well as dry on two sites, and there are 2 centralised pool storage facilities in Inner Mongolia (Jinta, capacity of 1200 t, and Diwopu, capacity of 500 t, which will be extended to 800 t).

China commissioned a pilot reprocessing plant in Diwopu (500 t) in 2010 using PUREX technology to produce FNR fuel for the CEFR. A second unit at the Jinta site (200 t/year) is expected to be operational by 2023, again to produce FNR MOx. A commercial plant project (800 t/year) based on PUREX technology is under consideration to produce PWR MOx in this case.

There are three storage sites for SLLILW (including one in the Guangdong province in the coastal area, where the reactors and major cities are mainly located, and two inland in the provinces of Gansu and Sichuan). Five other plants are planned in the coastal region as part of the 13th five-year plan (as the volume of SLLILW is set to reach 34,800 m^3 by 2020).

The selection of sites for the geological disposal of HLW in the granitic region of the Gobi Desert (Beishan region) is ongoing (construction of an underground lab will begin in 2020). The design is similar to that of the Swedish KBS3.

RUSSIA

Rosatom (a state structure) manages all Russian reactors and all plants in the cycle.

The fleet in operation (capacity of 29 GWe over 10 sites, 204 TWh produced in 2018, representing 20% of electricity production) has 38 reactors, including 20 PWR (VVER), 15 graphite-moderated and water-cooled reactors (RBMK and EG-P46 designs), 2 FNRs (BN 600 and BN 800) and 1 recently commissioned barge reactor (the "Akademik Lomonosov" equipped with two 35-MW KLT-40C reactors).

Four VVER-1200 reactors are in construction.

Russia, which has a very strong nuclear industry network, is highly export-oriented with nearly 33 reactor projects abroad, in 12 different countries. The state offers facilities for the financing of these projects.

It has long opted for a closed cycle but has recently faced some difficulties in mastering the manufacture of FNR MOx in the form of pellets and has developed a concept based on vibro-compacting the oxide directly inserted into the fuel cladding.

As the FNR programme is now confirmed and consolidated in the long term, Russia has stopped making its PWRs MOxed, but is still developing a technological offer (REMIX process announced as similar to the COEX™ process developed by France without separation of U and Pu) for its foreign customers wishing to commit to a strategy of mono-recycling or multi-recycling MOx in PWRs (VVER).

The RT1 reprocessing plant, located in Mayak, has a capacity of 230 t/year. This site also houses a centralised installation for intermediate storage of spent fuel and can store glass.

The RT2 plant (under construction) could eventually make it possible to reprocess MOx REMIX.

In addition to the sodium-cooled FNR system, other advanced reactor concepts offering separation and transmutation capabilities are being studied in Russia:

- the lead-cooled (lead-bismuth) FNR system, cf. BREST project, using a dense fuel (nitride) which is the subject of specific development in terms of design, manufacturing and processing and recycling;
- the MSR (molten salt reactor) system;

In terms of waste management, a federal law was promulgated in 2011 to establish a "polluter pays" principle.

There is indeed a poor track record in waste to be processed, mainly centralised in Mayak, and managed by the operator NORAO. The characterisation of waste is carried out according to IAEA rules.

The disposal of VLLW is permitted on site (if it is far enough from towns).

A regulatory release threshold is defined for each isotope.

Moreover, for waste with an unknown isotopic composition, the release threshold is set at 0.3 Bq/g.

Finally, there is a granite geological disposal project in Krasnoyarsk (commissioning of an underground laboratory in 2024 for disposal by around 2035) which is the subject of discussions with Andra.

USA

The proportion of nuclear power in the USA's mix remains stable (~20%). The use of coal is falling, offset by a growing contribution in the mix from gas (including shale gas) and renewable energies.

There are currently 98 reactors in operation (65 PWRs and 33 BWRs) in 30 states with a high availability rate (Kp) (the reactors operate at baseload in the USA, unlike France, which authorises load monitoring with its nuclear power plant), and 2 reactors (AP 1000) under construction.

However, as the electricity market is partially deregulated (only 50% of the reactors benefit from long-term contracts), some reactors have been closed (8 since 2013) because of a lack of competitiveness in a context of (non-conventional) cheap and abundant gas. This is why some states have implemented nuclear support measures.

However, the country is seeking to amortise the existing fleet as much as possible (87 reactors have had their operating license extended to 60 years and 6 have applied for an extension of their service life to 80 years) and is investigating the possible options to renew this fleet by 2035.

Three types of innovative technologies are envisaged, aimed primarily at improving the safety and competitiveness of nuclear power:

- SMRs (with power of less than 300 MWe) including the NuScale project initiated by a national laboratory (Idaho National Environment and Engineering Laboratory, INEEL) in cooperation with a university (Oregon State University) should lead to a first installation on the INL site by 2025 involving 12 50-MWe modules. Several other concepts for SMRs have been developed in the private sector;
- 4th generation reactor concepts covering a large range of systems, below is a list in order of decreasing technological maturity: SFR (Sodium Fast Reactor with at least two TWR projects and AFR1000), HTR and VHTR (Very High Temperature Reactor: NGNP and Xe100 projects), GFR (Gas-cooled Fast Reactor: EM^2 project led by GA), LFR (Lead-cooled Fast Reactor, SSTAR project, for example), and MSR (Molten-Salt Reactor: MCFR and FHR projects);
- microreactor (1-20 MWe) designs for niche markets (co-generation in remote areas, for example) often developed at the initiative of the DoD (Department of Defense) which defends the concept of small sealed reactors (due to resistance to proliferation), cooled by lead (see project by Oklo Inc. with pre-licensing by the NRC), and mainly for export.

Faced with this proliferation of concepts, the US administration is trying to regain control and support private sector operators through the GAIN initiative (opening of experimental facilities of the DoE labs for the qualification of concepts, contribution of the NRC to simplify the licensing of advanced reactors deviating from conventional PWR technology).

In terms of cycle and waste management, the US strategy remains unchanged since Carter's Non-Proliferation Act (1979): it is still based on an open cycle and is the subject of a law (Nuclear Policy Act of 1982, as amended in 1987).

However, the spent fuel still has no outlet as the Yucca Mountain geological disposal project is still subject to political clashes, which have resulted in the DoE paying compensation to operators (nearly 6 billion already paid). Spent fuel is currently stored at pool reactor sites or in one of the 75 dry storage facilities (spread across 34 states) that will soon be saturated. In this context, the construction of a centralised repository seems to be the temporary solution at the origin of two competing projects, one led by Orano in Texas and the other by Holtec in New Mexico.

There are now 4 VLLW disposal sites (Richland, Clive, Andrews, Barnwell).

The Wipp (Waste Isolation Pilot Plant) is reserved for (transuranic) military waste. After being stopped following an incident, its restarted operations in 2017 after a review of the ventilation.

The clean-up and decommissioning sector, regulated by the NRC, already has significant feedback (ten reactors have already been successfully decommissioned) and presents significant development prospects. It is in the process of restructuring with the emergence of a new business model based on transferring ownership of the facilities to be decommissioned and the funds dedicated to this to a private actor, implemented for the first time on the Vermont Yankee site at

NorthStar. The NRC systematically verifies that the consortium (or company) leading the project has stable means to take over the site. More specifically, the DoE will take over the ownership of spent fuel for disposal.

JAPAN

Before the Fukushima accident (2011), there were 54 nuclear reactors in operation in Japan (49 GWe, 29% of the mix). Since the accident, they have all been closed and new safety standards have been put in place that draw on the experience of this event.

In January 2019, it was confirmed that 9 reactors (complying with these new standards) were able to restart (of which 8 can potentially be MOxed), and 6 others are currently subject of final checks before receiving authorisation to return to service.

However, the closure of these reactors has led Japan to massively import fossil fuels to meet its needs (deterioration of its trade balance) and to increase its CO_2 emissions by 6.3% between 2009 and 2016. At the same time, the cost of electricity has increased by 26%.

The government suddenly revised its energy policy in 2018 and reaffirmed its commitment to the nuclear sector and the closed cycle option (with the development of FNR systems) despite the hostility of public opinion. It has set a target of 22% nuclear by 2030, mainly through the extension of the lifespan of power plants in operation up to 60 years.

Faced with the sluggishness of the domestic market, Japanese industry has turned to export and equity participation in foreign groups. However, as some of these export projects have been suspended, Japanese manufacturers (MHI, Toshiba, Hitachi) are all experiencing financial difficulties.

In terms of cycle and waste management, Japan has an enrichment plant and a strategic site (Rokkasho-Mura) for the interim storage of LILW, HLW and spent fuel. Rokkasho-Mura is also home to a reprocessing plant (the restart of which has been pushed back many times, it is now planned for 2021) and a MOx fuel production plant (J-MOX) still under construction. These facilities will have to meet new safety standards (with particular attention to earthquake resistance).

The FNR programme is also experiencing some difficulties (Monju closure and failure to restart Joyo) and the new road map for the FNR system (2018) reopens the field of possibilities (it is no longer focused on FNR-Na and integrates the option of a “fast reactor with molten salt as a fuel and coolant”) and relies on international collaborations (with France and the United States).

It should also be noted that Japan has committed to reduce its plutonium stockpiles through a bilateral agreement with the United States (section 123 of the agreement renewed in 2018).

Finally, it should be noted that Japan launched an initiative in 2000 to search for a geological disposal site (in a step-by-step approach) and created an agency (named NUMO) dedicated to the management of nuclear waste for this purpose.

SOUTH KOREA

South Korea is a major international player with an installed nuclear capacity of 22.4 GWe (27% of the mix in 2017) consisting of 24 reactors (20 PWRs and 4 CANDUs), 5 3rd generation reactor units (1400 MWe) in construction and a wide presence in the export market (Barakah project in the United Arab Emirates and JRTR in Jordan).

However, its nuclear power programme has been called into question since the election of President Moon Jae-In in 2017, who announced a complete nuclear exit by 2060.

Two commercial reactors have already been definitively shut down and the completion of six new units has been cancelled.

The Korean industrial sector is therefore weakened and is turning more than ever towards exports, with the aim of selling 6 reactors by 2025. It also wants to capitalise and enhance its skills in clean-up and decommissioning.

Constrained by a section 123 agreement with the United States on proliferation resistance (signed in 1973 and renewed in 2015), South Korea has adopted an open cycle strategy that prohibits any enrichment or reprocessing activity in the country (the option of reprocessing its spent fuel abroad was considered at one point).

The management of spent fuel and HLW is the subject of a “Basic Plan” that is heavily influenced by the strategy in force in the United States based on intermediate storage followed by a final disposal, the operation of which has been announced for 2053, with site selection by 2029.

Today, spent fuel (up 800 t/year) is being stored at reactor sites with storage capacities close to saturation (~ 70% for PWR spent fuel and ~ 85% for CANDU spent fuel). This is clearly a concern.

The Federal Agency, Korad, created in 2009, manages SLLILW radioactive waste in a centralised deep repository commissioned in 2015 and already being appraised for an extension to accommodate waste from the reactors in the C&D process.

EUROPE

Europe had 128 reactors in operation (840 TWh, 26% of the EU mix) in 2016, spread across 14 countries.

The global landscape is very heterogeneous, with 4 countries having clearly announced their desire to end nuclear power generation (Germany, Sweden, Belgium, Spain), 5 countries with sites under construction (France, Finland, United Kingdom, Slovakia, Hungary) some of which have experienced repeated delays, and 2 countries having clearly announced a strong desire to launch new projects (UK, Poland).

Despite uncertainties associated with Brexit (but having prepared well for leaving EURATOM), the UK has embarked on an ambitious process based on two pillars:

- short-term projects testing a new economic model for nuclear power (“Contract for Difference”) and mobilising expertise developed abroad (EPR project at Hinkley point led by EDF, HPR 1000 Huanlong Chinese-designed project at Bradwell B accompanied by EDF);
- calls for expressions of interest backed by public funding to mobilise the private sector to develop SMRs or AMRs (Sodium Fast Reactor-type or Molten Salt Reactor-type Advanced Modular Reactors) in the medium to long term and rebuild expertise in the nuclear field.

Poland, whose electricity production is heavily dependent on coal-fired power plants, wishes to develop a HTR (High Temperature Reactor) project offering prospects for co-generation and the use of industrial heat, in particular for the liquefaction of coal, and ultimately to reduce its CO_2 emissions.

In this context of nuclear disaffection by certain European countries with a blocking minority (Germany, for example) in launching an ambitious joint R&D programme under the EURATOM Treaty of 1957 (favouring a decision-making process by consensus), Europe is trying to maintain (in the context of a budget devoted to increasingly reducing fission in favour of fusion) a minimum of expertise (and the associated experimental means) aimed at reinforcing safety and security standards, radiation protection, and promoting sustainable and responsible waste management.

To this end, the instruments used in the EURATOM/H2020 (horizon 2020) framework to rally R&D efforts and capitalise on best practices are the technological platforms (Sustainable Nuclear Energy Technology Platform, for example) and the European Joint Programming (EJP), the JOPRAD project for example, Joint Program on Radioactive Waste Disposal.

The SNETP platform relates to reactor technologies based on 3 pillars: NUGENIA for generation 2 and 3 reactors, ESNII for 4th generation reactors (ALFRED, ALLEGRO, MYRRHA, ASTRID projects) and NC2I for co-generation.

However, there is a willingness at the European Commission to dust off the EURATOM Treaty to accompany the implementation of the next multiannual financial framework programme (2021-2027) for R&D (PCRD) in order to implement a qualified majority decision-making process in order to move away from a soft consensus around the lowest common denominator.

Finally, there are two topics that are gaining momentum in this PCRD:

- SMRs (from a safety point of view): there is a desire to standardise efforts;
- the desire to rally and capitalise on skills in clean-up and decommissioning at a European level via the SHARE project.

The European Commission also wants to reinforce the implementation of the 2011 Directive for the responsible management of waste and spent fuel. The first assessment report has now been released and reveals that only 3 countries have produced satisfactory (declarative) reports.

APPENDIX XI: PROCEDURES IN FORCE IN BELGIUM CONCERNING THE LICENSING OF WASTE DISPOSAL.

“Creation and operation” license for a nuclear waste disposal facility – procedures.

A creation and operation license for a nuclear waste disposal facility requires a procedure at the federal level that, depending on the level of risk of the facilities concerned, involves different opinions at various levels (municipal, provincial, or even European level in case of potential cross-border impact).

For a nuclear waste disposal facility, the process of obtaining a creation and operation license takes place in the following order:

1. Ondraf sends the license application to the Federal Agency for Nuclear Control (AFCN). The application includes general information about the facility, the preliminary safety report and an environmental impact report[1] in compliance with European directives and Euratom recommendations.
2. The AFCN then studies the file and checks that it is complete. The AFCN is assisted in this task by its technical subsidiary, Bel V, following which it will ask Ondraf to complete the file if necessary.
3. Ondraf takes the necessary actions to respond to questions asked by the AFCN and to complete the file[2].
4. If the AFCN considers the file to be complete, it is sent to its scientific board[3] for its opinion.
5. The scientific board provides a preliminary opinion and may asks additional questions to Ondraf.

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[1] The impact report includes:

1. A description of the activities and geographical scope, including a layout and the area over which the activity is likely to have an influence.
2. An analysis of harmful impacts. This involves identifying all potential harm to the environment (humans, fauna, flora, heritage, climate, noise, etc.), the effects of this harm, and the solutions to prevent harm or to resolve it.

[2]The safety file includes the following chapters:

1. File organisation and general information
2. Safety policy, safety strategy and safety concept
3. Management system
4. Characteristics of the site and its environment
5. Knowledge of the phenomenology of artificial barriers in their environment
6. Waste
7. Design and construction of storage packages
8. Design and construction of the repository
9. Operation
10. Repository closure
11. Measures after closure (control phase)
12. Radiation protection
13. Safety assessment – operational safety
14. Safety assessment – long-term safety
15. Compliance criteria for storage packages
16. Monitoring
17. Technical specifications

[3]The scientific board of the AFCN is an independent and multi-disciplinary body with around 20 members selected by the government who are nuclear experts. They issue opinions on licensing large nuclear facilities.

6. Ondraf adds it comments or submits an amended file.
7. The license application is then submitted to the following authorities for their opinion:
    - municipalities within a 5 km radius of the facility. The population has 30 days to consult the file and provide comments; municipal administration have 60 days from the date of receipt of the file to form an opinion.
    - the province. The governor of the province submits the file to the permanent deputation. They then have 30 days, from the date of receipt of the file by the governor, to give an opinion.
    - the European Commission: in the case of a disposal facility, the European Commission issues an opinion on any possible cross-border impacts of the installation within six months.
8. The AFCN gathers all of the opinions, which are not binding, and submits them to the scientific board.
9. The scientific board issues a new reasoned provisional opinion, which, if it is positive, may include special conditions for authorisation.
10. Ondraf has 30 days to add its comments.
11. The opinion of the scientific board is considered to be final if there are no comments. If there are comments, the board will deliberate again and deliver a definitive opinion. A negative opinion is binding. A positive opinion is not. The nuclear creation and operation license may in this case be agreed by Royal Decree, on the proposal of the AFCN.
12. Ondraf informs the European Commission of the project, as required in Article 41 of the Euratom Treaty ("Persons and companies engaged in the industrial activities listed [...] shall communicate to the Commission their investment projects relating to new installations [...]").
13. After the consultation, the AFCN checks that the facility complies with the conditions of the license. If the report is favourable, the King confirms the operation license, on the proposal of the AFCN.

Nuclear creation and operation licensing are a Belgian federal matter. The creation and operation license for the non-nuclear part of the file is a regional matter, which, depending on the region (Flanders, Brussels, Wallonia), may include other criteria. There is not currently a clear hierarchy between the federal and regional licensing decision in the event of conflict, nor is there any regulation or procedure specifically dedicated to surface or geological disposal.

The important role given to the scientific board, an independent body of the AFCN, whose opinion is binding if it is negative, should be noted.

Various highlights of 2018

Gradual phasing out of nuclear energy

The law on the gradual phasing out of nuclear energy was adopted by the Belgian parliament in 2003. It required the closure of nuclear power plants after 40 years of operation. This first three plants were due to close in 2015 and the last ones in 2025. In 2013 and 2015, laws were enacted to extend the lifespan of the first three plants until 2025.

The share of nuclear in Belgian electricity production is approximately 50%. Being aware of the difficulty, if not the impossibility, of replacing 50% of production with other sources by 2025, the producers and the AFCN are preparing for the possibility of a further postponement of the phasing out of nuclear.

The RECUMO project

For decades, Belgium has been producing and distributing medical radioisotopes, including Mo-99. This radioisotope is produced by means of irradiation of uranium targets in the BR2 research reactor of the Belgian Nuclear Energy Research Centre (SCK•CEN) in Mol. These targets are then processed by chemical process at the National Institute of Radioelements (IRE) in Fleurus. The highly radioactive residues resulting from this chemical process still contain materials that can be exploited. They will be processed at SCK•CEN as part of a public-public partnership running until 2045. The Belgian State will provide €255 million of project financing.

Myrrha

In 2018, the federal government decided to finance the first phase of the Myrrha project. Once it has been constructed on the SCK•CEN site in Mol, Myrrha will be the first prototype of a particle accelerator-driven nuclear reactor in the world. Financing of €558 million will be used for the construction of the first part of the particle accelerator and its irradiation stations.

The Council of Ministers also approved the constitution of the AISBL MYRRHA. An AISBL (international non-profit making association) is an organisation with a legal status suitable for large-scale projects co-funded by a number of foreign states.

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