CNE 2

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°3

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CONTENTS

Chapter 3 – INTERNATIONAL OVERVIEW

APPENDICES

SUMMARY – CONCLUSIONS

Over the course of the year 2008-2009, in accordance with the role bestowed upon it by law, the Board assessed research conducted into the sustainable management of all radioactive waste, as well as how to store and potentially dispose of the waste and the options for implementing an industrial partitioning-transmutation strategy for multi-recycling of actinides.

♦ Disposal in a deep layer of the Earth

In order to prepare for the 2025 deadline by which deep HAVL[1]/MAVL[2] waste disposal could enter service, Andra is actively continuing its research programme, drawing heavily upon the underground laboratory at Bure en Meuse/Haute-Marne. It has only had access to this laboratory since 2004; beforehand, it made use of opportunities to conduct experiments in underground laboratories abroad. Specific knowledge of the Bure site is therefore relatively recent, and research should be continued there during the time needed.

The 2025 deadline is contingent on the approval of the request for authorization to create a deep disposal site, which will be inaugurated in 2015. This application must specify what research is still needed in order to achieve the results by 2025 in accordance with law.

The Board reiterated its position with Andra, that the geological, hydrogeological, and geophysical data must play a decisive role in determining the boundaries of a zone of interest for further surveying (ZIRA) where the forthcoming underground disposal centre could be located. The Board emphasizes that the possibility of making decisions step by step is dependant on the level of knowledge acquired, particularly for implementing reversibility.

Mining engineering must take on a greater role within the HAVL project, as attested to by people having this specific knowledge joining Andra; however, the Board has not yet been informed of any concrete opinions assessments on mining techniques, methods for digging galleries and recesses, support structures, or even proposals for equipment to handle and transport heavy goods, canisters, and containers at the disposal facility.

Data acquisition and modelling, as well as an explanation of the restrictions related to mining engineering, are essential in order to clarify the effect on safety and reversibility.

By the end of 2009, important decisions must be made. For its scientific assessment, the Board needs to have all the data with adequate time for its consideration. The Board therefore wishes to have the following information by the end of 2009:

- ❖ The definition chosen for reversibility, with the technical options planned to implement it as well as its timeframe. To that end, the Board is appreciative that Andra is dealing with the issue of reversibility by developing it with an international framework.

[1] Long-lived high-level waste.
[2] Long-lived mid-level waste.

- The design inventory model (Mid) will be prepared by the end of 2009 and included in the authorization application. The Mid will inform the inhabitants affected of what is meant to be placed in the geological disposal facility. The Board is concerned about the slow pace at which the specifications for the final canisters intended for deep disposal are being drafted, particularly those for the recovery of old waste from Cadarache and Marcoule. Outside the standardized La Hague canister context, the Board is wary that a situation could occur in which the uncertainty that exists regarding compatibility between the yet-to-be-defined disposal facility and the final containment method would halt progress in resolving the problem at hand.

- The details of the evidence used to select the ZIRA where the forthcoming underground disposal centre might be located. The Board notes that Andra has offered it a summary of its recent data acquisitions. However, the Board also wishes that it be given the recently acquired geological and geophysical baseline data, which must play a decisive role in the selection of the ZIRA. The Board regrets that the socioeconomic studies are still in their preliminary stages, and that the true cost of a disposal site and its impact on the local economy are not yet known.

♦ Long-lived low-level waste

During the period 2008-2009, Andra underwent negotiations with local authorities in order to find candidate sites to be feasibility-tested for a FAVL[3] disposal facility. Upon a request by the government's Minister of Ecology, Energy, and Sustainable Development, the Board has examined the information submitted to it by Andra in December 2008 and conveyed an opinion to the Minister in January 2009. The Board believes that Andra has made the best possible use of the scant data that is currently available. However, in the absence of more accurate information on the properties of the rocks at the planned sites, there is no way to tell whether they will have the features needed for storing such FAVL waste under safe conditions. Ultimately, this is an initial safety assessment based on data acquired in drilling operations and on geophysical data, which will make it possible to render a decision regarding the quality of the sites adopted.

♦ Managing other radioactive waste

With respect to mining waste, the Board believes that the research efforts are primarily necessary in studying the very-long-term behaviour of old mining sites that include uranium residue, which is a particular type of long-lived, low-level waste.

♦ Partitioning-transmutation of long-lived radioactive elements

Ever since the laws of 1991 and 2006, research into partitioning-transmutation has advanced, particularly at the CEA, as part of a continuous progress strategy gradually expanding to multiple fields which form a whole greater than its parts.

The research pertains to Generation IV nuclear systems which must allow for actinide multi-recycling and promote an innovative, safe, and population-acceptable fourth-generation industrial supply reactor type. It also prepares and supports the development of facilities which are essential for separating actinides and manufacturing reactor fuel and transmutation fuel.

[3] Long-lived, low-level waste.

Law dictates that by 2012, industrial prospects for various Generation IV energy supply reactor types, which include fast neutron reactors (FNRs) and dedicated ADS[4]systems, must be firmed up. It also provides that by 2020 a prototype Generation IV FNR facility (Astrid)[5] should enter operation. In the extension to its n°2 report, in which it expressed concern as to the lack of fast neutron irradiation methods, the Board believes that the Astrid project will be our only FNR irradiation tool for partitioning-transmutation research.

The currently available scenarios demonstrate the value of americium alone transmutation, and to prioritize the concept of minor actinide-loaded blankets (CCAMs), the interest of which is the safety of the FNR.

Given the very tight schedule imposed by law, and the rapidly changing international context, research must immediately refocus on:

- the Astrid project;
- americium partitioning;
- the concept of CCAM transmutation.

The Board believes that any delay in assigning the necessary human and financial resources to the Astrid programme would compromise the 2012 assessment and the availability of the prototype by 2020, both of which are stipulated by the law of June 28, 2006. The research conducted into other fields besides innovative sodium-cooled fast neutron reactors should no longer take up resources.

Finally, the Board awaits a quantitative assessment of the impact of partitioning-transmutation on deep geological disposal, which could be significant. The research into the subject is far below expectations; it must be expanded.

International level

Internationally, partnerships between research laboratories as well as the progress of work in Sweden and Finland place Europe at the forefront of research into radioactive waste disposal. The research being conducted in France is among the best in Europe. However, the international example also shows that long-term experiments are still needed in order to assess a disposal concept adapted to Callovo-Oxfordian clay, and to select the technology that will be derived from the resulting scientific findings.

With respect to the new technologies for transmutation and the corresponding research into partitioning-transmutation, France already plays a leading role. However, in an international context geared towards Generation IV technologies that rely upon fast neutron reactors, particularly with multiple prototype projects whose deadlines are drawing near, France must clearly define its priorities and implement the resources required to avoid losing ground.

[4] Accelerator Driven System; The subcritical systems devoted to transmutation are controlled by the ADS accelerator, and include three components: a linear accelerator, a spallation target, and a subcritical nuclear reactor.

[5] Advanced Sodium Technology Reactor for Industrial Demonstration: The name given to the prototype sodium-cooled fast reactor stipulated under the law of June 28, 2006, to be built by 2020.

FOREWORD

The period from September 2008 to June 2009 is the 2nd full fiscal year for the CNE[6]; it is the subject of this report. From late June to October 2008, the Board presented the n°2 report to various audiences. The top tier included OPECST and ministerial departments. A Board delegation also visited Bar-le-Duc to present this work to the members of the CLIS (local information and monitoring council) of Meuse/Haute-Marne.

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In order to prepare its n°3 report, the Board used the same working method as the previous year, holding 12 hearings[7] each a full day long, as well as additional meetings. The twelve members of the Board, all of them volunteers, received 102 people from Andra, the CEA, and the CNRS, as well as academic and industrial institutions from France and abroad. These hearings, which brought together an average of about 50 people, were also attended by representatives of the Nuclear Safety Authority, Areva, EDF, the Radiation Protection and Nuclear Safety Institute, and the Central Administration.

The Board held a meeting with the Nuclear Safety Authority; it met with COSRAC and received a presentation of its work.

In order to prepare this report, the Board held five internal meetings, including a five-day-long one in a live-in seminar.

The members of the Board visited the Belgian Nuclear Research Centre in Mol, Belgium. They visited Areva's Georges Besse plants (I and II under construction) in Pierrelatte and a number of facilities at the CEA centres in Cadarache and Marcoule. Furthermore, the Board took part in a workshop organized by the Forum on the OECD/NEA's Forum on Stakeholder Confidence in Bar-le-Duc in April 2009.

The Board received documents[8] from the organizations that it heard. In order to complete its information some of its members took part in international conferences.

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In its n°2 report, the Board described the background in which it was working and the main deadlines. It did not revise them.

The period from September 2008 to June 2009 was a transitional period. No firm scientific deadline was stipulated, except that the reports registered in the PNGMDR decree be produced by late 2008.

Last year, the Board had restricted its assessment to research into long-lived waste and actinide partitioning-transmutation. Once again, these fields remain central to the assessment this year, due to the challenges involved in them. In 2009, decisions must be made regarding geological disposal facilities: studies into potential sites for FAVLs; choosing the ZIRA[9] for the deep geological disposal of HAVL waste. By 2012, and in due time, directions should be selected for determining the specifications of the forthcoming Generation IV fast reactor and the associated facilities.

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6 See List of members in appendix I.
7 See List of hearing topics in appendix II.
8 See List of documents in appendix III.
9 Zone of interest for further investigation.

In Chapter 1 of this report, the Board notes the progress or status quo in research devoted to HAVL, MAVL, and FAVL waste disposal facilities. The report also deals with the issues of managing sealed sources, mining residue, and tritiated waste. Finally, it sheds light on the progress and difficulties observed with respect to research into the socioeconomic aspects of waste management.

The second chapter enables the Board to discuss the partitioning-transmutation research and the relationship with the design of new reactor technologies.

The final chapter is devoted to an international overview of research; its purpose is to give a better idea of research trends and levels in France.

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Chapter 1

DISPOSAL AND STORAGE

1.1. DEEP DISPOSAL OF HAVL[10] AND MAVL[11] WASTE

In its n°2 report, the Board raised a set of questions regarding the types of waste that will be stored, and the physical properties of the Callovo-Oxfordian layer: delayed deformations of the bedrock, gallery wall desaturation-resaturation processes, the impact of hydrogen production, the formation of an Excavation Damaged Zone (EDZ), the radionuclide migration-diffusion process in the bedrock, engineering, reversibility and monitoring, and the groundwater flow model.

The Board had also requested that the criteria for choosing the ZIRA be explained and mainly founded on the geological data which is significant for the operation and safety of the disposal site.

The replies that the Board was able to receive attest to the major differences in progress among the studies carried out.

1.1.1. Inventory

The design inventory model (Mid) for the preparation of the request for authorization to create deep disposal must be drafted before the end of 2009. Besides the old defence waste, the waste in question is primarily that of the 58 PWR reactors currently in operation, and an EPR reactor currently being constructed. The preparation of this inventory was conducted under a steering committee that includes Andra, the CEA, EDF, Areva, and representatives from government authorities.

The details of the Mid have not yet been firmed up. The latest modifications take into account the new waste taken from the dismantling of Superphenix, the change in new containments for certain types of spent fuel, the remaining sludge which will not be refined into asphalt, the recovery of old asphalt drums, and structural waste from assembling natural uranium gas-graphite reactors.

New design scenarios have been established:

- the reprocessing scenario, which involves reprocessing old fuel, but which delays Mox reprocessing until the forthcoming fast-neutron reactors have been launched;
- the design scenario under which the reprocessing scenario is extended to take into account an increase in the lifespan of the current generating units, with an increase in waste quantities, which has been chosen to be 50%;
- the alternative scenario in which the generation of electricity with existing reactors is halted after 40 years of operation.

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[10] Long-lived high-level waste.
[11] Long-lived mid-level waste.

The 2009 design inventory model will give a list of the standard waste canisters that is different from the 2005 list; it will also give their characteristics. This list will be completed in 2010. In preparation for the authorization request, Andra will release "Draft disposal canister approval specifications" by 2014, and for setting up the disposal sites, the "Acceptance specifications" and first round of approvals by 2025. The authorization request will only cover waste for which disposal approval specification drafts have been prepared by 2014.

The Board is concerned about the slow pace at which these specifications are being drafted.

It is waiting for the 2009 version of the Mid to take a position on the need to continue or begin research that would cover the behaviour of all canisters intended for deep disposal.

With respect to possible deep disposal in the Callovo-Oxfordian layer of Meuse/Haute-Marne, the Board also notes that the new notion of "scarce resources" for disposal sites has appeared. To that end, the Board believes that it is necessary to clarify this notion, and that the 2005 application request must explicitly define the waste that will be stored, including a strategy for managing waste anticipated from future production.

1.1.2. Andra programme in the Meuse/Haute-Marne laboratory

By 2015, the underground Meuse/Haute-Marne laboratory, which entered service in 2004, will have been in operation for about a decade, which is less than many foreign laboratories. If the decision is approved in 2015, the research must therefore be actively pursued during the 2015-2025 period.

Andra's programme was structured into two phases. The first would run until 2009, while the second would cover the period 2010-2012. The initial findings of tests conducted in the underground laboratory (desaturation-resaturation, thermal behaviour, extent of the oxidizing zone which develops at the host medium's wall, the role played by bacteria, gas input pressure) are expected for the third quarter of 2009. This report therefore cannot describe the outcomes already achieved by the programme; it primarily pertains to surface laboratory tests and modelling/computing efforts.

With respect to the questions raised in report n°2, the desaturation-resaturation problems are being covered by a carefully prepared test planned for the underground laboratory. The generation of hydrogen through corrosion in the bedrock was studied heavily in the fields of computer modelling and determining the gas input pressure. The engineering programme seems well organized; it has already set out some interesting possibilities for improvement.

With respect to the combined mechanical/hydromechanical properties study, a fundamental programme was begun; its intent is to connect the large-scale observable properties to the mechanisms at play on the smallest scale; this is a direction which the Board approves of. On the other hand, the use of behaviour models, particularly mechanical ones, is essential to prepare for the tests planned in the underground laboratory and to carry out medium-term behaviour prediction calculations for studying the reversibility and design of the structures; in order to carry out this task, Andra does not seem to have stable, appropriate models when compared with the already available observation findings. Ever since the interesting findings achieved during the test carried out in the niche, significant progress does not appear to have been made in identifying and modelling the various effects which contribute to the observed deformations (whether short-term or delayed). Generally, the connections between the simulation, engineering, and *stricto sensu* scientific programmes seem to be functioning in a very uneven matter.

The Board recommends that, for the 2009 milestone, a progress report on modelling intended for planned calculations be presented, which identifies, if any, the fields in which these models are the least firmly established in their current condition. The Board also recommends that the heating and chemical aspects quickly be incorporated into the programmes.

♦ **Geomechanical problems**

The geomechanical problems raised by the construction, operation, and finally closure of a disposal site in the Callovo-Oxforidan argillite layer as deep as 500m are important.

From a conventional civil engineering standpoint, the experience accumulated over the past five years in the galleries at the underground laboratory is unquestionably favourable. When compared to the many tunnels, whether deep or not, which raised difficult problems with respect to the behaviour of the rock mass - though it is well known how to treat them - the galleries in the Callovo-Oxfordian layer pose no particular construction difficulties.

However, a structure that would make it possible to reverse the disposal of radioactive waste imposes additional requirements:

- the ability to remove canisters during the open phase;
- the design of the linings which limit the presence of outside materials, whether steel or concrete;
- an accurate estimate of the growth of the EDZ, which could halt the movements of water or gas; a review of the conditions under which this zone could leave a scar;
- in the very long term, a description of the thermomechanical behaviour of the rock and the changes in the disposal site, the fate of the canisters, and the spread of radionuclides.

The Board repeatedly emphasized the difficulty of this undertaking: the timeframe in question has nothing in common with the one involving normal civil engineering work, and an ordinary extrapolation of the findings and conventional methods will not be enough to support a convincing demonstration.

The laboratories group initial work deals with modelling fundamental phenomena that, on various scales of space, could contribute to the thermo-hydro-mechanical behaviour of the argillites, in both the short and long terms. The initial findings deal with the formulation of a behaviour law that combines the basic behavioural mechanisms of the clay sheet, clay aggregates, and then the composite environment incorporating the carbonated or silty portions, whether saturated or not. This work uses advanced scale-changing techniques.

The delayed behaviour (creep) is examined using similar techniques; at this stage, there are still differences between the teams' approaches.

The approach makes it seem as though ideas are flourishing, but without any central organization yet. After the results of the experiments conducted in the 2005 report, a summary table of the experiment programme could confirm that all of the important questions have been covered. However, the Board, which has repeatedly emphasized that the long-term forecasts should rely on an understanding of fundamental mechanisms, approves of the viewpoint adopted. This research effort should be given the time needed for it to reach well-established conclusions.

On the other hand, there are no mechanical behaviour descriptions that could be used to make reliable quantitative forecasts with respect to medium- and long-term changes. The Board emphasizes that this is a significant handicap for the engineering, seal design, and reversibility analysis studies.

♦ Seals

The problem with seals illustrates the difficulty of the lack of a reliable long-term mechanical behaviour law. The fractured, damaged area caused by the digging - no doubt that this area will change later as a result of the effects of desaturation, rock creep, changes to pore pressure, physical/chemical alterations, variations in temperature and pressure of the gases created - constitutes a potential obstacle in the geological barrier. Very early on, Andra identified the problem and conducted underground experiments which were preliminary, but which showed the benefit of research into this topic. New experiments are planned by 2015, but the Board has already requested that the current period be used to draw up a critical report on the theoretical position of the problem, which appears to be much too rudimentary, as well as its technological implications.

The Board reiterates this request, which it has already made several times.

♦ Ventilation and desaturation, SDZ experimentation

The ventilation of the underground structures causes air of varying moisture levels to circulate permanently for the entire period which spans from the creation of the recesses or galleries to their closing. The introduction of this outside element is one of the major disruptions to the natural underground environment. Its main effect is to desaturate the rock mass, at least in the vicinity of the galleries. The installation of a protective coating only delays the phenomenon slightly.

In the long term, desaturation may reliably delay the flow of water back into the structures. After the ventilation is turned off, the very low permeability of the medium is what determines the speed at which it becomes resaturated, so that the medium that cannot be resaturated for centuries, by delaying the contact between the water and the canisters for that long, is an advantage. From a safety viewpoint, the role of saturation is complicated, and it seems to be much too early to decide whether this phenomenon must be controlled, and in what manner.

The controlled ventilation experiment, known as SDZ, must make it possible to measure overall desaturation, to estimate moisture and hydraulic effects in the medium, and the mechanical consequences on the test gallery scale.

The experimentation has been computer-simulated beforehand, with the intent of designing the test, particularly to specify the positions of the sensors and to make predictions which will be reconciled with the test results. This is an approach of which the Board approves. The EDZ is simulated by an equivalent continuous porous environment; its behaviour in response to water forces is very quick, due to its high permeability. Mechanical coupling should be introduced shortly thereafter.

The SDZ experiment seems like it could provide a high-quality dataset. However, by its nature, it has a few limitations. First, the water phenomena are closely linked to the mechanical phenomena, so that the quality of interpretation will depend on the sophistication of the mechanical modelling, which is still uncertain. Secondly, these phenomena are only fast so long as they affect the EDZ and are much slower beyond it, so that it will be impossible to directly confirm the calculations that establish that in the long run, the effects of desaturation past the EDZ will remain low. Finally, the same difficulty related to the duration of the test makes it impossible to verify the assumptions with respect to restoration after the facility is closed. The possibility of extending the test beyond its planned term (2010-2011) should be considered.

♦ **Gas generation**

Significant quantities of steel (coatings, canisters, sleeves) are used and then left in the disposal facility while it is closed. Afterward, the surrounding environment quickly becomes a reducing environment, but the presence of water allows for corrosion and the gradual formation of hydrogen. This gas is vented through the porosity of the argillite, but the process is very slow - which is the downside to the medium's very low permeability - and the pressure of the hydrogen in the recesses and galleries may reach a high level that could micro-fracture the medium. Furthermore, the formation of gas may delay the flow of water from the medium back into the galleries and recesses; it may also influence how the seals function. None of these phenomena are very well known, even though they play an important role in other forms of underground disposal (natural gas and CO_2 disposal).

The Board had encouraged Andra to increase its knowledge, confirm its models, and reconcile its results with the ones obtained in other countries.

From the international viewpoint, Andra had taken part in the creation of a European programme, Forge[12], devoted to the problems posed by gas transfers. The programme includes an analysis of how the gas is formed, the gas source term, the role of the constructed barriers, the EDZ, and the safe zone are taken into account in safety studies; its goal is to improve the phenomenological and computer models.

The Board believes that this European programme and the significant role that Andra is playing in it creates significant progress conditions.

More generally speaking, Andra relies upon a group of laboratories whose purpose is to characterize the behaviour in response to gas (standardized diffusion and Darcy flow) of disposal materials, argillite, concrete, bentonite, and their interfaces, in cooperation with the European programme Forge.

The Board is appreciative of the directions taken by Andra's gas generation programme. The models used are ambitious, and give a much clearer and more detailed picture of the phenomena. The Board would like the programme to result in a summary which includes the tests conducted while drilling, if any, and which results in scientific publications. More than in other fields, the confirmation of the results must be a chief concern, because the phenomena described have almost no natural counterparts. To that end, the Board notes that some of the problems raised have no connection with the ones raised by other existing or planned uses of the underground space, and that some convergence of the results with respect to these various applications would strengthen their credibility. The Board approves of Andra's approach being opened to outside parties.

♦ **Design and architecture options**

In 2009, Andra plans to complete a review of the disposal facility design options that were presented in the 2005 submission. The relationships between this review and the choices of safety and reversibility options are very high.

The 2005 submission had only planned for the safety of the disposal site during operation in broad terms. The project has gradually taken on a more industrial feel, which requires a more detailed description of the technical options.

12 Fate of repository gases: a programme for improving the knowledge of gas transfer processes in raw materials found in various disposal concepts.

In these fields, Andra carried out significant, sustained international consultation activities, particularly by way of the European programme ESDRED[13], which the Agency played a key role in guiding.

The review deals with two major themes: the disposal facility's general architecture and its internal architecture.

The Board approves of Andra's effort in exploring different design and architecture options, particularly with respect to reversibility. It notes that the desire for reversibility should not under any circumstances cause harm to long-term safety. Given this perspective, the Board wishes for the engineering choices to rely on a good balance between operating safety, long-term safety, and reversibility. This balance has yet to be defined.

The Board also draws attention to surface facilities. Such facilities have not been presented to the Board. They should prioritize the use of known, proven technologies. For the majority of the disposal site's opening period, these facilities close to the public will pose major challenges from a safety standpoint. This comment would be strengthened if the surface facilities were to include an interim storage intended to store waste for a few decades, such as exothermic waste.

1.1.3. Geological modelling for the Meuse/Haute-Marne site

During the 2008-2009 hearings, Andra presented a summary of its geological model, including new data gathered during the 2007-2008 campaign. On this occasion, the Board was unable to examine the data incorporated into the presentations in detail, and was given little information on the methods used to interpret them. In light of the summary, some positive developments may be adopted, but more information is needed.

The Board request that Andra submit to it, prior to the publication of the ZIRA, the results of the measurements taken in 2007-2008 in the surveys using the geophysical surface or subsurface methods.

♦ **The conceptual geological model**

In its 2005 submission, Andra had presented a very sophisticated conceptual geological model of the Meuse/Haute-Marne site. This model had been used to define a transposition area about 250 km^2 in size, over which it could be hoped that the properties of the Callovo-Oxfordian layer housing the facility would be homogeneous. In 2007 and 2008, in accordance with the 2009 deadline goals, Andra sought to fine-tune this model by surveying the transposition area in greater detail. These studies were intended to identify a "zone of interest for further surveying" (ZIRA[14]), about 30 km^2 in size, allowing sufficient room to install a deep disposal facility, taking into account the various constraints on the ground's surface.

Having acquired experience in preparing the 2005 submission and taking heed of the evaluators' comments, Andra moved forward in three fields:

- the sedimentology model of the Callovo-Oxfordian host layer, and its covering with Oxfordian limestone;

[13] Engineering Studies and Demonstrations of Repository Designs: a programme for demonstrating the technical feasibility, on an industrial scale, of activities carried out to build, operate, and close a geological site.

[14] In French, Zone d'Intérêt pour une Reconnaissance Approfondie.

- the sedimentary context of the layers above (Oxfordian limestone) and below (Dogger) the host layer;

- the regional structural diagram, which provides a framework for understanding how the rocks may fracture.

This new knowledge was acquired by means of proving investigation techniques approved during the previous programme: a major campaign of additional drilling, the treatment of old and newly acquired seismic profiles, and geological surveys in the field. The interpretation of new data relies on multiple doctorate theses.

Andra has achieved a high degree of sedimentary homogeneity in the Callovo-Oxfordian host formation; it also has concluded that the geometric centre of this layer is located within a clay-heavy area whose clay content is very close to the maximum in the median sedimentary sequence.

Andra has begun a detailed study of the sedimentary facies in the Callovo-Oxfordian limestone covering. This improved knowledge has no impact on the assessment of the ability of this formation to serve as containment, because Andra has placed the Oxfordian limestone outside of the host formation, even though it has petrophysical properties which are very close to the Callovo-Oxfordian layer, as is the case near the underground laboratory. On the other hand, this new knowledge has confirmed the heterogeneity of the geological layers above the host formation and the presence of porous areas within it, spread throughout the entire transposition area, which makes the covering layer behave like an aquifer.

A large part of the knowledge regarding the upper host is currently being acquired by interpreting the data derived from EST433 deep-drilling, located at the centre of the transposition area, which has crossed through all of the secondary formations down to the lower Triassic.

Including the new seismic campaigns of 2007-2008, Andra's transposition area currently has a network of seismic lines whose total length is about 300 km, with area mesh size of about 3 km. This data has been interpreted or reinterpreted using 2-D techniques. Andra has drawn the following conclusions from it:

- secondary faults are visible only in the northern part of the transposition area;

- these faults are said to be secondary, because they do not extend far, as they very rarely cross two parallel seismic profiles;

- They are only visible in the Triassic, or sometimes the Liassic, but never in the Dogger and especially never in the Callovo-Oxfordian.

Besides the seismic results, geological surveys in the field have made it possible to improve mapping of the known N150 direction faults in the so-called diffuse fracturing area located in the southern part of the transposition area. It has been shown several times that these faults cross the major faults of the Gondrecourt trench; this information supports a regional geodynamic interpretation that credits these faults, which appeared during the Pyrenean compression, with playing a shock-absorbing role later on during the Oligocene rifting. This configuration has thereby protected the northern fracturing area, which explains the structural calmness observed in the transposition area.

Pending a submission of the raw data, the Board believes that Andra has strengthened its basic geographical knowledge during the year 2007-2008. The interpretation submitted reveals the structural and sedimentary homogeneity of the Callovo-Oxfordian layer, and the absence of major faults in this formation anywhere in the transposition area. However, this must be checked using a 3-D seismic survey in the area chosen as the ZIRA.

- **Conceptual hydrogeological modelling**

In accordance with the expectations for the 2005 submission's assessments, the sector's conceptual hydrogeological modelling made noteworthy progress based on new 2007-2008 investigations. This was achieved by fine-tuning the geological model and using the piezometric data provided by some forty new drilling operations. The primary new elements are:

- ❖ the aquiferous role of the Oxfordian limestone covering the host layer is confirmed due to the effect of hydraulic connections between the various porous layers that were identified there. The piezometric structure of this aquifer is now well known, showing recharge through outcropping areas in the southwest, and discharge in the Marne and Meuse valleys;
- ❖ past the southern limit of the transposition area, the diffuse fracturing area is a preferred underground circulation sector;
- ❖ the Dogger underlying the host formation was surveyed by five new drilling operations in the sector; these operations revealed that this formation was overall more aquiferous than previously thought, with locally high but heterogeneous levels of transmissivity. The piezometry was also fine-tuned; a dome-shaped structure discharging to the Marne and Meuse was made visible. It replaces the plateau-shaped structure, whose flow direction was vague, that had previously been assumed; could this situation indicate that the Marne fault, at some deep level, plays a hydraulic role?
- ❖ the absence of any faults developing in the Dogger anywhere in the transposition area argues for the absence of any hydraulic exchanges between the Dogger and the Oxfordian through nonconformities; this is corroborated by the different chemical compositions of the water between the two formations;
- ❖ the piezometric level measurement in the Triassic observed in the drilling area reveals a level less than that of the Dogger. The salt content of the Dogger's waters is therefore not the result of a current hydraulic communication process with the Triassic.

Regionally speaking, Andra has heeded the wishes of the evaluators by improving the geometric depiction of the major faults of the Paris Basin in order to simulate their hydraulic role, and as a result, it has made the determined boundary conditions of the sector's groundwater flow model more realistic.

The Board believes that major progress has been made in conceptualizing the underground hydraulics on the level of the sector surrounding the transposition area. These improvements deal with the morphology of the aquifers enclosing the host formation, the structure of the underground flows and of the boundary conditions for both of these surrounding aquifers, and the flow parameter values. New information has been gathered on the chemistry of the Dogger's waters. With them, it should be possible to add constraints to the flow model. The Board will be attentive to improved understandings of the geochemical data that the groundwater flow model could thereby benefit from.

The Board notes that few results were drawn from the Triassic drilling, probably due to the time needed for the studies so that they could be completed.

♦ **The numerical groundwater flow model**

Andra undertook with the University of Neuchâtel to create the numerical groundwater flow model. The model's basic concepts, drafted by IFP[15] for the 2005 submission were used again, taking heed of the evaluators' comments. These comments mainly deal with the reconciliation of the regional model that affects all aquifer systems in the Paris Basin with the Marne-Meuse sector's model, the ability to take into account the hydraulic role of the geological nonconformities in the Paris Basin, the necessary improvement of the depiction of the flows in the underlying the Dogger aquifer, and the introduction of constraints into the flow model by taking into account the transfer of natural chemical indicators.

To that end, the University of Neuchâtel endeavoured to construct a single model that would combine both the sector's issues and regional issues. A review of the geological data was begun in order to create the geometry of the layers, so as to better characterise the drawing and throw of the major faults; the parameterization of the hydrodynamic coefficients of the 2005 model were reviewed, with care to maintain connections between the region and the sector.

> *The Board believes that Andra, together with the University of Neuchâtel, carried out a hydrogeological modelling approach which meets all of the comments made regarding its previous approaches, and which uses the best methods and tools currently available to the scientific community. However, in order to achieve the goal, there is still much work to be done, and it is doubtful that it will be finished by the 2009 deadline; this becomes even more clear given that it must incorporate the results of studies which have not yet been completed, particularly those dealing with the interpretation of knowledge acquired from deep drilling in the transposition area. As these hydrogeological studies are necessary for the safety analysis that will be included with the 2015 submission (the authorization request), this delay is not serious and will not affect the choice of the ZIRA.*

1.1.4. Reversibility and observation-monitoring

The law of June 28, 2006 institutes the concept of reversible disposal in deep geological layers. The request to authorize its creation must be made in 2015; provided its authorization is received, the centre will enter operation in 2025.

The law requires that Parliament be informed twice:

- in 2016, in order to set the conditions of reversibility;
- afterward, in order to authorize the closing of the disposal site.

By its nature, a potentially permanent underground disposal site involves work geared toward a centennial installation and operation phase followed by a control phase, and then closing. In the 1990s, Parliament introduced the option of reversibility, provided that this reversibility does not compromise the safety of the disposal facilities. In this context, Andra has developed its research in order to propose a process which, at every step, makes it possible to either move onto the next step, to pause, or to return to the previous step.

Various countries (Sweden, Finland, United Kingdom, United States) have introduced new concepts such as "step-by-step decision-making" and "iterative approaches" in which progress towards final closure is made in steps.

The notion of reversibility remains an imprecise one, which is subject to various interpretations.

[15] French petroleum institute.

Thinking on the subject is far from reaching maturity. Andra finds itself in the difficult situation of needing to recommend solutions, by itself alone, to a problem which will not truly be defined until after its proposals have been written and evaluated. In this matter, where technical requirements (the safety of the disposal facility) and societal requirements (reversibility) converge, a great deal of care should be taken in defining the concepts being proposed and discussed.

In 2008-2009, Andra made progress in two aspects (technical and socioeconomic) of its overall activity regarding the reversibility of the disposal site. As for reversibility, since it is a requirement primarily imposed by a widespread social request, the Agency is involved in a broader task than the exclusively technical ones which had been its mandate until now. It is actively devoted to this task; Andra is strengthening its socioeconomic expertise, is seeking to train its executives in carrying out dialogue with stakeholders, and has begun research into the social issues of reversibility. Within the NEA, Andra is leading global thinking in this field. Finally, it is also concerned with carrying out an exchange procedure with OPECST, which the Board has applauded.

At its core, Andra is continuing to take into account the same triad of social motivations:

- ❖ the ability to remove the canisters in the event of a problem, while reducing risks through the battery of tests conducted on the canisters prior to their placement in disposal;
- ❖ preserving future generations' freedom of choice, should better methods emerge for reducing the hazards associated with the waste, or if the waste were to become a resource (i.e. only waste which is considered final, under the technical/economic conditions of the time, would be placed in disposal);
- ❖ act wisely when dealing with a complicated subject that requires a very long-term commitment.

Operationally speaking, the approach adopted focuses on the definition of technical options related to the design of the disposal site, and the creation of proposals with respect to the decision-making process for managing the disposal site. New technical solutions have been developed for HAVL waste (new design for the opening of a recess in order to facilitate withdrawal operations, the installation of a leak-tight mechanical plug while awaiting the seal) and MAVL waste (passive ventilation, new handling options). This research is completed by the research undertaken for the underground disposal facility observation-monitoring programme.

The creation of an international reversibility standard has made progress, thanks to discussions within a workgroup coordinated by the NEA. For the moment, the new version proposed by Andra includes five levels, which correspond to an increasing difficulty in returning waste to the primary canister, and to better-identified degrees of decisions:

- ❖ level 1: placing the primary canisters into the disposal canisters; storage on the surface;
- ❖ level 2: operation of the disposal site (the disposal canisters are easily recoverable);
- ❖ level 3: operation of the disposal site (partial backfilling, which, if disposal canisters are being removed, requires preparatory work);
- ❖ level 4: after closing the disposal site, the disposal canisters may still be retrieved after the mining work;
- ❖ level 5: disposal site closed, with passive safety active; if the canisters are altered, the waste may nevertheless be removed through mining operations.

In France, the process can only move on to level 2 (creating the disposal site) or to level 4 (closing the disposal site) after a law has been passed; the intermediate decisions to move on should be consistent with the decennial review by the Nuclear Safety Authority (ASN); these measures would thereby tidy up the possibilities for local consultation.

As Andra is committed to this approach, the Board will take interest in reviewing the results announced in June 2009 for the studies currently underway regarding "the phenomenological analysis of disposal facilities being operated, including reversibility and sliding timelines". Is expected that this analysis will provide a convincing argument, to be incorporated into the 2009 submission, regarding the possible reversibility durations at the various levels of the suggested scale and the limiting technical factors that determine them.

1.1.5. Issues with choosing the ZIRA

The PNGMDR has tasked Andra with proposing a "restricted zone of interest suitable for installing a disposal site where deep exploration techniques shall be implemented" to the government by the end of 2009. The ZIRA, whose surface area will be about 30 km^2, primarily concerns the area where the underground disposal facilities will be installed; it shall be located within the 250 km^2 transposition area. The ZIRA could be assigned to one or more surface facility installation areas (ZIIS), whose location shall be defined in combination with the land use.

In its n°2 report, the Board had emphasized that the decisive factor in choosing the ZIRA should be the geological quality. In March 2009, Andra presented a review of the geological restrictions. It made no declarations regarding the choice of the ZIRA, confining itself to conclude that in light of the results of the 2007-2008 survey campaign, no discriminating geological criteria have surfaced for choosing a particular area within the transposition area. However, Andra points out that for the purpose of maximizing the disposal facility's post-closing safety, the restrictions dealing with the hydraulic gradient and the thickness of the host layer may be taken into consideration, should be considered alongside the comment that additionally that in order to optimize the operating conditions, the layer's dip and depth restrictions should also be taken into account.

Andra has shown interest in accessing the waste at the disposal site using an inclined drift from the ground surface; this device would allow some distance between the ZIRA and the ZIIS, as it would theoretically make it possible to prioritize the underground space's quality for placing the disposal facility and land-use criteria for placing the ZIIS(s).

The Board believes that Andra currently seems to have all of the scientific evidence needed to propose a ZIRA within the transposition area. In order to complete its assessment, it wishes that before the ZIRA is chosen, Andra should offer a detailed geological and geophysical data available for the transposition area, which shall form the basis of the choice of the ZIRA.

Furthermore, the Board recommends that the placement of the ZIIS(s) and their destination be made clear at the time that the choice is submitted.

1.2. DISPOSAL FAVL[16] WASTE

As part of Andra's investigations into researching at FAVL waste disposal facility, the Board held a hearing for Andra on the design of FAVL disposal facilities, and analyzed its summary memo on the geological context of the candidate communities.

[16] Long-lived low-level.

In his letter dated December 23, 2008, the Minister of Ecology, Energy, and Sustainable Development requested that the Board gave an appraisal of the analysis methodology adopted by Andra, particularly with respect to the Board's recommendations as given in its n°2 report. The Board submitted its opinion on January 16, 2009. Since then, in this project, that Board has not been made aware of any progress.

The recommendations made by the Board in its report n°2 in light of the generic studies, which were intended to research a clayey formation with sufficient thickness of about 100 m that would make it possible to install structures at a depth of about 100 m in order to protect the public, have largely been taken into consideration by Andra. This will induce the operator to develop mining engineering appropriate for such a depth.

The Board renews the recommendation that all aspects of such a facility, and those of an option in which all or some of the "graphite" wastes would be collected into a HAVL/MAVL disposal facility, be evaluated.

Furthermore, the Board reaffirms the need to specify the uncertainties regarding the radiological list of waste, so that it is possible to make sure that the disposal options adopted are valid. The importance of this matter has been emphasized by the appearance in 2008 of the ability to add a portion of the waste refined into asphalt.

1.3. MINING, TRITIATED, AND HISTORICAL WASTE; SEALED SOURCES

1.3.1. Mining waste management

Article 4 of the Law of 2006 and Article 10 of the PNGMDR Decree of April 16, 2008 require Areva to craft a submission by the end of 2008 dealing with "a long-term impact report on disposal sites for uranium mining residue and the institution of a strengthened monitoring plan for these sites". This submission shall be assessed by the ASN. Areva presented the research that it has conducted since 1993 aimed at the long-term management of mining residue disposal sites to the Board.

The mining residue results from the chemical treatment of the uranium ore. They were stored in specially furnished sites near the treatment plants. They are distinct from the tailings, which did not undergo any chemical treatment and largely stayed near the extraction sites.

The Board believes that the mining residue is a special type of low-level waste containing long-lived radionuclides. Their long-term behaviour may only be analyzed through modelling that must take into account the specific features of each of the storage sites and the geochemical behaviour of the residue. This analysis must rely on additional measurements beyond the basic monitoring measurements, and on detailed inventories for each site. Areva has launched several studies with this purpose, and eight appropriate measures for disposal sites and the environment. Areva has also studied processes for improving corrective measures for environmental protection purposes.

The Board recommends that this research be continued, if not amplified, as appropriate for the sites, which each constitute a unique situation. They must clearly appear as the scientific basis of a "Post-Mine" Areva submission. This submission must make it possible to identify which of Areva's actions fall under long-term environmental protection.

1.3.2. Tritiated waste management

Article 4 of the Law of 2006 and Article 9 of the PNGMDR Decree of April 16, 2008 require the CEA to prepare a submission on produced or forthcoming tritiated waste storage solutions by the end of 2009. This submission shall be assessed by the ASN. The CEA presented the majority of its research to the Board in support of this submission.

> *Tritium is not an extremely dangerous radionuclide. The Board believes that the management of tritiated wastes, as it is practiced as the CEA plans, does not require any major research development. However, given the tritium mobility in the environment, and the significant increase of accumulated quantities of tritium that will be disposed of in the future, the Board highlights the need to exhibit a satisfactory understanding of environmental marking and human tritium incorporation mechanisms.*

1.3.3. CEA waste management

In its report n°2, the Board raised questions regarding the optimization of MAVL waste management other than those derived from current reprocessing; it recommended that waste producers, Andra, and government bodies examine this question. Because this waste may be old waste that is often poorly characterized, or has changed over time, this management may be complex and difficult.

> *The Board notes the current management efforts led by the CEA; it is aware that the CEA and Andra are seeking to optimize the management of old MAVL waste, in particular the 60,000 tanks of asphalt from Marcoule.*

> *The Board notes that the publication of specifications for canisters intended for disposal will enable waste producers to provide for optimal final containment. It warns against the situation in which the existing uncertainty regarding compatibility between the containment of canisters and the yet-to-be-defined disposal site would halt progress in resolving the problem at hand.*

1.3.4. Sealed source management

Article 4 of the Law of 2006 and Article 8 of the Decree of April 16, 2008 have assigned Andra the task of conducting a study on "processes for storing used sealed sources (past the 10 years after their production, in accordance with the health code) in existing (CSFMA[17]) or as-yet uncreated centres (FAVL and HAVL) disposal sites." This study was submitted to government bodies in late 2008; it was presented to the Board in 2009.

There is a regulatory framework for treating spent sources, which should ultimately lead Andra to retrieve the countless sources circulating in France since 1901. These sources initially included radium 226, and later artificial radionuclides.

The sources come from French and international manufacturers, who in principle are required to take back the ones which they produced. The diversity of the sources results from the nature and activity of the radionuclides, as well as their shapes and dimensions required by their very large number of applications (research, industry, medicine, everyday use).

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[17] Low – and medium-level waste storage centre located in Soulaines, Aube.

The current inventory of sources, written by Andra with the assistance of the IRSN and manufacturers/custodians shows that the most commonly used sources are far from being completely collected from among the thousands to millions which were produced; these sources reflect very diverse and varied uses (smoke detectors, surge suppressors, lightning arrestors, luminescent objects, radium-based objects). They include long-lived radionuclides (americium 241, radium 226) or short-lasting ones (tritium, strontium 90).

On the other hand, more restricted sources (plutonium 238 pacemakers, cobalt 60 and cesium 137 irradiators, neutron sources), containing short-lasting or long-lived radionuclides, have been inventoried.

The criteria used for storing sources at CSFMA (FMAVC[18] waste, 15%) is the activity limit when standardizing the structure. The activity limits are founded on recovery and usage scenarios appropriate for the dimensions of the sources. This criterion is also applied for a shallow disposal of sources considered to be FAVL waste (83%) which fall under SCR[19] or SCI[20].

Andra thereby identified the disposal technologies for each type of source appropriate for its characteristics (shape, period, activity, heat power, chemical nature). Certain technologies include radioactive decay storage and/or destructive treatment for containment (liquid or gas sources). Only the most active long-lived sources or short-lasting exothermic sources (2%) are intended for disposal with HAVL waste. Andra also recovers radium-related objects.

> *The work carried out by Andra falls under the conventional safety analysis methodology; the containment of the sources, if necessary, uses known methods that can be adapted. The study conducted by Andra is complete. It does not exhibit a need for any special research.*

1.4. EVIDENCE REGARDING SOCIOECONOMIC ASPECTS

The law of June 28, 2006 stated that any decision regarding the management of radioactive waste may not go forward without public consultation and a procedure involving numerous stakeholders. This group would include waste management organizations, waste-producing organizations, the Nuclear Safety Authority, local communities, elected officials, and experts. The law stipulated the need to examine the social and economic aspects of the radioactive waste issue.

The issues involved in nuclear waste draw upon fields of scientific and technical knowledge, as well as a diverse array of fields that fall within the umbrella term "socioeconomics" (economics, sociology, ethics, law, anthropology, psychology, etc.).

1.4.1. Economic aspects

For now, the Board has not received any submissions to be assessed involving the economics of nuclear waste management, whether from Andra or from the CEA. In its previous report, the Board had noted the need to obtain accurate information on these issues.

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18 Short-lasting, low and medium activity.
19 Storage under a reworked cover.
20 Storage under an intact cover.

During the hearings, some information was indeed reported by Andra or by the CEA, but the Board believes that it is necessary to go further in specifically reviewing economic and social issues. This year, there was no opportunity to identify the existence of major work into economic issues related to current projects (the cost of a disposal facility, the impact of waste management costs on per-kWh costs, externalities, its effect on the trade balance, its impact on the regional economy, etc.) or future ones (the costs of facilities for implementing transmutation, funding, etc.). However, studies should be explored, if not encouraged, among various relevant or competent institutions (Andra, Areva, CEA, Cour des Comptes, EDF, ministries, etc.), even if it has seemed difficult to request the assistance of nuclear power stakeholders in this issue, given the commercial challenges.

1.4.2. Sociological aspects

There have also been no opportunities in this field for distinguishing major background works regarding social questions, besides a few scattered initiatives. The analysis given in the Board's report n°2 remains valid. As social issues are human-level and deal with the intersection between "hard sciences" and "human and social sciences", they are difficult to pinpoint: Who are the stakeholders? What must be studied and assessed? How? This aspect is taken into account better abroad (Sweden, Belgium, Canada); however, it seems extremely difficult to implement in France. The first programmes identified[21, 22], which are still nascent, deserve to be granted resources so that they may develop.

Although there are actions under way with respect to dialogue and debate with the public, it is important not to lose sight of the issue: providing information and consultation are tools which are inseparable from guiding a large-scale technical project and placing it into a local environment, but they are not the answer to socioeconomic research needs. In brief, handling such tools for "information and consultation" is a complicated matter, given the differences between stakeholders (experts and citizens) which may produce a false consensus far from the sought-after goal.

Therefore, communication alone is not sufficient in moving towards an understanding of the mechanisms underlying relationships between society and nuclear waste management.

In conclusion, the Board believes that for now, this aspect has not been given consideration in France commensurate with the scope of the expected challenges; it notes that there is a genuine imbalance between the scientific and technical research aspects and the sociological research aspects, in its widespread acceptance.

Below, the Board notes the results of some work by the NEA and Andra into these issues.

1.4.3. Some findings from work conducted under the auspices of the NEA

Among the many lessons drawn from the international workgroups[23] which covered the issue of society's expectations with respect to radioactive waste, some which were directly drawn from work conducted under the auspices of the NEA are particularly noteworthy.

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[21] The ALIEN (Germany as a laboratory of nuclear energy ideas) programme of CNRS' Pacen programme.
[22] Andra's sociological study programme.
[23] 2006 OECD report; NEA n°5297.

In particular, the NEA believes that prerequisite conditions for confidence are:

- establishing a clear relationship between the use of nuclear energy and the need to safely manage waste;
- clearly and accurately defining the scope of the programme (origin, type and quantity of waste, type of installation, etc.).

Furthermore, the NEA mentions consultation and decision-making processes several times. It notes that, since the 1990s-2000s, public questions have played an increasing role in formulating and implementing long-term solutions for managing radioactive waste. Consultation has become a keyword in this management. Information appears insufficient; true public participation in decision-making has proven to be critical[24].

The consultation process must be in the form of a series, giving all stakeholders the time to study and consider the benefits at stake and the solutions. These processes are an opportunity for significant mutual education. The goal is to prioritize a step-by-step decision approach; at predefined steps, various forms of societal control are possible, making it possible to go back to previous decisions or to modify them when possible.

Ultimately, for the NEA, the challenge is to provide detailed knowledge, to affirm the influence of stakeholders and increase confidence in institutional players, in the legitimacy of the decisions and in the support provided to them. Radioactive waste management facilities must therefore be designed and arranged in accordance with the values and interests of local communities.

For the NEA, this means that if retailers are necessary for building confidence:

- safety, which experts are responsible for;
- participation, which requires that the public be sufficiently acclimated to nuclear power;
- local development.

The NEA[25] also notes the need to include, in any radioactive waste management project:

- an economic aspect, particularly describing the funding methods that guarantee that the costs to be paid are covered, even in the distant future;
- a social and ethical aspect, as important as the technical issues; with the understanding that "a balance must be struck between what is *desirable* from an ethical viewpoint at the local level, and the ethical *imperatives* on the national level".

1.4.4. Andra's PIC programme (informing and consultation)

The law gives Andra a leading role in informing and spreading scientific and technological culture in the field of radioactive waste management. Besides the scientific and technical research that it is responsible for, it is important that an analysis-and-action approach founded in communication, information, and consultation be a part of its programme and encourage the public's participation.

[24] 1993 NEA/OECD report; “Public Participation in Nuclear Decision Making”.
[25] 1996 NEA/OECD report; “Informing the Public about Radioactive Waste Management”.

Andra's PIC programme submitted to the Board clearly falls within such an approach. In the step-by-step decision-making process reversibility approach, Andra also proposes an iterative process which aims to facilitate membership and participation.

In order to analyze this programme, it is necessary to be able to gradually go into greater detail in the questions raised by stakeholders, even if these questions do not strictly speaking pertain to conventional scientific and technical disciplines.

The Board has raised questions regarding the placement of this programme with respect to the NEA's recommendations.

1.4.5. Socioeconomic aspects specific to the Meuse/Haute-Marne site

The "Safety guide regarding the permanent disposal of radioactive waste in deep geological formations", published by the Nuclear Safety Authority, names the protection of human health and the environment as the fundamental goal of deep disposal. In order to achieve this goal, it sets out a criterion and a principle. First, the individual effective doses calculated during the safety studies should not exceed 0.25 mSv/year under the baseline situation. Second, the concept adopted for disposal must make it possible to keep the radiological impact at the lowest reasonably achievable level, in light of the scientific knowledge available, the state of the art, and social and economic factors. This quantitative criterion and general principle complement one another. The quantitative criterion, which is independent of the host rock and site which are chosen, as well as the disposal architecture and the inventory being stored, is generic in nature. It is obviously somewhat rudimentary, and may only be used in conjunction with keeping the entire safety study in mind. It must be understood as being a safety measure intended to rule out or substantially change a project at several possible stages in its progress if it exhibits manifest risks and does not meet the fundamental goal being sought. The general principle pertains to a specific site for which enough studies and research have been completed that a credible estimate of its performance and cost was feasible.

For a reversible deep disposal site in the Callovo-Oxfordian layer of eastern France, initial indications are already available, owing particularly to the 2005 submission prepared by Andra. This submission includes an operational overview of the disposal system. The calculations show that for the stored waste inventory set forth by the law of 2006, the individual effective doses calculated for the baseline situation would be about two orders of magnitude less than the 0.25 mSv/year baseline. For other inventories which include spent fuel, the doses would be higher, though without exceeding the limit dose indicated above. On the other hand, the Board was unable to obtain a reasonably reliable initial estimate of the cost of disposal.

However, these two figures - the calculated individual effective dose and the cost of disposal - accompanied by the general submission which specifies how they were determined, are important data for the public debate required by law. They constitute essential contractual terms that our society will assent to at that time, particularly with respect to the desirable safety level for workers, the public, and future generations, and with respect to the expenses agreed to in order to ensure that level of safety.

The Board believes that it is essential that the necessary research be conducted so that the initial elements are available in an accurate, complete, and transparent manner.

1.4.6. Opinions of the Board

Nuclear waste management raises a certain number of socioeconomic issues:

1) issues related to assessing the costs of disposal and storage sites: direct monetary costs for constructing the site, long-term costs for monitoring the sites; the impact that these costs have on both the current and projected market price of nuclear kWh;

2) issues related to the socioeconomic fallout of managing this waste (what economists call positive or negative "externalities"): impact on local employment, tax effects for the local communities affected, impact on the landscape and the value of both developed and undeveloped property, effect on tourism; as well as impacts on the trade balance (via recycling and transmutation opportunities);

3) issues related to funding these operations: in France, waste producers must fund the disposal, by way of various mechanisms provided for by law. It is important to know in detail the mechanism by which these provisions work and how they are managed;

4) societal issues related to the social acceptability of nuclear power in general, and of waste management in particular; it may be helpful to get expert opinions on how information and communications are accomplished in this matter, particularly information on potential health effects. It is also important to assess how social acceptability in France and other countries may change.

Work has been done into these issues, particularly in the parliamentary publications, in published notices from various public debate boards, and in reports published by the agencies affected (Andra, Areva, CEA, EDF, Cour des Comptes etc.).

However, it would be useful to get updated insight into these various issues in order to analyze how they have changed, as well as to conduct comparative analyses of the situation observed in other countries (in particular Sweden, Belgium, England, and the United States). Special attention should be paid to the mechanism for implementing provisions and their long-term management. The Board suggests holding hearings with the main agencies (Andra, CEA, Areva, EDF,) on the issues mentioned above in order to write up an up-to-date, accurate report of the present situation.

The Board recommends that research grants be disbursed by the Ministry for studying socioeconomic issues related to recycling and waste management. There appear to be few theses underway regarding these issues, at least from a socioeconomic viewpoint. Targeting a few positions (tasked with research at CNRS or University chairs) regarding these issues would also be helpful.

By way of example, below are some themes that could be selected, though these are only a few possibilities:

- *a comparative study of long-term funding for nuclear waste management (France, Sweden, Belgium, England, Canada, United States);*

- *externalities related to waste management: a "contingent evolution" approach (via field surveys).*

- *the choice of nuclear technology, irreversibility, and the "real options" method;*

- *managing nuclear waste and health: is behaviour rational? Can the "precautionary principle" serve as a guide?*

- *Bringing nuclear power back to the world: what economic impact it would have on the waste to be stored, and what solutions are sustainable from an environmental viewpoint?*

The Board approves of the efforts implemented by Andra at incorporating human and social sciences approaches in the issue of reversibility, and for getting the corresponding scientific community involved in them using different methods (doctorate thesis grants, study days, interdisciplinary seminars at Nancy in June 2009, preparing an international conference in 2010, etc.)

This fundamental research approach must be suitably combined with a dialogue with stakeholders initiated by Andra on the most immediate issues, and help it better write the corresponding questionnaires. It will succeed by gradually bringing together industrial firms (Areva, EDF, GDF-Suez) and nuclear institutions (CEA, ASN, IRSN etc.).

Chapter 2

PARTITIONING-TRANSMUTATION

The partitioning-transmutation research programme carried out by the CEA and its partners is built around three goals to be achieved by 2012 in order to satisfy the objectives set by law:

- To assess both the contributions and the cost or potential drawbacks of transmuting long-lived actinides, throughout the entire cycle;

- To develop methods for implementing it, i.e. fuel partitioning and separation methods, and transmutation and recycling systems;

- To provide data for assessing the implementation conditions, provided by deployment scenario studies and cost/benefit analyses.

The Board also wishes to note the quality of the work which has been presented to it.

In this chapter, the Board will come back several times to the twin requirements of abiding by the timeline for the Astrid[26] fast reactor prototype, without which the partitioning-transmutation programme would be compromised, and of maintaining a high level of innovation in order to promote a safe, population-acceptable Generation IV French industrial technology for multi-recycling actinides.

2.1. PARTITIONING-TRANSMUTATION

The partitioning-transmutation strategy is planned for a future group of plants that includes Generation III reactors (pressurized water reactors, PWRs) and Generation IV reactors (fast neutron reactors, FNRs), which are gradually replacing the current ones. This strategy would make it possible to change the nature of the high-level waste by significantly reducing the quantity of long-lived radioactive elements in the final waste, and more specifically by removing minor actinides (neptunium, americium, and curium). The question is whether this is industrially possible. The approach taken to answer this question involves examining how to transmute these elements, both scientifically and technologically. This must involve the ability to separate them multiple times, because they will need to be recycled. The corollary issue is examining what impact partitioning-transmutation would have on the disposal of final waste, which would have a substantially lower minor actinide content.

The top priority is how to transmute the minor actinides, i.e. elements heavier than uranium, formed in reactors by capturing one or more neutrons (americium, curium, neptunium), because their timelife is measured in thousands, if not millions of years. After a few centuries, the fission products contribution to the waste's radiotoxicity inventory will have decreased substantially.

Is also important to keep in mind that the research into partitioning-transmutation covers the long-lived, high-level waste of a future set of reactors, not the long-lived, high-level waste of the current mix, which must be placed in deep disposal as provided for by law.

[26] Advanced Sodium Technology Reactor for Industrial Demonstration: The name given to the prototype sodium-cooled fast neutron reactor stipulated under the law of June 28, 2006, to be built by 2020.

Last year, the CEA had presented a research programme within the framework of the law of 2006 and clarified under the PNGMDR. During the year 2008-2009, the Board noted some rigidity in the declared strategy orientations, which could lead to delays in making certain decisions.

In the context of partitioning-transmutation, the Astrid Prototype must play a central role both in crafting a sodium-cooled fast neutron system and in supporting a transmutation strategy.

2.1.1. Research: industrial stakeholders and issues

In accordance with the law of 2006, the CEA must "provide an assessment report on the outlooks for various industrial partitioning-transmutation technologies" in 2012. The law of 2006 requests that the research not solely be assessed in isolation, but is placed in the technical/economic context. The Board therefore requested that EDF and Areva specify the challenges they face in transmutation, and how they foresee it developing. Their responses were given in the spirit of a "nuclear renaissance".

♦ EDF

EDF's views on transmutation seemed extremely reserved. EDF believes that the current renewed interest in nuclear power will result in a widespread installation of Generation III reactors. It therefore perceives the next-generation reactors as potential technological and economic competitors. For EDF, transmutation will draw upon one or more technologies that do not yet exist; EDF, along with Areva and the CEA, is contributing to research into the Astrid prototype sodium-cooled fast reactor. EDF does not believe that a delay in the industrial deployment of FNRs to well after 2040 would mean any difficulties. Instead, this delay would make it possible to consolidate results drawn from EPRs, a technology which EDF believes to be mature. EDF believes that the amount of natural uranium needed for Generation III reactors (EPRs) is currently available, and therefore rejects the idea that resources are needed for Generation IV reactors. EDF brought up the major efforts that it had to agree to in order to meet the safety, operational, consistency and performance requirements of the nuclear cycle, as well as those related to economic competitiveness and waste management, for Generation II and III reactors; efforts on at least the same scale will be necessary to move on to the Generation IV. EDF therefore wants to be certain that the development of sodium-cooled fast reactors does not penalize the fuel cycle for pressurized water reactors (PWRs and EPRs). However, the reprocessing of spent Mox, which is needed to launch Generation IV, is considered to be under control, and EDF will be able to implement it when the time is right. To EDF, the goal of incinerating nuclear waste does not appear to be an industrial priority.

♦ Areva

Areva is taking into account the law of 2006, the research programmes and requests from the international market. The American programme GNEP could make use of the COEX[27] process or potential upgrades to it. Areva's American market does not allow it to make a distinction between potential developments in neptunium partitioning-transmutation, which is mobile within a geological disposal site in an oxidizing environment, as planned to date in the United States.

27 Combined extraction of uranium and plutonium.

In the current context, for reprocessing, Areva wishes to avoid technological breakthroughs. Its priority is the COEX process (proliferation-resistance, improvements to fuel behaviour, possible accounting for neptunium) which gives it the ability to provide a broad range of commercial offerings, both reactors and fuel, taking its customers' requirements into account at a very early stage. In France, Areva prefers to recycle only americium, because of the radiation protection restrictions that the presence of curium would require; Areva therefore wants for an industrial process to be developed that would chain together COEX and americium partitioning.

Areva has expressed its worry that the innovative French Generation IV reactors are arriving onto the market too late, given developments currently underway in India and China.

The Board believes that the industrial companies' position in supporting the research have firmed up since last year. It notes the collaborative participation of the stakeholders, particularly within the European platform SNE-TP[28], which the CEA is coordinating and which examines possible industrial deployment strategies. The Board wants stakeholders to be able to find the resources to reconcile timeline requirements with the need for innovation for the Astrid prototype.

2.1.2. Scenarios

Scenarios form an essential tool for estimating the impact of strategic and tactical decisions on the power generation system. They are restricted both by physical laws and by economic data. The scenarios set the course for an analysis of the advantages and disadvantages of transmuting fissile material.

The Board notes that a Committee has been set up formalizing coordination between the three stakeholders, CEA, Areva, and EDF, and the implementation of work on scenarios that cover scientific and technical issues as well as economic aspects.

Contrasting situations, ranging from different transmutation implementations to the total shutdown of nuclear power, were carefully selected by the three partners and have already been analyzed; they include transitions between plant mixes. With respect to reactors and fuel, the transition from water reactors (Generation III) to fast reactors (Generation IV) has been studied, including refurbishing the cycle's plants. For example, the reprocessing of spent Mox fuel, prior to the deployment of fast reactors in order to produce the plutonium needed is accompanied by an increase in the flow of americium to be transmuted. The masses of actinides present in the cycle may be stabilized. They are 900 t of plutonium for 60 GWe from FNRs; an additional 100 t of minor actinides would be added if they are to be recycled.

In the detailed scenarios that were studied, adding economic databases or developing an assessment method are new steps. The economic studies deal with investments over the transitional period, from about 2040 to 2110 environ, during which time the reactors installed would switch over from Generation III to Generation IV. Part of the current work consists of writing up a list of indicators to compare the various scenarios.

The final report on the scenarios is expected for late 2011. These studies will be essential for the 2012 assessment.

[28] Sustainable Nuclear Energy Technology Platform; the goal is to coordinate R&D devoted to nuclear fission on the European level (FP7).

2.1.3. Transmutation

Minor actinides may be transmuted inside fast neutron reactors (Generation IV) or in dedicated systems, known as ADSs, which combine a subcritical fast neutron reactor with an accelerator. The unresolved problems are related to the neutrons in the core, which are modified to some extent by the transmutation method chosen, and to the production of fuel or transmutation targets that incorporate minor actinides. The issue of what materials should be used to create these fuels or targets, which must withstand high-flux radiation and are to be recycled, is central to the innovations needed for transmutation to be industrially feasible in these systems.

The goal of the research is therefore to specify the benefits that transmuting each of the actinides found in the spent fuel would provide, as well as the resources that would be needed to industrially implement the process, and the research steps to be completed by 2012 in order to take a position on possible courses for the future.

Until now, the transmutation of minor actinides has been seen in a broader, unfinished context. In fast reactors, it may be conceived homogeneously by diluting minor actinides in the fuel, or heterogeneously by providing minor actinides in the targets.

Two options are foreseeable: in the first one, all minor actinides (neptunium, americium, and curium) are cycled; in the second, only americium is recycled.

♦ Homogeneous recycling

In homogeneous recycling, adding actinides to the FNR's fuel affects safety and harms the functioning of the core. In order to meet safety conditions, the minor actinide content must remain low (less than 3% in sodium FNRs). This has consequences on all facilities in the cycle, from production to reprocessing. Remote fuel production is essential. A low minor actinide content would require a large fraction of the FNRs available, if not all of them, in order to significantly transmute the actinide stock. The handling and transportation of new fuel are subject to penalties.

This option has already been the subject of detailed studies; it is considered mature by the CEA. The majority of radiation experiments to date have dealt with materials whose minor actinide content is relatively low.

♦ Heterogeneous recycling

The first option calls for certain assemblies to be placed within the core, which includes target pins containing minor actinides spread throughout a magnesium oxide-based inert matrix. In order to achieve a significant transmutation rate, these targets must remain in the reactor core for about a decade. Many findings have been obtained regarding irradiated materials in Phénix, or in the Bor-60 Russian fast neutron reactor.

The second option involves minor actinide-loaded blankets (CCAMs), where actinides are spread throughout a uranium oxide inert matrix (their content not exceeding 20%) placed on the edge of the core. In this situation, the core's functioning is not modified by the presence of minor actinides. This option makes it possible to use a standard fuel for FNRs cores. Due to its potential benefits and the novelty of this approach; it is currently being heavily studied. Consuming of minor actinides on the order of tens of kg/TWh would require their irradiation for longer than a decade. Unlike the previous option, the benefit of this option is based on the close similarity of blanket assemblies to those used in standard UOX fuel, which suggests that they could be treated together. A battery of experiments is being set up with the HFR[29] and Osiris[30] reactors; it is necessary to estimate how representative irradiation in thermal reactors is for fuels intended for fast neutron reactors.

[29] High-flux reactor installed in Petten, Netherlands.
[30] Test reactor installed on CEA's site in Saclay, France.

Given all the studies that have been conducted to date regarding the various methods for recycling minor actinides, and noting the fact that placing them inside the blanket of the FNR reactor does not affect the core's functioning neither the reactor's safety, the Board recommends that priority be given to the CCAM concept studies.

♦ The hybrid accelerator-reactor system (ADS[31])

Generation IV power-producing fast reactors offer true transmutation potential. However, another possibility would be to perform transmutation in specially designed systems (ADSs). In ADSs, the fast neutron reactor core is subcritical, meaning that it cannot develop a chain reaction without neutrons being provided from outside; on the other hand, it can support high rates of minor actinides. It is coupled to an accelerator which provides the outside neutron source.

With ADSs, the goal is to attain fuels containing about 50% minor actinides. The European programme Eurotrans[32] is fully devoted to ADSs over the 2005-2010 period. Its final report must lead to the draft prototype design (XT-ADS, 70 MWth) and its industrial extrapolation (EFIT, 400 MWth).

Its sub programme Demetra[33], coordinated by FZK[34], has mainly been used to deal with corrosion problems of structural materials when they come into contact with liquid metal (lead or lead-bismuth eutectic) while being irradiated (measurements, post-irradiation analyses of the Mégapie target, experiments on lead rings). An additional interest in this work results from the fact that a lead-cooled fast reactor is also planned in Europe.

Studies combining an accelerator and a reactor have experienced multiple delays; they are now focused on the Guinevere experiment, which will be performed at the Vénus reactor at SCK•CEN[35] in Mol, Belgium. This experiment, which combines a zero-power fast reactor with a neutron source is essential for demonstrating that the core's status is constantly being checked, and therefore to ensure the safety of an ADS. The CEA has provided the fuel in the form of enriched uranium which is 30% uranium-235, and CNRS has provided the accelerator that can generate a pulsing or continuous source of neutrons. The experiment will begin in autumn 2009.

In 2009, the European Union approved a new CDT (Central Design Team) programme, which will make it possible to write up the detailed initial draft for a fast neutron irradiation installation that operates in both subcritical and critical modes. CNRS is participating in work on the accelerator, and the CEA in work on the fuel. This work is preparatory for the construction of a fast neutron irradiation device, Myrrha[36], at the SCK•CEN site in Mol. The partners want to make Myrrha a European support infrastructure (comparable to RJH[37]). Its construction could be authorized around 2013.

The Board will examine the Eurotrans programme report, which must be finalized by March 2010.

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31 Accelerator Driven System; The subcritical systems devoted to transmutation are controlled by the ADS accelerator,and include three components: a linear accelerator, a spallation target, and a subcritical nuclear reactor.

32 EUROpean Research Programme for the TRANSmutation of High-Level Nuclear Waste in an Accelerator Driven System.

33 Development and assessment of structural materials and heavy liquid MEtal technologies for TRAnsmutation.

34 Forschungszentrum Karlsruhe.

35 Studiecentrum voor Kernenergie•Centre d'Étude de l'énergie Nucléaire, Belgium.

36 Multipurpose hYbrid Research Reactor for High-tech Applications, which will be subcritical reactor with a power of about ~50 MW.v.

37 Jules Horowitz test reactor currently being constructed at the CEA site in Cadarache.

2.1.4. Partitioning

After the initial long-term period corresponding to the decrease of short-lived fission products, the main contributors to the spent fuel's radiotoxicity inventory are plutonium and minor actinides; long-living fission products' contributions appear to be negligible. Mono-recycling plutonium is currently performed in France in Mox fuel.

The question is how to assess the benefit in separating the second component of the waste: neptunium, americium, curium. An additional criterion in the radiotoxicity inventory, justifying the partitioning of minor actinides, is that of the residual thermal power of vitrified waste canisters, which affect the disposal facility's architecture (room, ventilation, footprint). Curium makes a noteworthy contribution up to about 100-150 years; afterward, americium provides the dominant contribution to the residual thermal power of the glass canisters. This is the reason why research into partitioning-transmutation of americium alone is given particular interest.

The range of research into partitioning currently under way is fairly broad. The CEA has always noted their flexibility, particularly in the fields of partitioning-conversion, the fabrication of targets, and the fabrication of transmutation fuels. It has always made sure that the proposed scientific solutions be as close as feasible to industrial implementation. The CEA's research may certainly be geared towards new priorities that may appear, e.g. if the choice was to be made to transmute americium alone into FNR blankets (CCAM concept).

The CEA believes essential that the minor actinide partitioning-conversion processes be adaptable to the eventually new transmutation methods. These methods are based on the findings of scenarios, which must set the priorities of the actinides to be transmuted. It will then be possible to have enough elements to appraise the conditions for industrially implementing the processes.

The sought-after flexibility has led the CEA to study three processes in parallel:

i) the Diamex[38]-Sanex[39] process following the Purex[40] (or Coex[41]) process, used to extract americium and curium, and potentially to separate them if need be,

ii) an Exam[42], process, a variant of the foregoing, which would only extract americium,

iii) the Ganex[43] process would separate both uranium and the other actinides.

A special effort will be made for the partitioning-conversion of americium alone. Furthermore, the CEA is now working on a "process consolidation" programme, specifically to consider the possibility of their industrial implementation.

All of the partitioning processes studied by the CEA rely upon a common method, include common individual operations, and are founded on the use of a minimum quantity of chemical reagents, which are as common as possible across all tests. This provides the flexibility needed for research, in accordance with the goal that the CEA has set for itself. This research has been partially integrated into the Euratom FP7 programmes. The test timeline is set for the coming years. In this field, it is important to note the fundamental role that the Atalante facility in Marcoule is playing.

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38 DIAMide Extraction: a method for separating lanthanides and minor actinides from fission products.
39 Partitioning of Actinides through Extraction: a process for separating lanthanides and minor actinides.
40 Plutonium Uranium Refining By Extraction: a hydrometallurgical process for separating uranium and plutonium.
41 A process for co-extracting all minor actinides.
42 AMericium extraction.
43 Combined transuranic element extraction.

By 2012, tangible results for partitioning must contribute to the decisions to be made with respect to partitioning-transmutation, which will affect the selection of options for Astrid. Due to the advantages that transmuting americium alone might exhibit, the Board recommends that the research into americium partitioning be completed by 2012.

Research and studies into partitioning-conversion must constantly rely on fundamental research. To that end, the Marcoule Separative Chemistry Institute (ICSM)'s goal is to expand the knowledge of the fundamental mechanisms used in minor actinide partitioning processes, mainly to simplify them and increase their effectiveness.

The Board wants for ICSM to develop its research topics in accordance with the research conducted at Atalante and the CEA, particularly in preparation for the opening of ICSM's own laboratory at Atalante, which is expected in 2010-2011.

2.1.5. Manufacturing targets and fuels

♦ Physical studies

The development of fuels intended for transmuting minor actinides is particularly difficult; it relies on both manufacturing and measuring facilities. The CEA has such facilities suitably equipped to access the physical/chemical properties of new or irradiated fuels (Atalante, LEFCA, LECA).

The Board has already warned of the lack of fast neutron systems for irradiating transmutation fuels and targets. Neutron reactors, which are often outfitted with high-level on-line instruments, are indeed available for conducting small-scale analytical experiments. This will be true for the RJH reactor where samples may be irradiated by a high flux of fast neutrons, but within a limited region of the core. Nevertheless, in order to test the behaviour of materials under representative conditions, and in order to achieve high doses in order to characterize the containing and structural materials, a fast neutron spectrum is necessary for large volumes.

Modelling and computer simulation play a key role here. A major effort has been undertaken to develop powerful codes that guide the design of future fuels, while incorporating the knowledge acquired in earlier irradiations. Noteworthy work into the usage of fuel behaviour models were presented to the Board; these models are founded on situation analyses that have been well-explored by now and applied to new situations, such as designing fuel elements for the CCAM concept (special conditions related to heating, the migration of chemical elements, material densification, and gas production).

♦ Manufacturing

The composition spectrum of fuels for transmutation whose minor actinide content may vary from a few percentage points (homogenous recycling) to 20% (heterogeneous CCAM recycling) and more than 50% (ADS fuel), as well as the specific nature of the targets to be designed, will have an effect on the manufacturing conditions (hot-cell operation); it will be necessary to further develop robotics in order to completely automate this work. The already-observed difficulties have led to the ALFA[44] project opportunity study (about a few kg of pins, or no more than a few hundred grams of minor actinides). This submission is expected to be finished by the end of 2009.

[44] Planned workshop for manufacturing minor actinide-loaded pins.

♦ **Recycling**

The physical/chemical properties of minor actinide oxides suggest that there is a great deal of similarity between the behaviour of a transmutation fuel that contains a low minor actinide content (a few %) and the behaviour of standard fuel. The homogenous recycling option was heavily studied. Homogenous transmutation will henceforth be demonstrated through prototype-stage irradiation in a fast reactor.

A CEA-USA collaboration (irradiation in the American ATR[45] reactor) will make it possible to test the fuel pins loaded with high-burn-up minor actinides. As part of the international GEN-IV Forum, the Gacid[46] programme, which involves France, Japan, and the United States, is meant to demonstrate the quasi-industrial feasibility of homogenous minor actinide recycling.

The "Advanced Fuels" project, which includes the United States, the European Union, Japan, and South Korea, is aimed at optimizing fuel under high-burn-up and high doses of irradiation. This study will also deal with minor actinide-loaded fuel.

The ESFR[47] project launched in early 2009 represents the European contribution to the GENIV programme for sodium-cooled FNR technology. The programme includes studies on the reactor's architecture, safety, and fuel.

♦ **Fuel for ADSs**

As part of Eurotrans, the sub programme AFTRA[48] devoted to fuel is coordinated by the CEA. Eurotrans is interested in two levels with ADS; the fuels are highly specific, with very high actinide content.

Collaborations with Japan have led to considering nitride fuel, the solution which Japan currently prefers.

Even when they deal with low minor actinide concentrations, the irradiations performed for the FNRs are essential steps in engineering of fuel for ADSs. This reprocessing is where an important qualitative difference appears: pyrochemistry would seem to be particularly suitable for reprocessing these fuels; the CEA is reorienting its pyrochemistry programmes in connection with the ACSEPT[49] programme of FP7.

2.2. IMPACT OF PARTITIONING-TRANSMUTATION ON DISPOSAL

As currently planned, the purpose of partitioning-transmutation is to reduce the minor actinide activity of final waste. It must be noted that since the volumes of glass are governed by the fission products' content, they will practically never vary from those currently in production, for a given amount of energy generated. On the other hand, glass derived from reprocessing and containment would have very few minor actinides; they would be less exothermic and less radiotoxic.

A CEA report to the Board dealt with the impact of partitioning-transmutation on the footprint of the HAVL waste disposal facility. Limiting the temperature at the cavity's wall to 90°C, as found in the 2005 submission, requires that the disposal facility's footprint increase along with the heat capacity of the canisters. In particular, it increases along with the fraction of americium. By removing the americium from the canister, its heat capacity decreases, and its footprint is minimized without changing the design of the disposal facility.

45 Advanced Test Reactor.
46 Global Actinide Cycle International Demonstration.
47 European Sodium Fast Reactor - FPS.
48 Advanced Fuel for Transmutation.
49 Actinide reCycling by Partitioning and Transmutation - FP7.

However, the footprint also depends on the duration of warehousing preceding disposal and the nature of the radionuclides - by way of their half-life - contained within the canisters. A simple computer model which is consistent with the calculations given by Andra in the 2005 submission, shed light on a number of scenarios. In particular, it makes it possible to estimate the impact of selecting the date for reprocessing the Mox.

However, the study on the effects of heat phenomena on the disposal site is not yet sophisticated enough to enable a full quantitative assessment of the benefits of transmutation from this standpoint. Corresponding studies will begin in the underground laboratory at Meuse/Haute-Marne in 2009.

> *The impact of transmutation, particularly on the design and behaviour of a geological disposal facility, has not sufficiently been assessed. As the Board has already noted, the CEA and Andra must conduct a mutual review of the consequences transmutation could have on the cost and safety of the disposal facility. Given the 2012 deadline, this study has become urgent.*

The effects of the partitioning-transmutation strategy on the fuel cycle have also been studied as part of the European programme Red-Impact[50]; the studies particularly dealt with waste management and geological disposal. Different scenarios illustrate the benefits of advanced cycles in reducing the heat given off by the waste and the radiological effects. They confirm that the content at the outlet, in the Boom clay used as a baseline, can only be the result of fission and activation products, during a non-accidental situation.

2.3. PROTOTYPE SODIUM FAST REACTOR, ASTRID

In accordance with the law of 2006, the CEA's ambitious goal, accompanied by French industrial firms, is to make the Astrid prototype both the forerunner to an industry-leading Generation IV power-producing reactor and an irradiation tool for preparing to recycle plutonium and americium, then other minor actinides.

First, its design must incorporate technological breakthroughs from the previous generation of sodium-cooled FNRs (in terms of safety, energy efficiency, lifespan, operating conditions, etc), which means that choices must be made in 2012 for the prototype to enter operation by 2020 and for an industrial reactor type design to be launched by 2040. Second, these choices will require that the transmutation research be completed by that deadline, which means a minimum level of visibility with respect to transmutation methods and the availability of appropriate experiment resources.

Although Astrid's fuel differs from Superphénix's while still remaining oxide-based, its manufacturing poses no special major difficulties, but experimental pin irradiations using fast neutrons will definitely be necessary. Could they take place in Monju by 2015? With respect to Astrid's funding, an international consortium must be set up.

[50] European Research Programme to assess the Impact of Partitioning and Transmutation on Final Nuclear Waste Disposal - FP7 2004-2007; 23 partners, including the CEA and Areva.

By 2012, the CEA must propose a set of specifications for Astrid, which must fulfil a dual purpose: researching sustainable power-generating capabilities, and making irradiation and transmutation capabilities available. The task is a large one because it is necessary, under a tight schedule, to create a project that represents true technological breakthrough in order to avoid pursuing courses that may quickly prove obsolete. The Board, however, believes that it may be completed successfully, provided that the CEA assigns the project top priority so that it can meet the deadline required by law.

On December 20, 2006, the Atomic Energy Committee set research funding through 2012. The execution of the budget through 2012 and research funding beyond that are a major concern. For research into the Astrid fuel cycle, drivers and transmutation, the CEA's 2007 and 2008 budgets have shortfalls of about 10%; these budgets have been maintained for the reactor itself (see 2008 COSSYN report).

The Board believes that any delay in assigning the necessary human and financial resources to the Astrid programme would compromise the 2012 assessment and the availability of the prototype by 2020, both of which are stipulated by the law of June 28, 2006.

The CEA, with significant research resources, is also developing research into gas-cooled fast reactors, which are considered an alternative technology to sodium-cooled FNRs. Owing to the high operating temperature of gas-cooled FNR reactors, this technology could make it possible to benefit from industrial heat or hydrogen generation in addition to power generation. A prototype reactor, Allegro, should be constructed under European guidance; this project assumes that by 2012, difficult to fuel and material problems will have been solved, and the reactor's feasibility will have been ascertained.

The Board recommends that when options are chosen for Astrid in late 2009, the CEA should also state the respective proportions of its efforts that it will devote to both of these technologies.

The Board notes that if the feasibility of partitioning-transmutation in Generation IV fast neutron reactors at reducing the impact of waste is to be demonstrated, the Astrid prototype offers the best chances of success within the timeline set by law.

2.4. AVAILABILITY OF TOOLS FOR RESEARCH

Research into transmutation which requires that minor actinide-loaded fuels be engineered first must be able to draw upon neutron irradiation experiments. The Board has already pointed out the lack of fast neutron irradiation resources, once Phénix is taken off-line (March 2009). Although some of the studies may be conducted in thermal reactors, and that is also expected that new possibilities will be offered in 2015 by the RJH in Cadarache, the CEA's teams will have to evoke considerable efforts to translating the findings obtained for thermal neutrons to the conditions for fast neutrons. This translation is a difficult physical problem whose resolution must rely upon solid data. The RJH will only offer limited solutions, and research in France will not be able to rely on useful means of irradiation until the Astrid prototype enters service (2020).

The construction of Astrid requires that a driver fuel fabrication workshop with an annual capacity of a few metric tonnes be constructed in Hague. The transmutation experiments in

Astrid require the simultaneous construction of a minor actinide-loaded fuel micropilot manufacturing workshop, whose annual capacity is between 10 and 100 kg of pins, with a few % of minor actinides. The Board notes that discussions for the construction of these workshops are underway, and that the CEA has excellent analysis resources for developing fuels.

Finally, the CEA is studying the opportunity of installing the smaller facility (ALFA) at the Atalante site, making it possible to prepare minor actinide-loaded samples for irradiation experiments (pins, then capsules).

In accordance with its recommendations regarding Astrid, the Board believes that the construction of the ALFA laboratory is the first essential step for conducting transmutation experiments in Astrid.

2.5. MATERIALS FOR REACTORS

It is widely recognized that structural materials form a key factor in the feasibility of Generation IV nuclear systems. The Board itself had noted this in its n°2 report. However, given the deadlines set by the law of 2006, particularly with a view to the 2020 Astrid prototype, this topic has not lent itself to a summary presentation during the past year.

It will not be until late 2009 that the results from the initial research to prepare Astrid, which are being conducted from 2007 to 2012 as part of the three-party programme (CEA, Areva, and EDF) will be published. These results will make it possible to specify how to proceed further in 2010-2012 in order to be fit to assess the industrial outlooks for various Generation IV technologies by the end of 2012, in accordance with law. Naturally, the three-party programme only affects some of the materials, whether directly through new alloys for core structures, or indirectly through sodium hazard reduction, in-service inspection, reliability, and "repairability". The end-of-2009 results, in particular, will incorporate the findings from the ODS[51] steel and fuel irradiation tests, which are scheduled at Phénix.

Besides the Astrid-focused research, the problems of materials for gas-cooled fast neutron reactors and ADSs continue to be inspected in longer-term programmes, both as part of international collaborations at CEA, and for single-block and composite ceramic materials, at CNRS. Despite their reduced urgency, it will be necessary to draw up an exhaustive report on them for the 2012 benchmark.

In the field of materials, it is necessary, but insufficient, to take into account the feedback from Phénix and Superphénix. This feedback, even during an optimal operation period, does not meet the performance and safety levels that are currently expected in new sodium-cooled fast reactors.

The Board notes again how important it is that the Astrid prototype be innovative and high-performance. It notes that sodium-cooled fast neutron reactor construction products are becoming more common worldwide, but it is conceivable that they will not necessarily benefit from major innovations in the critical field of materials.

[51] Ferritic steel strengthened through oxide dispersion.

Chapter 3

INTERNATIONAL OVERVIEW

Although national approaches for setting up a disposal facility differ, many international cooperative efforts are undertaking research in the various countries affected, which go beyond informal discussions. In Europe, research into the deep geological disposal of spent fuels or reprocessing waste is mainly proceeding as part of the European Commission's and Euratom's 6th and 7th Framework Programmes for Research and Technological Development Andra, the CEA and CNRS are stakeholders in many of them. Andra has become one of the leaders in the European programmes and the preferred partner of counterpart agencies in other nuclear countries. This change is due to two factors. First, the Meuse/Haute-Marne laboratory is open to the world, and secondly, the French research programme conducted by Andra is supported by the institutional means that the law of 2006 instituted, with a firm view on opening a disposal site in 2025.

International collaborations between research laboratories, as well as the progress of work in Sweden and Finland, give Europe a pioneering role in research regarding the disposal of radioactive waste. The research being conducted in France is among the best in Europe. These collaborations will enable Andra to partially compensate for the delays compared with other European centres, following the late construction of its underground laboratory. Long-term experiments remain necessary in order to qualify a disposal concept appropriate for the Callovo-Oxfordian layer and to select technologies that will be derived from the scientific findings received.

With respect to research into new partitioning-transmutation technologies, France currently has a leading position. In an international context geared towards Generation IV technologies that rely upon fast neutron reactors, particularly with multiple prototype projects whose deadlines are drawing near, France must clearly define its priorities and implement the resources required to avoid losing ground.

France plays a major role in international research programmes. 38 French institutions have participated in the project described in this chapter; the following is the frequency of participation:

- CEA, 21 times, 4 of which as a coordinator;
- CNRS, 16 times, one of which as a coordinator;
- Andra, 13 times, one of which as a coordinator;
- Areva and EDF, 10 times;
- IRSN, 7 times;
- BRGM, 3 times;
- Joseph Fourier University in Grenoble, twice;
- other institutions once (Ecole des Mines de Nantes and the Observatoire Méditerranéen de l'Energie as coordinators).

The following paragraphs first give the international legal context, followed by the main underground laboratories and disposal sites around the world, as well as sources of fast neutron irradiation. The research conducted into disposal within the European and international framework are then given, followed by research into new reactor technologies for partitioning-transmutation.

This chapter ends with a short description of projects related to establishing nuclear databases, economic aspects, and education and training aspects.

3.1. INTERNATIONAL LEGAL CONTEXT

Radioactive waste management, and by extension research into waste management, takes place within a national and international legal context. The French legal context is well known. The international context covers four distinct aspects:

- Protection of the marine environment, via the international OSPAR Convention,
- The Aarhus Convention on access to information and public participation in environmental affairs,
- The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,
- The Convention on Environmental Impact Assessment in a Transboundary Context (the Convention on Nuclear Safety and the Espoo Convention).

The European Commission has just created the "High Level Group on Nuclear Safety and Waste Management" (ENSREG), one of his duties is to prepare new European rules for the safety of nuclear facilities and the management of spent fuel and waste.

3.1.1. International OSPAR Convention

Following the London and Oslo conventions for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, and the Paris Convention for the Prevention of Marine Pollution from Land-Based Sources, European countries ceased disposing of radioactive waste in the Atlantic Ocean in 1982. In 1992, the conventions were combined into the International OSPAR Convention, ratified by France in 1997 and officially entering force in 1998.

For any hazard resulting from the disposal of waste into the sea, the convention requires that the precautionary principle be applied, with the polluter paying, and that the best environmental techniques and practices available always be chosen.

3.1.2. Aarhus Convention

The Aarhus Convention governs public participation in decision-making processes and environmental justice. It entered into force in 2001, and was ratified by France in 2002. Right to information may be exercised from all public authorities and utilities. The convention also stipulates that public participation in decision-making processes must be permitted whenever all options and solutions are still possible. The results of the participation must be duly taken into account. Finally, access to justice must provide for sufficient measures, without prohibitive costs.

3.1.3. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

The purposes of the convention, negotiated under the auspices of the IAEA in 1997 are:

- to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management, through the enhancement of national measures and international co-operation;

- to ensure that during all stages of spent fuel and radioactive waste management there are effective defences against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation.

To date, 42 States have ratified the Joint Convention, including France in 2001.

3.1.4. Convention on Nuclear Safety

The goals of the convention are as follows:

- to achieve and maintain a high level of nuclear safety worldwide through the enhancement of national measures and international co-operation including, where appropriate, safety-related technical co-operation;

- to establish and maintain effective defences in nuclear installations against potential radiological hazards in order to protect individuals, society and the environment from harmful effects of ionizing radiation from such installations;

- to prevent accidents with radiological consequences and to mitigate such consequences should they occur.

Adopted in 1994 by the IAEA, the convention was approved by France in 1995. By 2005, every country that operates nuclear power reactors had ratified it.

3.1.5. Espoo Convention

The Convention on Environmental Impact Assessment (EIA) in a Transboundary Context stipulates the obligations of the Parties to assess the impact of certain activities on the environment as soon as planning for them has begun. It further stipulates that the States have a general obligation to give notice and consult regarding any major project being studied, which may have a major harmful transboundary impact on the environment. The Convention entered into force on September 10, 1997 and was ratified by France in 2001.

3.2. RESEARCH LABORATORIES OR UNDERGROUND DISPOSAL FACILITIES

In Europe, the main research regarding geological disposal is performed in Belgium (Mol, GIE Euridice), Finland (Olkiluoto, Posiva Oy), France (Meuse/Haute-Marne site, Andra), Sweden (Âspô, SKB) in Switzerland (Mont Terri and Grimsel sites, Nagra).

Depending on the local geological characteristics, research into the host medium focus on clay, granite, or salt. Finland and Sweden have opted for granite. The disposal concepts are very similar; however, the laboratory being constructed in Finland will eventually become part of the disposal centre, while the one in Sweden will not. In Belgium, France, and Switzerland, the preferred host layer is clay. Germany has opted for disposal in a salt layer, but the choice has become politically controversial. Spain has examined all three options, but is currently focusing on long-term storage.

In the United States, there is a disposal centre in a salt layer for military-generated long-lived, medium-level waste: The United States Department of Energy's Waste Isolation Pilot Plant (WIPP).

♦ Germany

The Konrad mine, a former iron mine 800 to 1 300 m deep, is located below a very thick layer of clay. In 2002, the German government authorized the disposal of FAVL and MAVL waste there. Following legal challenges, the operation of the disposal facility was delayed. Ultimately, the green light to begin operation was obtained in 2008, and the first canisters are expected beginning in 2013.

From 1967 to 1978, the former salt mine in Asse received FAVC[52] and MAVC[53] waste as part of a disposal project. Afterward, the mine was used as an underground research laboratory, mainly for studying the effects of heat on the salt surrounding heated containers used to simulate HAVL waste. This disposal site is currently experiencing difficulties due to brine seepage.

The possibility of disposing all categories of waste, as well as spent fuel, in the site in Gorleben, also a former salt mine, has been studied for 30 years. The laboratory 840 m deep was operational between 1998 and 2000, when a political moratorium interrupted research.

The former salt mine in Morsleben received the first radioactive waste in 1971. In 1981, a temporary license for disposal was obtained, becoming permanent in 1986. The mine continued to receive waste canisters until 1998. It is experiencing serious problems with stability, which have led to the addition of more than 4 million m^3 of backfill.

♦ Belgium

Since 1982, Belgium has had the Hades laboratory 225 m deep, located in a layer of clay below the Belgian Nuclear Centre in Mol; the laboratory is operated by GIE Euridice. The laboratory is currently more than 200 m long, and houses several dozen experiments. The research and experiments, some of which have been going on for more than 20 years, primarily deal with construction techniques, corrosion, radionuclide migration, waste behaviour and instrumentation. Most of the research projects are performed in an international framework. Andra participates in them regularly.

A large-scale thermo-hydro-mechanical and chemical experiment, Praclay, is currently being installed. Its purpose is to simulate the heat field around a gallery for burying high-level waste. To that end, a gallery whose dimensions correspond to the Belgian disposal concept will be heated for 10 years at 80°C for a distance of 30 m. As part of the Forge project, an experimental device 40 cm in diameter will be installed there in order to study the effect of on-site constraints on the flow of gases. This experiment is being completed by a major surface-level laboratory research programme, involving modelling.

For more than 10 years, two experiments have been under way as part of the Coralus programme intended to study the influence of different boundary conditions (chemistry, temperature, and radiation) on the leaching of actinides incorporated into nuclear glass. In these experiments, glass plates with representative concentrations of uranium, plutonium, americium, and neptunium isotopes (order of magnitude: Ci/g), prepared by the CEA, were placed in contact with various porous materials. The gamma radiation field is being simulated using sources of cobalt 60 (order of magnitude: kCi). The Hades laboratory is currently the only one which has a license to operating at such levels of activity.

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[52] Short-lived, low-level waste.
[53] Short-lived, medium-level waste.

♦ **Canada**

Canada has an underground research laboratory located near the laboratories in Pinawa-Whiteshell, Manitoba. It had been created in 1982 to study the feasibility of safely disposing of nuclear fuel waste in granite rock. The laboratory is no longer operational; it is in the initial stages of decommissioning.

An investigation programme is underway at Bruce peninsula (Lake Huron, Ontario) with the goal of very deep limestone disposal (about 1000 m deep). The project pertains to FAVL and MAVL radioactive waste disposal. To date, three drilling operations have been completed, and two others have begun. The Bruce site, where eight nuclear power plants are located, is also a site for storage of spent fuel.

♦ **United States**

The WIPP (Waste Isolation Pilot Plant) disposal site located near Carlsbad, New Mexico, has received transuranic waste derived from military activities since 1999. The waste is disposed in a 250 million-year-old layer of salt, located 700 m deep.

The fate of the Yucca Mountain laboratory in Nevada, for which the United States Department of Energy requested a building permit, is uncertain, since President Obama's new administration has withdrawn all research funding for it.

♦ **Finland**

Finland chose the granite site at Olkiluoto, where an EPR is currently being constructed, as its disposal site for spent fuel. The first galleries have been used as measurement and research laboratories since work began in 2004. This laboratory, which is to become a part of the disposal site, will reach the intended depth of 400 m in 2010. The building permit application for the disposal galleries, not including the laboratory, will probably be submitted in 2012. The concept chosen is the Swedish one: the spent fuel is placed in copper canisters stored in shafts filled with bentonite. The inauguration of the final disposal site is planned for 2020.

♦ **France**

P.m.: the Bure (Andra) and Tournemire (IRSN) laboratories.

♦ **Japan**

Two methodological research laboratories are currently under construction, one in Mizunami in crystalline rock, and one in Horonobe in sedimentary rock. Their goal is to, one day, offer a choice of sites for a laboratory to select a disposal concept.

♦ **Sweden**

The Aspo laboratory near the city of Oskarshamn has been dug into granite at a depth of 400 m. Unlike the Finnish approach, the laboratory will not be a part of the final disposal site, but rather will serve to approve the selected concepts. The research being conducted there is mainly focusing on construction techniques, hydrogeology, radionuclide migration, and modelling.

The Aspo laboratory has been operational since 1995, and its research, as well as its developments in its demonstration activities, have drawn keen international interest. Besides SKB, nine organizations representing eight countries collaborated with Aspo's activities in 2007. Six of them (Andra, BMWi, Criepi, JAEA, NWMO, and Posiva), as well as SKB, constitute the Aspo International Joint Committee, which is responsible for coordination and for the experiments resulting from this international involvement. Most of the organizations that form part of the Aspo partnership are concerned with hydrogeology, radionuclide migration, and rock characterization. Some of these organizations are participating in experiments as well as in two Aspo Task Forces: (1) the Task Force on Modelling of Groundwater Flow and Transport of Solutes (2) the Task Force on Engineered Barriers

The "Bentonite Laboratory" entered service in the spring of 2007; it is located at the Aspo laboratory. This laboratory examines whether bentonite - which forms a buffer around the containers and serves as a filler material for the tunnels - is fulfilling its role in different groundwater flow patterns. It complements the underground activities and enables the large-scale testing of various operating methods under varied conditions. Machines and robots are also developed and tested there.

The "Canister Laboratory" in Oskarshamn is SKB's centre for developing canisters. There, SKB develops the technology for welding the lids and bottoms of the canisters intended for spent nuclear fuels. Methods are also being engineered for inspecting the welds and materials located there. Another major field of research consists of verifying that the machines and equipment that will be used in the encapsulation plant function adequately. This laboratory will also serve as a training centre for the corresponding plant's future staff.

♦ **Switzerland**

Switzerland has two research laboratories: Grimsel and Mont Terri. The Grimsel laboratory is located in the granite on one side of the Aar mountain. The laboratory, which is about 1000 m long, was particularly the site of the Febex experiment simulating HAVL disposal and spent fuel in order to study the behaviour of a series of protective barriers. Most of the research was conducted in an international framework, and Andra regularly participated in it.

The Mont Terri laboratory is located along a highway tunnel in an opaline clay layer. A few hundred meters long in total, it includes dozens of international experiments into the geological, hydrogeological, geochemical, and geotechnical characteristics of opaline clay. The experiments are both methodological and aimed at selecting clay as the host medium for a disposal site. Andra participates in a large number of experiments, partly due to the similarity between the clay at Mont Terri and that at the Bure laboratory.

3.3. SOURCES OF FAST IRRADIATION

The number of reactors that offer the ability to irradiate using fast neutrons is extremely limited on the global level. This heavily compromises projects for developing new technologies and transmutation experiments.

♦ **Belgium**

The BR2 research reactor (1963-2022?), 50-70 MWt, can irradiate a small volume (1.5 to 3 cm in diameter) with a fast-spectrum high flux.

♦ **China**

The 65 MWt CEFR research reactor is under construction.

♦ **France**

P.m.: since the Phenix shut down, there is no longer any fast reactor available. The Jules Horowitz research reactor, which is under construction, will make it possible to irradiate a small volume with a fast-spectrum high flux.

♦ **India**

Since 1985, India has a 40 MWt fast reactor, the FBTR.

♦ **Japan**

The Joyo (1977-2006, ?) and Monju (1994-1996, ?) reactors are currently shut down.

♦ **Russia**

The Bor-60 (1969-2011, possibly 2015) is a 60 MWt research reactor. The BN-600 (1980-?) is a power-generating reactor.

There are currently no plans to use the Indian and Chinese reactors for irradiation experiments.

3.4. DISPOSAL SITE DESIGN AND PERFORMANCE STUDIES

The nature of the host medium imposes specific techniques for the industrial excavation, operation, and sealing of the disposal tunnels. Additionally, the characteristics of the waste or spent fuel affect the choice of structural barriers, which, in combination with the host medium, will influence the performance of the disposal facility. A specific problem arises with "graphite" waste which contains extremely mobile long-lived radionuclides such as chlorine-36.

At the request of Andra, the NEA created a workgroup on reversibility within its Committee on Radioactive Waste. The goal of the group, which is made up of 13 partners, if is to define a reversibility chain that expresses the gradual nature of the various steps to disposal and describes the change in the ability to retrieve weight.

3.5. ENVIRONMENTAL IMPACT OF THE DISPOSAL FACILITY

A study of the environmental impact of the disposal facility is essential in assessing the potential risk for future generations. By necessity, it is based on an advanced model that draws upon the most accurate possible data on radionuclide migration through various artificial and natural barriers. One of the major difficulties of the study is the importance of the timescale: certain radionuclides will not reach the Earth's surface for hundreds of thousands of years. Therefore, not only do the long-term models have credibility problems, their relevance for the current human race is questionable, and underlying these problems are intergenerational ethical issues.

3.6. GOVERNANCE AND PARTICIPATION FROM STAKEHOLDERS

Public participation in decision-making processes and environmental justice has become a right. This means not only transparency in the choices and decisions to be made, but also prior access to knowledge and a willingness by authorities to adopt new good governance rules.

3.7. NEW TECHNOLOGIES FOR PARTITIONING-TRANSMUTATION

Transmutation strategies primarily rely upon fast neutrons, whether in critical or subcritical systems (ADS). The Generation IV initiative and the Sustainable Nuclear Energy Technological Platform (SNE-TP) aim to develop new types of reactors that include fast neutron reactors which recycle a maximum amount of fuel (4^{th} generation). These new types of reactors will require the development of new materials and innovative fuels that incorporate radionuclides derived from new partitioning techniques. Pressurized water reactors (PWRs and EPRs) are unsuitable for the transmutation of radionuclides, which are therefore currently considered to be waste.

3.8. NUCLEAR DATABASES

The new reactor concepts and corresponding safety studies will require modelling methods based on nuclear data that is currently less well-known than that available for the current generation of reactors (Generations II and III).

3.9. ECONOMIC AND GEOPOLITICAL ASPECTS

The development of a new reactor park or disposal site must take into account all costs both internal and external, positive and negative, as well as geopolitical elements so that the safety of supplies is optimally guaranteed.

The Secure[54] project allows the study of the safety of supply, the geopolitical context, the energy market and cost structure, both in France and around the world. Nuclear power is one of the forms of energy being considered.

3.10. EDUCATION AND TRAINING

One of the key elements in developing nuclear power is a potential lack of human resources, available laboratories, and competent institutions for providing nuclear education and training. The situation is different in each country, but in all countries where there is an interest in nuclear power, a true effort in instituting education and training is underway. In Europe, the ENEN programme, divided into Petrus II and ENEN II, takes care of these aspects.

The goal of the ENEN II[55] project is to consolidate the findings obtained by the ENEN Association[56] and the partners in the ENEN I (FP5) and Neptuno (FP6) projects, then to expand the education and training activities to radiation protection, radiochemistry, radioecology, and radioactive waste management.

As part of the ENEN association, the Petrus[57] II group Is studying the requirements and resources needed for training in the field of radioactive waste management.

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54 Security of energy considering its uncertainty, risk and economic implications; 2008-2010, FP7, 10 countries, 14 partners including the Observatoire Méditerranéen de l'Energie and CNRS.

55 European nuclear education, training and knowledge management; 2006-2008, 11 countries, 40 partners including the CEA, Andra, IRSN and the Ecole Polytechnique.

56 European Nuclear Education Network Association.

57 Petrus II Sub-group; 2009-2008, FP7, 10 countries, 17 Partners including Andra and the Institut National Polytechnique de Lorraine.

Appendix I

MEMBERS OF THE NATIONAL ASSESSMENT BOARD AS OF JUNE 30, 2009

Bernard Tissot - Honorary chairman of the Institut Français du Pétrole - Member of the Académie des sciences – Member of the Académie des technologies - President of the National Assessment Board.

Pierre Berest – Research director at the Ecole Polytechnique.

Frank Deconinck – Professor at Vrije Universiteit Brussel - President of the SCK•CEN, the Belgian Nuclear Research Centre in Mol, Belgium.

Hubert Doubre – Professor emeritus at the University of Paris XI-Orsay.

Jean-Claude Duplessy - Research director emeritus at CNRS.

Robert Guillaumont – Honorary professor at the University of Paris XI-Orsay - Member of the Académie des sciences - Member of the Académie des technologies.

Philippe d'Iribarne - Director of research at CNRS.

Maurice Laurent – Honorary director of the Parliamentary office for assessing scientific and technological choices.

Emmanuel Ledoux – Director of research at the Ecole des mines de Paris.

Jacques Percebois – Professor at the University of Montpellier I, Director of CREDEN (Centre de recherche en économie et droit de l'énergie).

Claes Thegerström – President of SKB (the Swedish company tasked with managing nuclear waste and fuel).

André Zaoui - Director of research at CNRS – Associate member of the Académie des sciences – Member of the Académie des technologies.

Appendix II

HEARINGS OF ANDRA, AREVA, THE CEA AND CNRS

October 8, 2008:	Areva - Uranium mining residue
October 9, 2008:	Andra - FAVL and storage
October 29, 2008:	CEA - Partitionings and ICSM
October 30, 2008:	CEA - Tritiated waste
December 17, 2008:	Andra - Canisters and simulations
December 18, 2008:	CEA - The challenges of transmutation
January 14, 2009:	CEA - Irradiation programmes for transmutation
January 15, 2009:	Andra - HAVL project
February 11, 2009:	Andra - Progress of the HAVL project
February 12, 2009:	CEA - Future technologies
March 11, 2009:	CNRS - National research groups (GNRs)
March 12, 2009:	Andra - HAVL – 2009 submission

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December 1, 2009:	Andra – Follow-up meeting for the FAVL submission
February 4, 2009:	Andra - Follow-up meeting for the CNE2's recommendations in its n°2 report.
February 5, 2009:	CEA - Follow-up meeting for the CNE2's recommendations in its n°2 report.

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VISITS BY THE CNE2

November 11 to 13, 2008:	Visit to SCK•CEN in Mol, Belgium
March 25, 2009:	Visit to the Georges Besse plant (I&II) in Pierrelatte, France
March 26 and 27, 2009:	Visit to the Study Centres in Marcoule and Cadarache, France

Appendix III

LIST OF DOCUMENTS SUBMITTED BY ANDRA, THE CEA, AND CNRS

Andra

- Avancement des projets HA-MAVL et FAVL – April 2009.
- Clays in natural and engineered barriers for radioactive waste confinement (2007) – J.F. Aranyossy, M. Cathelineau, N. Clauer, M. Delage, R. Dohrman, C. Fairhurst, J.L Michelot, T. Popp, J. Stucki, F. Villieras - Andra – Ondraf – Nagra – SKB – published March 9, 2009.
- Projet HA-MAVL – Présentation de recherches et projets sur les stockages et les entreposages à l'international (reference code INT.RP.ADAI.09.0003) – February 4, 2009
- Rapport d'étape préalable à la recherche de site – Projet de stockage des déchets de faible activité à vie longue (reference code F.NT.APRG.07.0040A) – June 2008.
- Dossier à destination des collectivités locales – Un projet national et une opportunité pour développer votre commune (Andra & Ministère de l'Écologie, de l'Énergie, du Développement durable et de l'Aménagement du Territoire) – Recherche d'un site de stockage pour les déchets radioactifs de faible activité à vie longue (FA-VL) (FA-VL) - June 2008.
- Internal document - Scientific programme – HAVL Project – 2008-2012 (reference code C.PE.ADS.08.0010) – June 18, 2008.
- Internal document - RG (Radiferous-Graphite) and HAVL (Long-lived, high-level) projets - Constitution des dossiers de connaissances des familles de déchets conditionnés ou non (reference code Z.SP.ADP.07.0019) – June 2007.

CEA

- Recherches en séparation-transmutation – Principaux objectifs 2012 – CEA/DEN/DPCD May 2009
- Effectifs affectés aux programmes de recherche "Séparation/Transmutation" - CEA/DEN/DPCD – May 2009.
- Les ADS – Bilan et orientations - April 2008.
- Propositions de scénarios pour le Groupe de Travail Technico-Economie des Scénarios – March 2009.
- Transitoire entre le parc naturel et le parc du futur avec ou sans séparation-transmutation des actinides mineurs: applications au RNR-Na – études préliminaires – March 2009
- Rapport annuel de l'Evaluation 2007 du CEA – released March 12, 2009.

- La lettre de l'I-tésé – Issue 6 – March 2009.

- Rapport d'évaluation des recherches sur les systèmes nucléaires du futur – HC - December 2008.

- Procédés avancés de séparation des actinides mineurs: proposition de programme 2009-2012 des études de consolidation - December 2008.

- Programme pluriannuel de R&D de fabrication des combustibles carbures: bilan des acquis et propositions - December 2008.

- La lettre de l'I-tésé – Issue 5 – November 2008.

- Pré-dimensionnement d'une aiguille et d'un assemblage CCAM chargés à 20% d'actinides mineurs dans le cœur d'un RNR-Na - November 2008.

- Etude de faisabilité d'une irradiation de Couvertures SFR Chargées en Actinides Mineurs en réacteur expérimental à eau - October 2008.

- Méthodologie proposée pour le remontage technico-économique des scénarios du GT - September 2008.

- La lettre de l'I-tésé – Issue 4 – July 2008.

- Bilan 2007 et programme des études et essais menés au DRCP en 2008 et 2009 en soutien au développement des procédés de séparation des actinides mineurs – July 2008.

- Systèmes sous-critiques pilotés par accélérateurs – ADS CNRS and CEA programme (May 2008) - CNRS/IN2P3/2745 - CEA/DEN/DDIN/152 of June 23, 2008.

- Monographie de la Direction de l'Énergie Nucléaire - Le traitement-recyclage du combustible nucléaire usé – La séparation des actinides – Application à la gestion des déchets – Le Moniteur Publishing – May 2008.

- Recueil des présentations – 7ème journées scientifiques de Marcoule – La Grande Motte (34) – June 4 to 8, 2007.

CNRS

- The CNRS Research Programme on the Thorium cycle and the Molten Salt Reactors – Thierry Auger, Gérard Barreau, Jean-Pierre Chevalier, Xavier Doligez, Sylvie Delpech, Hubert Flocard, Bernard Haas, Daniel Heuer, Elsa Merle-Lucotte – June 2008.Generation IV reactor systems and fuel cycles (horizon 2030): technological breakthroughs in nuclear fission (int'l RD&DD) – Georges Van Goethem EC DG RTD J2, May 2008.

CNE 2

NATIONAL ASSESSMENT BOARD

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