No. 2159
NATIONAL ASSEMBLY
CONSTITUTION OF 4 OCTOBER 1958

TWELTH LEGISLATURE

Recorded at the Presidency of the National Assembly on 16 March 2005

No. 250
SENATE

2004 -2005 ORDINARY SESSION

Annex to the minutes of the sitting of 16 March 2005

PARLIAMENTARY OFFICE
FOR SCIENTIFIC AND TECHNOLOGICAL ASSESSMENT

REPORT

on

PROGRESS AND PROSPECTS OF RESEARCH ON THE MANAGEMENT OF RADIOACTIVE WASTES

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Members of Parliament

Tabled in the Bureau of the National Assembly by Mr Claude BIRRAUX, First Vice-President of the Office

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NB : the verbatim report in French of the three days of public hearings can be consulted on the National Assembly (www.assemblee-nationale.fr) and Senate (www.senate.fr) websites.

INTRODUCTION

Ever since 1990, the Parliamentary Office for Scientific and Technological Assessment has been interested in radioactive waste management and involved in the quest for solutions.

It was in December 1990, in effect, that the Parliamentary Office adopted the report by Christian BATAILLE on radioactive waste management, which largely inspired the Act of 30 December 1991 on research on radioactive waste management[1].

In order to monitor correct performance of the research laid down by the 1991 Act, while broadening the field of its analyses to related questions, the Parliamentary Office subsequently published six other reports on this field[2,3,4,5,6 and 7].

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[1] La gestion des déchets nucléaires de haute activité (Management of high-level nuclear wastes), by Mr Christian BATAILLE, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 1839, Senate no. 184 (1990-1991), December 1991.

[2] La gestion des déchets très faiblement radioactifs (Management of very low radioactive wastes), by Mr Jean-Yves LE DEAUT, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 2624, Senate no. 309 (1991-1992), April 1992.

[3] L'évolution de la recherche sur la gestion des déchets nucléaires de haute activité - tome I: les déchets civils (Evolution of research on the management of high-level nuclear wastes - Part I: Civil wastes), by Mr Christian BATAILLE, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 2689, Senate no. 299 (1995-1996), March 1996.

[4] L'évolution de la recherche sur la gestion des déchets nucléaires de haute activité - tome II: les déchets militaires (Evolution of research on the management of high-level nuclear wastes - Part II: Military wastes), by Mr Christian BATAILLE, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 541, Senate no. 179 (1997-1998), December 1997.

[5] L'aval du cycle nucléaire - tome I: étude générale (The back end of the nuclear cycle – Part I: General study) by Mr Christian BATAILLE and Mr Robert GALLEY, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 978, Senate no. 492 (1997-1998), June 1998.

[6] Les conséquences des installations de stockage des déchets nucléaires sur la santé publique et l'environnement (Consequences of nuclear waste disposal facilities on public health and the environment) by Mrs Michèle RIVASI, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 2257, Senate no. 272 (1999-2000), March 2000.

[7] Les possibilités d'entreposage à long-terme de combustibles irradiés (Possibilities of long-term storage of spent nuclear fuels) by Mr Christian BATAILLE, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 3101, Senate no. 347 (2000-2001), May 2001.

Since 1990, Parliament has been exercising close scrutiny over the field of radioactive wastes. Majorities have changed and so have ministers, ministerial cabinets, and directors of major administrations. Even if dossiers have been transmitted since then between those responsible, it is Parliament which possesses the living memory of the issues related to nuclear wastes. Moreover, no majority has challenged the 1991 Act nor cut back the corresponding research credits.

This report is the eighth by the Parliamentary Office on these technically difficult and politically thorny issues. It appears at a special time, the beginning of the year 2005, close to the end of the 15 year period which the Act of 30 December 1991 assigned exclusively to research before any decision is taken on the creation, if applicable, of a disposal centre for high-level radioactive wastes.

This year, 2005, will therefore see all the research players transmit their results and recommendations to the public authorities which, for their part, will undertake analysis, assessment and synthesis work to determine how the lengthy process of analysis and experimentation initiated by the 1991 Act should possibly be followed up.

To clearly demonstrate Parliament's interest for radioactive waste management, the National Assembly Bureau—at the initiative of the chairmen of the four National Assembly political groups: Groupe de l'Union pour un Mouvement Populaire, Groupe Socialiste, Groupe de l'Union pour le Démocratie Française, Groupe des Député-es Communistes et Républicains—referred on 4 June 2003 this report on *'Progress and prospects of research on the management of radioactive wastes'* to the Parliamentary Office for Scientific and Technological Assessment.

As the opening up to foreign countries appeared critically important to place the French radioactive wastes situation in its international context, detailed studies were conducted by the Rapporteurs on research, projects and developments in six significant countries in the field of radioactive waste management: Belgium, Finland, Germany, Sweden, Switzerland and the United States. In all, more than 180 researchers and directors of laboratories or administrations were heard on the spot, which allows a concrete picture of the radioactive wastes issue in these countries to be painted in a precise and lived manner.

At the national level, visits were made to the national research centres working on radioactive waste management, with a total of 70 researchers heard on the spot or in Paris at private hearings[8].

Also the Rapporteurs insisted on travelling to Chaumont on 2 December and to Bar-le-Duc on 3 December 2004 to meet the local elected representatives of the Haute-Marne and the Meuse concerned by the Meuse/Haute-Marne underground laboratory. These highly fructuous meetings with more than fifty elected representatives led to a better understanding of the perception of research and also of the expectations or concerns of the populations concerned in the first instance by the process set in motion by the 1991 Act.

Lastly, three full days of public hearings open to the press were devoted to the three strands: 20 January 2005 to strand 1 of the Act (separation-transmutation); 27 January 2005 to strand 2 (reversible or irreversible disposal in deep geological formations); and 3 February 2005 to strand 3 (long-term conditioning and storage). All of the stakeholders were invited to participate in these hearings—national or foreign research organisations, public authorities, those responsible from European or American countries, territorial authorities, trade unions and environmental protection organisations—and came along, except for one association which refused to state its views, putting forward what it claimed to be the 'undemocratic' character of these public hearings open to the press and organised within Parliament.

In any case, these three days of public hearings, of which the shorthand report is to be found on the National Assembly website, led to in-depth disclosure of the results of the research and also allowed the stakeholders to express themselves. The Rapporteurs welcomed a strong delegation from the General Council of the Haute-Marne led by their President, Senator Bruno SIDO, as well as a strong delegation from the General Council of the Meuse led by their President, Mr Christian NAMY, and also delegations from the Regional Councils of Champagne-Ardenne and Lorraine.

These hearings undoubtedly contributed to the human and political prelude to any debate on this scientific and technical issue.

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[8] An annex gives a list of the personalities met during missions in France and abroad or heard in Paris.

The sources of this report are therefore specific, numerous and factual from a scientific and political viewpoint.

Rather than proposing hereafter the long and detailed report of the research conducted in France and abroad, which the wealth of information gathered would have allowed, the Rapporteurs propose a synthesis and a placing in perspective of the progress of research, as well as a political analysis of the follow-up to be given to the Act of 30 December 1991.

Whatever technical solutions are envisaged for radioactive waste management, research must be fully completed before its practical application. Nuclear industry timeframes are in fact always far longer than in other industries. But, as electricity plays such an important role in the daily life of the French—electronuclear power covering 80% of their power needs—it is the responsibility of all the Nation to advance in the direction laid out by the 1991 Act: responsibilities must be assumed with future generations in mind.

Chapter I – *Scientific findings* : Research conducted under the 1991 Act has underscored the respective assets of transmutation, disposal, and storage and shown their complementarity

In its Article 4, the Act of 30 December 1991 classified research on the management of high-level long-lived radioactive wastes into three fields, commonly called the strands of the 1991 Act, namely:

- Search for solutions allowing the separation and transmutation of the long-lived radioactive elements present in these wastes (strand 1).
- Study of the possibilities of reversible or irreversible disposal in deep geological formations, particularly thanks to the building of underground laboratories (strand 2).
- Study of the processes of long-term conditioning and storage at the surface of these wastes (strand 3).

After fourteen years of research, the respective assets of these three major categories of management methods of high-level long-lived radioactive wastes can be demonstrated and their implementation schedule can be specified.

I. *STRAND I* : SEPARATION AND TRANSMUTATION OF HIGH-LEVEL RADIOACTIVE WASTES IS ENVISAGEABLE BY 2040

Separation can be defined as a set of chemical operations aimed at isolating the various constituents of spent nuclear fuels, with a view *then* to applying differentiated processing to them. This processing can consist in various disposal methods or their retrieval from the reactor.

Transmutation, in the legendary acceptance of the word, means the change of one chemically pure element—for instance lead—into another, gold. More simply, the definition of the word in physics is the modification of a simple body into another simple body, leading to a change in atomic number.

Of course separation and transmutation cannot have any practical application unless processing-recycling is the option chosen for the back end of the nuclear fuel cycle. In the opposite case, as in Sweden, Finland or the United States, spent fuels are disposed of directly and no separation operation with a view to transmutation can be envisaged.

France, for its part, uses processing-recycling technologies on an industrial basis. At the reprocessing plants in La Hague, spent fuels are dissolved and then unburnt uranium and plutonium, recyclable energetic materials, are separated from high-level long-lived radioactive wastes, the former being recycled and the latter being immediately vitrified.

Pursuant to the Act of 30 December 1991, separation, which consists in additional steps to the processing operations currently practiced, and transmutation, are two techniques aimed at diminishing radiotoxicity and the thermal load of high-level long-lived radioactive wastes.

These technologies target a very low share of the total volume of radioactive wastes.

For instance, if the case is taken of the stock of wastes produced in France since the beginning of the applications of nuclear energy until 31 December 2002, high-level long-lived radioactive wastes represented 1639 cu. m out of total of 869,874 cu. m.

If high-level long-lived radioactive wastes are prioritised whereas they represent only a low volume in absolute value and a very low share—0.2%, of the total volume[9]—it is because they represent 96% of the radioactivity of radioactive wastes as a whole.

[9] The total volume considered here groups high-level long-lived wastes, intermediate-level long-lived wastes, low-level long-lived wastes and low- or intermediate-level short-lived wastes. Source: National inventory of radioactive wastes, ANDRA, 2004.

In addition, high-level long-lived radioactive wastes contain radionuclides whose period is the longest[10].

1. The feasibility of separation is scientifically demonstrated but awaits its industrialisation

Separation consists in isolating the two categories of radionuclides contained in high-level long-lived radioactive wastes, in other words minor actinides and fission products. This operation is of major interest to optimise the back end of the nuclear fuel cycle because minor actinides[11] and fission products have different properties in terms of radiotoxicity and their radioactivity period. Separation therefore allows different management methods to be applied to them.

Since 1992, research on separation has been conducted in France by the CEA, mainly at its world-unique ATALANTE facility at Marcoule. The CEA has based itself on its internationally acknowledged competences and has also been wise enough to cooperate nationally and internationally with many other bodies and companies.

Liquid phase separation methods have been explored primarily but the other approach represented by pyroprocessing has not been ignored. The first approach is an extension of operational reprocessing methods. More innovative, pyroprocessing must overcome serious technological difficulties. In the process, far from going it alone and taking research routes which could be feared to be dead ends, the CEA has seen its approach strengthened by the American AFCI (Advanced Fuel Cycle Initiative) programme.

In terms of results, research has demonstrated the feasibility of separation at the level of the laboratory, the main categories of radioelements being separable from one another.

Apart from specific cases to be solved, the feasibility of these operations remains to be proven industrially, which will suppose the construction of an industrial pilot plant. Also, the economic interest of separation in the general framework of radioactive waste management must be assessed.

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[10] The period is the time after which the number of radioactive atoms is divided by two.

[11] Neptunium, americium and curium are the minor actinides. They are called *'minor'* because they are present in low quantities in spent fuels with respect to the *'major'* actinides, uranium and plutonium.

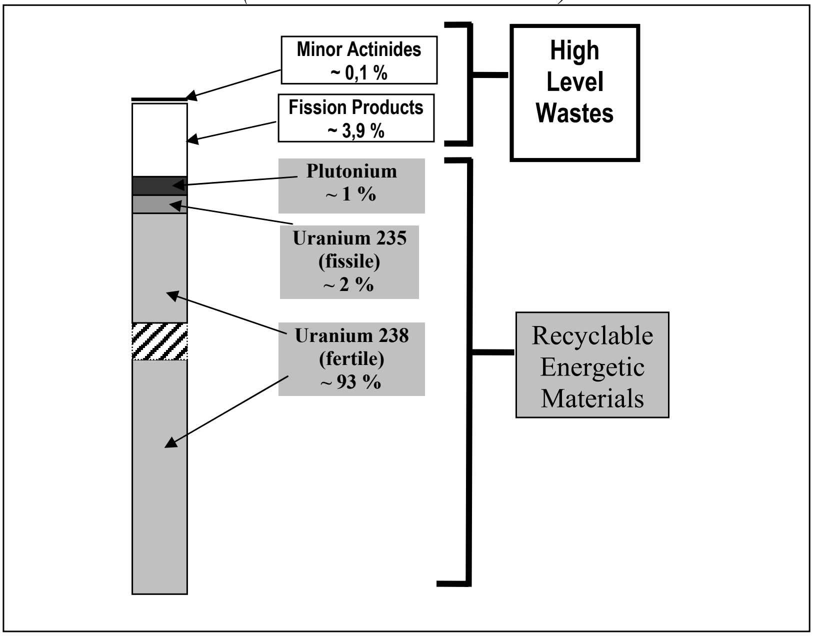
1.1. Thanks to separation, differentiated treatment can be applied to the various wastes with a view to their better management

On leaving an EDF pressurised water reactor[12] , spent uranium oxide fuel keeps a large share of its unburnt energetic materials: 93% of uranium 238, 2% of uranium 235, 1% of plutonium. It also comprises high-level wastes: 3.9% of fission products and 0.1% of minor actinides[13].

[12] Uranium mineral has contents included between 0.5% for the poorest deposits and 10% for the richest deposits (Canada, Australia). Whatever the content of the mineral, uranium is present naturally in the form of two isotopes, uranium 235 which represents only 0.7% of the total and uranium 238 which represents 99.3%. Uranium 235 is fissile which means that, when struck by a neutron, it breaks or fissions into fission products while releasing energy. Uranium 238 is fertile which means that, when struck by a neutron, it captures the latter and becomes transformed into a new nucleus, itself fissile. Light water reactors (pressurised or boiling), which form the majority in the electronuclear industry, operate thanks to the fission of uranium 235, in a fuel which contains enriched uranium, in other words which contains 3 to 5% of uranium 235.

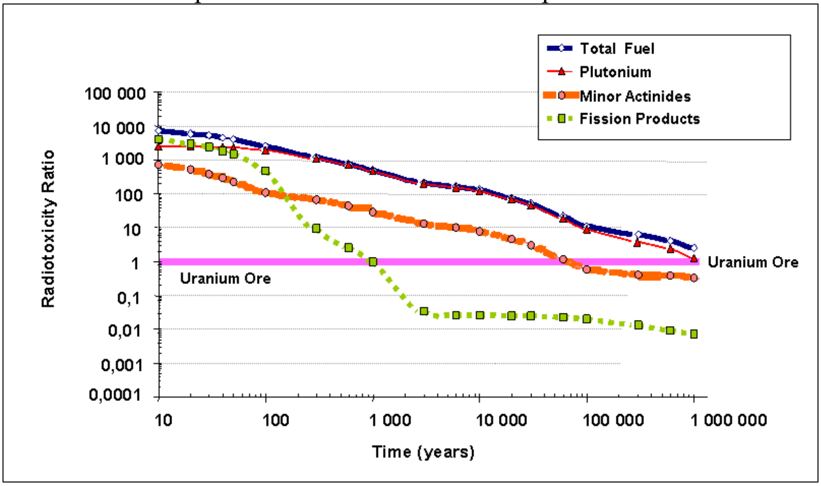
[13] Actinides are natural or artificial radioelements whose atomic number is included between 89 (actinium) and 103 (lawrencium). Major actinides are the heavy nuclei of uranium or plutonium formed in low quantities by successive captures of neutrons from fuel nuclei. Minor actinides are long-lived isotopes of which the main ones are neptunium 237, americium 241 or 243, and curium 243, 244 or 245.

Diagram 1 : Composition of unloaded irradiated fuels of the UOX type (uranium oxides) as a % of their total mass
(source: CEA and COGEMA)



The reprocessing carried out at the La Hague facilities allows uranium and plutonium to be isolated and its main aim is to recover uranium and plutonium, energetic materials, with a view to recycling them. Its second consequence is to reduce the long-term radiotoxicity of wastes.

Diagram 2 : Simplified chart of the evolution of the radiotoxicity of spent nuclear fuel and of its components



As shown by the above diagram, the radioactivity of spent fuel decreases over time but reaches that of uranium mineral only after one million years.

While uranium and plutonium, which are the primary cause of the long-term radiotoxicity of spent fuel, are recovered by processing-recycling operations, minor actinides are responsible for the remaining long-term radiotoxicity and a factor of 10 is gained insofar as their radiotoxicity reaches the level of uranium mineral after 100,000 years.

In comparison, the radiotoxicity of fission products reaches the level of uranium mineral after 1000 years.

Therefore once plutonium and uranium have been extracted by reprocessing, two categories of radioelements, if separated, justify specific processing—fission products that it can be envisaged to store for lengths of approximately one thousand years, and minor actinides for which every effort must be made to transform them into elements whose radiotoxicity decreases more rapidly over time.

The following table summarises the main properties of the various components of spent fuel

Table 1 : Main characteristics of the components of spent fuels

Spent fuel component	Uranium	Fission Products (Strontium, Cesium, Zirconium, Palladium, etc.)	Long-lived Radioelements (Plutonium, Minor Actinides, Long-lived Fission Products)
Percentage of Total	95	4	1
Radioactivity	Negligible	Intense	Intermediate
Required Confinement Time	0	200-1000 years	100,000 years

A major spin-off of separation is not only that it can manage optimally the different radiotoxicities of the various radioelements but also that it can adopt specific management procedures as regards the thermal load of waste packages, as the thermal load also varies depending on the radioelements concerned.

1.2. The CEA, cooperating nationally and internationally with other bodies and companies, is the main player of highly complex research

The so-called PUREX technologies, for the separation of uranium and plutonium after the dissolution of spent fuels, have been industrially operational for over twenty years. Minor actinides and fission products are the wastes of this process. Despite the industrial maturity of the PUREX process and despite the acquired experience, extending the process to additional separations has proved a particularly difficult task for several reasons.

As the telemanipulation of solutions of minor actinides and of fission products is mandatory owing to their very high radioactivity, only complex facilities can be used. The construction and then the start-up in 1992 of the world-unique ATALANTE facility at Marcoule, have provided a major asset. Yet, even if liquid phase extraction techniques are well mastered, it was necessary, on the chemical plane, to seek and test many molecules having suitable properties—very high selectivity with respect to the various elements, aqueous separation and resistance to radiations. Lastly, minor actinides have chemical properties of which some are close to those of uranium while others are close to another family of elements, lanthanides.

In all, 38 CNRS laboratories and universities cooperated nationally in the complex research on separation. As the leader, the CEA also coordinated strong international cooperation in Europe as part of the 5th PCRD (Programme-cadre de Recherche et de Développement – Framework Programme for Research and Development) (1998-2002) and the 6th PCRD (2002-2006), and also with Japan, Russia and the United States[14].

1.3. Research is taking place according to two approaches reinforced by the American AFCI programme

In order to take advantage of the experience accumulated scientifically and technically with the operational PUREX process for uranium and plutonium extraction, the CEA has striven to go even further, particularly to extract certain fission products like iodine and technetium, and also neptunium, a minor actinide whose chemical behaviour is close to that of uranium and plutonium. Extensions have been developed to extract, in a first stage, fission products and, in a second stage, lanthanides, with a view to finally isolating americium and curium. To do so, new extractants, diamides, have been developed.

Complementarily, French teams have explored the pyroprocessing approach consisting in dissolving fuel elements in high temperature molten salt baths and extracting the radioelements by molten metals, electro-deposition and precipitation.

This twin approach is also used by the US Department of Energy’s Argonne National Laboratory.

Pursuant to the Ford-Carter doctrine of the 1970s aimed at combating nuclear weapon proliferation, the separation of *‘isolated’* plutonium, in other words unmixed with any other radioelement, is banned in the United States. However, the AFCI programme conducted by the US Department of Energy pursues some aims related to separation. The aims are in effect to recover energetic materials contained in spent nuclear fuels, reduce civil plutonium stockpiles, reduce the radiotoxicity and heat from wastes and optimise the Yucca Mountain underground disposal project.

[14] Nationally, cooperation took place within the framework of PRACTIS research alliances.

As part of the AFCI programme, the UREX liquid extraction process is aimed at the joint separation of plutonium with other radioelements. Pyroprocessing, which has been prioritised at the Argonne National Laboratory, is based on electro-refining, with the co-deposit of minor actinides with plutonium.

The directions taken by French research are validated by the American approach and by the cooperation set in place by the two countries.

1.4. Feasibility has been demonstrated at the laboratory scale

The number of radioelements present in uranium oxide spent nuclear fuels is considerable: 5 types of heavy nuclei, 34 fission products, 6 activation products and 2 fission and activation products.

Research on separation performed as part of strand 1 have had as their priority targets, on the one hand, the minor actinides—americium, curium and neptunium—as the main contributors to long-term radiotoxicity after the recovery of uranium and plutonium and, on the other hand, certain long-lived fission products—iodine, cesium and technetium—whose abundance in spent fuel is significant and whose mobility in the biosphere is higher than that of the other elements.

99% separation of neptunium, whose chemical properties are close to those of uranium and plutonium, could be performed by a complementary method to the well known PUREX process. Iodine and technetium are also extracted by a similar method.

Separation then continues by the DIAMEX process, which yields, on the one hand, fission products and, on the other hand, minor actinides and lanthanides[15].

Lastly, the SANEX process allows the separation of lanthanides on the one hand and americium-curium on the other hand. For this purpose, new extractants of the diamides type have been developed. Chemical synthesis has allowed molecules to be built presenting a set of favourable properties in terms of their electronic properties, steric size, lipophily and chelation.

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[15] Lanthanides are elements whose atomic number is included between 57 and 71.

With some molecules, 99.9% of americium has been recovered and 99.7% of curium, the separation ratio between americium-curium and lanthanides being higher than 800.

Also, laboratory tests have demonstrated that americium and curium can be separated to within approximately 1%.

Referring to long-lived fission products, specific molecules called calixarenes or cage molecules have been developed with success to extract cesium, of which 99.8% is recovered. However, it is envisaged to leave cesium in vitrified solutions as its mobility in rock is very low. Technetium raises a specific problem insofar as it is difficult to solubilise, which limits its recovery to the fraction in solution. As for iodine, for the time being discharged into the sea at extremely low concentrations, the CEA has demonstrated its 99% recovery by the adapted PUREX process and a derived process.

In any case, the work carried out for separation represents a very great scientific and technological success.

1.5. Industrial demonstration is necessary before commercial operation around 2040

After having demonstrated the feasibility of separation in a laboratory on a few grams of radioactive wastes, the CEA will carry out experiments during 2005 to test the processes on approximately 15 kg quantities. Overall, the operations will take around one hundred hours. Apparently, there are no specific problems except for the inevitable and tricky adaptation of equipment to a higher scale.

However, separation still remains to be adapted to an industrial scale.

In the present state of techniques and envisageable industrial applications, advanced separation, which can be envisaged as a priority for the future, would consist in sticking to grouped extraction for minor actinides on the one hand, and all the fission products on the other hand, in accordance with the GANEX process. Minor actinides would then be transmuted in nuclear reactors and fission products conditioned in glass matrixes and disposed of definitively, their radiotoxicity decreasing to the level of that of natural uranium after approximately one thousand years.

According to concordant estimations, the industrial facility to be built to implement advanced separation would be comparable in size and cost to the UP3 plant at La Hague.

The investment cost of separation may therefore appear high and raise the problem of its funding, inevitably related to the obligations imposed on radioactive waste producers.

The opportunity of such an investment would however have to be appreciated in a global framework by taking into account all the factors of the back end of the cycle, some of which would perhaps compensate the additional cost of separation. If geological disposal were to be limited to the incineration products of minor actinides, then high reductions in the construction costs of the disposal site could be deducted. Similarly, lesser volumes and shorter timeframes would also reduce storage costs.

Industrialisation to be reached for separation will probably take one to two decades.

The horizon for transmutation, which in the French approach can hardly be distinct from separation, is for its part much more distant.

2. The feasibility of transmutation is scientifically demonstrated but is awaiting the construction of technological demonstrators

Transmutation, of which there are two forms, takes place by neutron bombardment. The first form involves the capture of a neutron, which leads to the formation of a heavier nucleus than the initial nucleus. This new nucleus is stable or instable, which leads to a new transformation. The second form is that of direct fission of the nucleus into lighter, often shorter-lived elements.

Whatever form it takes, transmutation must be performed by neutrons. Various methods can be envisaged, each with its advantages and disadvantages.

The scientific feasibility of transmutation is now demonstrated thanks to experiments conducted with the Phenix reactor. But the road to industrialisation is long.

The switch to higher quantities remains to be made, in a context in which France will lack experimentation means owing to the shut-down of the Phenix reactor in 2008.

Alongside scientific and technical demonstration on significant quantities of radioactive wastes, studies will have to have made headway regarding the two industrial reactor types: Generation IV reactors and accelerator driven reactors (ADS).

It will also be necessary to determine how transmutation goals can be taken into account by these reactors, in a dual electronuclear context with reactors of different generations.

2.1. Various methods and various instruments exist to perform transmutation

To transmute radioactive wastes, primarily minor actinides, two methods have been experimented with.

The first method consists in mixing minor actinides with the uranium oxide of each pellet of each fuel assembly rod. Homogeneous irradiation or recycling is then spoken of. As the neutrons produced by fission of the uranium 235 of the fuel to uranium oxide must be sufficiently numerous for the chain reaction to continue without any incidents, the quantity of radioactive wastes which can be mixed with the base fuel is necessarily limited. Moreover base fuel management requirements take precedence over the degree of advancement of the transmutation reaction. As transmutation reactions are relatively slow, fuel assemblies must be taken out when the maximum combustion rate is reached. Consequently, the radioelements to be transmuted must be reinjected into the reactor within the new fuel. Multi-recycling is therefore essential, consisting in a series of successive operations of separation and irradiation with a view to reaching the best transmutation rate.

The second method consists on the contrary in inserting, into the heart of the reactor, rods or even fuel assemblies that contain only the radioelements to be transmuted, immobilised in specific matrixes. Heterogeneous irradiation or recycling is then spoken of. The fuel assemblies are then not identical throughout the heart. On the contrary, specific fuel assemblies containing wastes to be transmuted are placed in some parts of the heart. The aim is then to transmute the radioelements in a single irradiation period in the reactor[16].

However, in what types of reactors can transmutation reactions be performed?

Transmutation requires neutrons in all cases and can be performed, in the first instance, in the conventional electricity producing pressurised water reactors in operation in the electronuclear sector. The thermal neutrons of the latter then perform the transmutation reactions. As the speed and rate of transmutation are limited, a choice must then be made between homogeneous recycling (mixing of wastes in conventional fuel) and heterogeneous recycling (specific rods comprising only the radioelements to be transmuted).

Fast neutrons, however, remain the ideal instrument for transmutation insofar as their efficacy is far superior. The fast neutron reactor is the reference machine not only for theoretical reasons but also because it is with the Phenix fast neutron reactor that it was demonstrated that minor actinides can be transmuted.

However, another scheme is proposed: accelerator driven hybrid reactors where a sub-critical reactor receives additional neutrons supplied by an external source of spalliation[17] driven by a particles accelerator.

2.2. The feasibility of transmutation is scientifically demonstrated

As part of the research performed pursuant to the Act of 30 December 1991, the CEA has demonstrated that the transmutation of minor actinides can be carried out homogeneously and heterogeneously, the latter method being far more effective.

Also, and above all, it has been proven that the various minor actinides can be effectively transmuted. The Phenix fast neutron reactor at Marcoule has played a decisive role in this respect.

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[16] A *one through* approach is then spoken of.

[17] Spalliation corresponds to the phenomenon according to which a target, made of heavy metals like lead, is bombarded by high-energy accelerated protons and produces neutrons that are also high-energy: the protons impinging on the heavy nuclei eject part of the neutrons.

Americium has been transmuted in isolation using the heterogeneous method with a transmutation rate of approximately 90% during the ECRIX-B and ECRIX-H experiments performed with Phenix between 1991 and 2004. Previously, americium and also neptunium had been transmuted using the homogeneous or heterogeneous method with a high concentration, with the SUPERFACT experiment (1986-1988). The transmutation of curium has also been demonstrated indirectly, insofar as irradiated americium transforms in the first instance into curium[18].

It has been established, in any case, that transmutation will produce ultimate waste whose radiotoxicity will not exceed approximately a thousand years and for which the only possible management will be definitive disposal.

Many questions however remain unanswered. The main ones no doubt concern the speed of transmutation, and therefore the time during which high-level long-lived radioactive wastes stay in the reactor, and the quantity of wastes which can be processed by a given transmuter.

2.3. The recycling of radioactive wastes in reactors is firstly a problem of fuels

Whether the minor actinides to be transmuted are mixed with a standard fuel, whether on the contrary they must be isolated in specific assemblies, or whether light water reactors, fast neutron reactors or accelerator driven systems are used, the prerequisite for transmutation is the production of fuels and the analysis of their impact on the operation of the reactors themselves.

As regards the production of fuels, various methods have been tested, both regarding their production techniques and the matrixes to condition them. These tests have however been carried out on very low quantities, of approximately a gram and, in due time, they will have to be extrapolated to higher quantities to reach an industrial level. One major consequence has not yet been clarified: what types of production of fuels are to be set in place and what will their major differences be with respect to plants producing UOX or MOX fuels?

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[18] The reason why the direct transmutation of curium has not been performed is that it is extremely difficult to produce a curium target, this minor actinide being not only a strong alpha emitter but also a strong neutron-emitter, with a strong thermal power. To solve these difficulties, the CEA envisages using a Russian process .

A fundamental question for the feasibility of transmutation, what will be the impact of the presence of minor actinides on the operation of reactors of whatever kind? What type of recycling will in fact be possible—homogeneous or heterogeneous? What quantities of minor actinides will be able to loaded into the reactor without disturbing its operation?

The answers to these questions will determine whether the current electricity producing plants can be used for transmutation or whether specialised equipment will have to be built.

2.4. The recycling of minor actinides in light water reactors is not a promising solution

Theoretically, minor actinides can be recycled in light water reactors. Owing to necessarily limited performances, this approach does not however appear to form a reference option.

Transmutation by the thermal neutrons of light water reactors, particularly by pressurised water reactors, is theoretically possible. To optimise their yield it can be imagined replacing a uranium oxide matrix by a metallic matrix, avoiding the formation of plutonium from fertile uranium 238. Such recycling takes place using the heterogeneous method.

In order not to complicate the operation of electronuclear facilities, a nuclear operator like EDF would of course opt for heterogeneous recycling. But is this option compatible with simple management of electronuclear plants, insofar as some reactors would operate with MOX fuel recycling plutonium, whereas others would recycle minor actinides, with a presence at the heart for a length of time unknown for the moment.

In any case, many safety demonstrations would have to be performed, firstly on the behaviour of metallic fuels, and then on the compatibility of the presence of fuel rods loaded with minor actinides, or even on the juxtaposition at the heart of one and the same reactor of MOX fuel assemblies and fuel assemblies comprising minor actinides.

While this approach is likely to complicate the management of electronuclear plants, the complexity of the fuel cycle is also likely to be singularly worsened. Multi-recycling would in effect probably be necessary, leading to a multiplication of fuel separation and production operations, and these moreover would be far more difficult than at present owing to the high radioactivity of minor actinides.

That is why Generation II reactors (REP 900 and 1300 MW reactors), III (N4 reactors) and even III+ (EPR) do not appear to lend themselves to the recycling of minor actinides, the only real hopes being Generation IV reactors and ADS.

2.5. Generation IV reactors will probably be the preferred equipment for minor actinide transmutation integrated in electricity production after 2040

Generation IV reactors represent the probable future of civil nuclear energy[19] in around 2035.

The organisation of research and development efforts in order to fine-tune them is the subject of international cooperation initiated by the US Department of Energy. Ten or so countries are now grouped within the GIF (Generation IV International Forum)[20] for this purpose.

Considering that R&D should be as open as possible but that efforts should not be dispersed in unpromising areas, the GIF has selected six technology clusters which are in fact reactor /nuclear fuel pairs.

The main function of Generation IV reactors is to produce electricity. These reactors are expected to replace or, more probably, bearing in mind world energy requirements, join the conventional light water reactors presently in operation worldwide.

However, in order to take better into account, on the one hand, the rarity of fissile materials by seeking to extract all their energy content and, on the other hand, the constraints of the back end of the cycle and especially radioactive waste management, not only reactor concepts were chosen but also reactor / fuel pairs.

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[19] La durée de vie des centrales nucléaires et les nouveaux types de réacteurs (The lifespan of nuclear power plants and new types of reactors), report by Messrs. Christian BATAILLE and Claude BIRRAUX, Members of Parliament, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 832, Senate no. 290, Paris, March 2003.

[20] The member countries of the GIF, an initiative launched initially by the US Department of Energy, are: the United States, the United Kingdom, France, Japan, Canada, Argentina, South Korea, South Africa, Switerland, and Brazil.

Taking these aims into account, the selection of reactor / fuel pairs led to the choice of three types of fast neutron reactors out of the six types of reactors selected[21].

Generally speaking, the commercial start-up of Generation IV reactors is not expected before 2035[22]. In a first stage, many technological obstacles will indeed have to be overcome. In a second stage, pilot facilities and demonstrators will have to be built and tested over several years. In a third stage, reactors that are the first of a series will have to be operated for several years before proceeding to their series production strictly speaking, which brings us to the year 2040.

Bearing in mind that fast neutron reactors supply precisely the neutrons whose energy is especially suitable for transmutation reactions, what functions can be assumed by the fast neutron reactors of a set of reactors whose main goal would be the production of electricity, when it comes to the transmutation of high-level long-lived radioactive wastes?

Scientifically, the experiments conducted in the Phenix reactor leave no doubt about the aptitudes of fast neutron reactors to effectively transmute minor actinides.

In the event of homogeneous recycling, where high-level radioactive wastes are mixed with standard fuel—uranium 238 and plutonium—, full-scale tests will however have to be performed to determine what maximum proportion of wastes can be accepted without disturbing the operation of the heart.

In the event of heterogeneous recycling, where specific fuel assemblies contain exclusively radioactive wastes, it will also be necessary to determine the maximum number of this type of assemblies compatible with safe operation of the reactor core.

Then again, bearing in mind that in France the presently operating Generation III pressurised water reactors will be in service until at least 2035, if not until the end of the century with the start-up of the EPR, what should be the place of fast neutron reactors in the global electronuclear field?

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[21] The six choices are as follows: 3 fast neutron reactors (sodium, helium or lead), 1 supercritical water reactor, 1 very high temperature reactor, and 1 molten salt reactor.

[22] Christian BATAILLE and Claude BIRRAUX, Parliamentary Office, op.cit.

Two scenarios must be taken into account: first that of fast neutron reactors being deployed progressively from 2035 and, second, that of an electronuclear sector exclusively formed by fast neutron reactors.

In the hypothesis in which the electronuclear sector is dual, in other words formed by a decreasing share of pressurised water reactors and an increasing share of Generation IV reactors as time elapses, the radioactive wastes produced by the conventional reactors in Generation IV reactors could be recycled in order to transmute them.

Simple questions will however have to be answered: after what time lag will recycling be possible? What will be the necessary number of Generation IV reactors with respect to the number of pressurised water reactors in operation? After how much time will radioactive wastes be transmuted? What will be the resulting volumes to be disposed of definitively?

In the case of an electronuclear sector formed solely by Generation IV reactors, a balance would be reached after five to six irradiation periods in reactors, in other words fifty years—including the production times of specific fuels—in terms of the inventory of long-lived radioactive wastes. The only place where minor actinides would remain over a long time would be the heart of reactors. It would therefore no longer be necessary to dispose of minor actinides in geological repositories.

In this case, as in the previous one, many questions remain, even in the hypothesis in which the feasibility, acceptance and commercial operation of Generation IV reactors is deemed possible by 2035. Safety issues, when the heart will comprise a significant proportion of minor actinides, are not the least difficult to solve.

The year 2040 therefore appears plausible for the operational start-up of transmutation.

2.6. ADS reactors could be the specialised equipment for transmutation, provided a demonstrator is built

The technology of accelerator driven reactors also brings the hope of optimal transmutation of radioactive wastes.

This technology was imagined at the beginning of the 1990s by the teams of Professor Carlo Rubbia, a physics Nobel Prize winner.

The principle of an accelerator driven reactor is to connect a proton accelerator, a spallation target and a subcritical nuclear reactor.

The accelerator produces high energy protons which impinge on a lead target which then releases neutrons transmitted to the subcritical nuclear reactor. The reactor receives the neutrons it lacks to carry out with a high yield the transmutation reactions.

The expected advantages of ADS systems concern safety and efficacy in waste management. Referring to safety, the subcriticality of the reactor allows its automatic shut-down should all the power supplies fail. In particular, the shut-down of the accelerator leads to the shut-down of the production of additional neutrons and therefore to that of the reactor. Referring to the efficacy of transmutation, ADS systems should be able, owing to their very design, to accept a relative quantity of radioactive wastes far higher than that of Generation IV fast neutron reactors, while being sufficiently flexible to accept all types of wastes.

On a more general level, by combining particular physics and nuclear physics, ADS would appear in a more attractive light than nuclear science alone, and could therefore attract new scientists and technicians, unlike the nuclear sector which is struggling to renew its manpower. This is a research area in which the CNRS is taking great interest.

Lastly, ADS could complete conventional electronuclear facilities composed of light water reactors of the present generation or of the EPR generation (Generation III+), at the rate of one ADS for 5-7 conventional reactors.

However there appear to be numerous uncertainties regarding accelerator driven reactors owing to the great lack of experience in this field.

The design of ADS has admittedly progressed since 1991. The MUSE experiment performed by the CEA at Cadarache has allowed the successful simulation of a lead target placed at the heart of a subcritical reactor simulated with the MASURCA reactor. However, the work performed worldwide is work on design or on the testing of the key technological components of ADS reactors, the latter not yet having been tested experimentally in their globality.

That is why there are still many questions on the limits of ADS systems.

In the first instance, even if theoretical studies and engineering studies demonstrate the feasibility of the transmutation of long-lived radioactive wastes with an ADS system, no experimental proof exists in this field. Then, ADS systems are deemed to possess intrinsic safety, which has however been challenged for several years by some experts. In fact, to take account of these criticisms and increase the safety of an accelerator driven reactor, it appears necessary today to provide the heart of the subcritical reactor with control rods similar to those of conventional reactors, which can lead to the comment that ADS systems would add to the complexity of a conventional nuclear reactor, the additional complexity of an accelerator. The coupling of a subcritical reactor with an accelerator actually remains to be experimented with in dynamic start-up or shut-down conditions. However, particle accelerators are very costly machines to build and operate. In addition, their insufficient reliability would prevent them from being connected to the electricity grid, which would lead to a loss of income with respect to fast neutron reactors.

In the present state of knowledge and projects, it appears very difficult, if not impossible, not only to make a choice between fast neutron reactors and accelerator driven reactors, as regards their efficacy compared with transmutation, but even to determine their respective ideal fields of ideal application.

Therefore it appears particularly necessary to pursue research and build an experimental pilot facility.

2.7. A new nuclear fuel / radioactive wastes problem could arise with molten salt reactors

Lastly, mention must be made of the specific sector of molten salt reactors, which was selected by the Generation IV International Forum. Molten salt reactors do not set out to be a solution to recycle wastes produced by the present electronuclear facilities but rather as a pivot for a new nuclear age based on new technical bases.

The CNRS in fact sees many advantages in this new sector.

The first advantage of molten salt reactors should result from the fact that a new fuel cycle would be operated, based on thorium, an element far more abundant than uranium, and should also stem from their low consumption of fissile fuels[23]. Their second advantage would be to divide by a factor of 100 the production of wastes, these being drawn from the reactor, conditioned and directly sent for disposal without it being necessary to recycle them for transmutation in another reactor.

Theoretically appealing, molten salt reactors however require many technological breakthroughs, in particular to develop materials resisting corrosion by high temperature molten salts. The disadvantages and advantages of the setting in place of a new fuel cycle must also be assessed. It is also a sector which, for the time being, has been the subject of only a very low number of tests, which moreover have been performed on very low power models.

The interrelation of this sector with the presently operating electronuclear facilities must also be examined in depth.

2.8. Future radioactive wastes should be transmuted in 2040

The main instruments of transmutation which can be envisaged pursuant to the scientific and technical knowledge accumulated over the 1991-2005 period are the pressurised water reactors of the present electronuclear sector, Generation IV fast neutron reactors, and accelerator driven reactors.

Apart from the electronuclear reactors presently in operation, whose capacity to transmute radioactive wastes in sufficient proportions can be doubted, all the new transmutation instruments are not expected to start up on a regular commercial basis before 2040. Therefore transmutation can enter into force only after that year.

For safety reasons, it appears impossible to defer the conditioning in the form of vitrified wastes of the high-level long-lived wastes resulting from treatment-recycling operations, which shall continue in the meanwhile.

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[23] These reactors operate with thermal neutrons and are fissile material breeder reactors.

Transmutation therefore appears to concern only the high-level wastes produced after 2040.

3. The transmutation of already conditioned high-level wastes and the exploitation of intermediate-level long-lived wastes are running into major difficulties

High-level long-lived wastes—fission products and minor actinides—resulting from the reprocessing of spent fuels since the start-up of the Marcoule facilities (C0 wastes) then from La Hague (C1 wastes) represented a volume of 1639 cu. m on 31 December 2002, and their volume is expected to reach 3612 cu. m in 2020 in accordance with the projections established by the ANDRA[24].

The dissolution of vitrified wastes containing high-level long-lived radioactive wastes is technically possible. In the present state of knowledge, this operation however appears very costly. Consequently, the separation and transmutation of wastes already produced and conditioned appears difficult to envisage.

Bearing in mind the essential conditioning, for safety reasons, of fission products and minor actinides resulting from reprocessing, this means that it cannot either be envisaged to separate and transmute the radioactive wastes produced from the beginning to 2040, the date of the start-up of reactors capable of transmuting wastes in a large quantity.

The question of intermediate-level long-lived wastes is also worth examining.

On the face of it, it could be believed that an approach identical to separation-transmutation should apply to intermediate-level long-lived wastes in order to diminish their possible impact in the long term, since their volume represents 4.6% of the total, for 3.87% of the total radioactivity.

Their volume reached 45,359 cu. m on 31 December 2002, and is expected to reach 54,509 cu. m in 2020.

In reality, the concentration of radioelements in these wastes is low and would require recovery operations in matrixes or extremely

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[24] National wastes inventory.

varied media—bitumen, cement—which operations would themselves generate new radioactive wastes.

The exploitation of intermediate-level long-lived wastes appears extremely difficult for those already generated and also in the future.

Therefore, for want of any separation-transmutation prospect at all for this type of wastes, the only solution to manage them are disposal or long-term storage.

II. *STRAND 2* : IT IS VERY LIKELY THAT REVERSIBLE GEOLOGICAL DISPOSAL WILL BE FEASIBLE IN FRANCE BETWEEN 2020 AND 2025 EVEN IF SOME TECHNICO-SCIENTIFIC UNCERTAINTIES MUST BE CLEARED

Disposal in geological formations represents the definitive solution most nuclear countries prefer for their high-level radioactive wastes and spent fuels.

Pursuant to the Act of 30 December 1991, France is focussing its research at the Meuse/Haute-Marne laboratory, a reference solution which requires further research.

The construction of a competing facility should be excluded.

1. According to the International Atomic Energy Agency, the geological disposal of wastes provides maximum safety

The IAEA (International Atomic Energy Agency) in Vienna, a UN specialised agency, has taken an interest in the safety of radioactive wastes and spent fuels for several years. Pursuant to its general method, the agency has developed for radioactive waste management a set of recommendations—fundamental safety principles, safety rules, safety guides and good practices.

The fundamental safety principles published by the IAEA date back to 1995. According to the international agency, generally speaking, radioactive waste management must be aimed at the protection of public health and of the environment at all times now and in the future, without imposing undue costs on future generations. *'While it is not possible to ensure total confinement of radioactive waste over extended time-scales, the intent is to achieve reasonable assurance that there will be no unacceptable impacts on human health. This is typically achieved by applying the multibarrier approach in which both natural and engineered barriers are utilized'*[25].

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, adopted in 1997 and which entered into force in 2001, is the first binding international legislation in this field. This convention, signed by 34 contracting parties, sets forth a set of safety requirements for the construction and operation of storage and disposal facilities, without however directly taking a stand on specific technical solutions.

Another fundamental step in the IAEA approach, the international conference organised under its auspices in Cordoba in March 2000 concluded that *'The perpetual storage of radioactive waste is not a sustainable practice and offers no solution for the future.'* Consequently, the general IAEA conference of September 2001 adopted an action plan comprising in particular the *'assessment of the safety implications of the extended storage of radioactive waste and of any future reconditioning which may be necessary.'*

Pursuant to this plan, the IAEA published in 2003 a document on the topic of the *Long-term Storage of Radioactive Waste: Safety and Sustainability*[26] elaborated by a panel of international experts set up by it. Aimed at serving, according to the IAEA, as a central reference and as an authoritarian source for national discussions, this document states that: *'Confinement of radioactive wastes is considered to be best achieved through their emplacement at significant depths underground, that is, by 'geological disposal''.*

Why does such a clear and precise position in favour of geological disposal not appear in the joint convention of 1997?

In recent years, a clarification of the position of experts appears to have taken place on the advantages of disposal with respect to storage.

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[25] The Principles of Radioactive Waste Management, Safety Fundamentals, Safety Series N°. 111-F, IAEA, Vienna, 1995.
[26] A Position Paper of International Experts, IAEA, Vienna 2003.

Moreover, the joint convention expresses a consensus of the contracting parties: the States had various facilities, mostly in the form of storage facilities and did not wish to underwrite a binding obligation to build a disposal site. In the European Union this refusal of States to have practical and dated obligations imposed on them could be seen again during the discussion of the *'nuclear package'* proposed by European Energy Commissioner Mrs Loyola de Palacio.

The position of the experts gathered by the IAEA was however endorsed by the agency in a perfectly clear manner: geological disposal is the optimal radioactive waste management solution as regards safety.

2. According to studies carried out in various countries, disposal in deep geological formations offers a high level of safety

If disposal in deep geological formations is considered by the IAEA and many countries to be the reference option to dispose of high-level radioactive wastes, it is because in addition to the artificial or engineered barriers that can be set between wastes and populations, a natural barrier of several hundred metres of rock forms a highly effective obstacle slowing down the possible movement of radioelements towards populations.

Defence in depth thanks to the multibarriers concept then finds its fullest acceptance.

2.1. Defence in depth is ensured by various artificial or engineered barriers

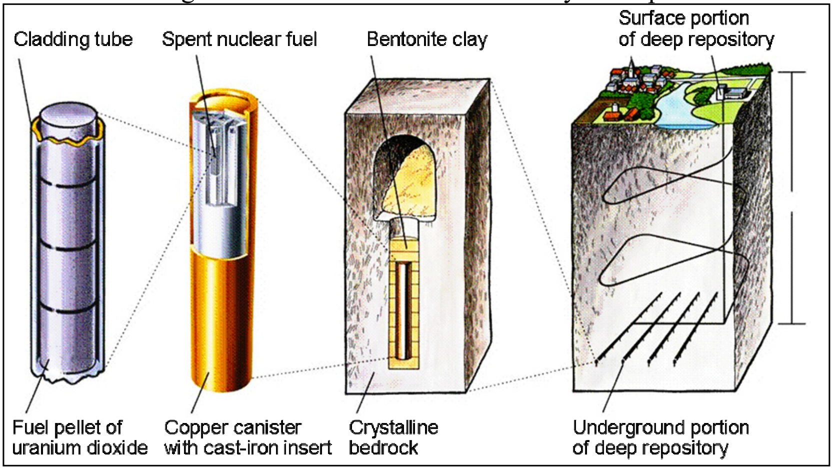
Depending on whether spent fuels or high-level radioactive wastes are being addressed, the number and nature of the artificial or engineered confinement barriers differ.

One of the most advanced confinement methods for spent fuels is the Swedish KBS-3 method developed by SKB.

In this method, there are five artificial or engineered barriers.

Spent fuels are in effect made up of fuel pellets (1st confinement barrier: the fuel matrix puts up resistance against the migration of radioelements), themselves inserted in a fuel rod forming a sheath (2nd barrier: the metallic sheath offers imperfect but real imperviousness), several rods being grouped in ‘fuel assemblies’. The fuel assemblies are in turn inserted in a cast-iron insert (3rd barrier), which itself serves as the internal cladding to a thick copper canister of which the thickness of the walls is 5 cm (4th barrier).

Diagram 3 : The Swedish KBS-3 safety concept



Lastly, the copper canisters are surrounded, when stored, by bentonite clay (5th barrier) impervious to water and which immobilises radioelements.

In such a layout, deep disposal presents the interest of interposing a geological medium (6th barrier) chosen for its properties of low exchange with the surrounding rocky medium (7th possible barrier) if the latter is different.

In the case of reprocessed fuels, the initial situation is still better. In effect the volumes of high-level radioactive wastes are lesser by a factor of 5 than those of spent fuels, and also the wastes confinement matrix presents much improved properties (see paragraph III on long-term confinement and storage).

The immobilisation of high-level long-lived wastes in glass matrixes indeed presents the interest of very high durability owing to the intimate mix of wastes and glass, and the stable character of glass over very long periods.

As vitrified wastes are themselves placed in CDS-V metallic canisters, the stainless steel of the latter then represents the 2nd confinement barrier. Cylindrical casks developed by the CEA then represent a 3rd barrier. A super-canister can also be envisaged for deep disposal (4th barrier). The ONDRAF, the body tasked with waste management in Belgium, proposes for its part an even more advanced solution, the insertion of the super-canister in a concrete cylinder (5th barrier), itself covered with stainless steel.

In any case, geological disposal is required for very long-lived radioelements.

2.2. The various geological media have high, even if different, confinement performances

The essential role of the geological medium is to delay as long as possible the possible arrival of radioelements in the biosphere.

Serious sources demonstrate that many rock formations confine long-lived radioelements.

The evolution of uranium deposits and the example of natural nuclear reactors help to better understand the transfer mechanisms of radionuclides into the biosphere.

Uranium deposits are limited to very low volumes. Further, the natural Oklo reactor operated some 2 billion years ago in Africa, producing inter alia plutonium like today's reactors. This plutonium has moved very little and, on the contrary, has become fixed in the rock cracks.

In short, the radioactivity of the elements contained in a spent nuclear fuel can be compared with that of natural uranium mineral.

According to the calculations by STUK, the Finnish safety authority, the radioactivity of spent fuel is 4,000,000 times higher than that of uranium mineral when fuel is unloaded from the reactor. One year later, it is no longer higher than by a factor of 60,000. After 40 years, it is no longer higher than by a factor of 7,000. After 500 years, spent fuel radioactivity is no longer more than 100 times higher than that of uranium mineral and after 1000 years, 15 times. Finally, after 200,000 years, radioactivity is no longer higher than by a factor of 1.5.

The whole issue therefore consists, if not in preventing the transfer of radioactivity into the biosphere, in delaying it to maximum extent, so that at the time of a possible release, radioactivity is comparable with that of natural uranium mineral.

The possibilities of bypasses or shunts in the rocky barrier decrease its safety, the main possibilities being the circulation of possible underground waters as well as access shafts and disposal galleries themselves.

The media studied for disposal are therefore most often anhydrous and when they are not anhydrous, like granite, special precautions are taken regarding the other confinement barriers.

Also galleries and shafts are backfilled and engineered barriers are set in place in the form of sealings or even artificial plugs in order to give its confinement properties back to the geological medium, even if possible imperfections of such work can be expected, especially owing to damage to rocks during the excavation.

What is then gained in safety is lost in reversibility, in other words the possibility to retrieve packages without difficulty. Examined later on in this report, the choice between reversibility/irreversibility must in any case take other factors into account such as acceptance by populations.

In any case, foreign experiences provide information on the confinement provided by various geological media.

Salt is the geological medium in which is built the WIPP (Waste Isolation Pilot Plant) in Carlsbad, New Mexico (United States), the world’s first operational geological disposal site given over to military low-level transuranic wastes.

Dating back 225 million years, the one kilometre thick Carlsbad salt layer is located at a depth of 350 metres and extends over several hundred kilometres north, south, west and east. Built at - 650 m, the disposal site is formed by a set of galleries where disposal cavities have been excavated in a rake-like layout[27].

[27] The cavities where wastes are placed are 10 m wide and 100 m long, there being an approximately 30 m separation between each of them.

As regards disposal, salt has the advantage of being a medium not only totally lacking in water since all traces of interstitial water are trapped by it, but also a spontaneous ‘prison’ for wastes emplaced there. The salt gallery walls draw together at the rate of 3cm/year and the galleries naturally close in on themselves after 150 years owing to the pressure. After approximately 1000 years wastes are totally encapsulated and the medium reconsolidated.

Salt is also considered in Germany as having interesting confinement properties. As early as 1963, the federal government recommended the use of an underground saline formation to dispose of radioactive wastes[28]. After a long site selection process, Lower Saxony accepted the construction of an underground disposal site at Gorleben, in a salt dome. The site characterisation work and gallery construction at – 880 m already undertaken would have allowed the disposal of high-level wastes, intermediate-level long-lived wastes and even of non-reprocessed spent fuels had the federal ministry for the environment not decided in 1999, for purely political reasons, to resume from scratch the site selection process with a view to building a centralised single site for wastes of all types and spent fuels.

A no longer mined iron ore deposit—another type of medium with interesting characteristics for disposal—was studied in Konrad, near Salzgitter in Lower Saxony, Germany. The sloping galleries located at a depth of between 800 and 1300 m were studied with a view to the disposal of non thermal radioactive wastes, mainly low- or intermediate-level short- or long-lived wastes. The opening of the Konrad site was authorised in May 2002 by the Land of Lower Saxony but is however upheld by four judicial appeals and also by a construction license from the federal government.

Volcanic tuff is the geological medium at the Yucca Mountain site in Nevada chosen by the United States for the geological disposal of spent fuels from commercial nuclear power plants and high-level wastes from military activities[29].

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[28] Between 1981 and 1998, low-level wastes were disposed of in a former salt and potassium mine at Morsleben, near Magdebourg in Saxe-Anhalt, former East Germany. This centre was then closed by the Chancellor Schröder’s SPD / Green Government

[29] Yucca Mountain is located 160 km north-west of Las Vegas, within the Nevada Test Site where many nuclear tests have been performed, including those of the Plow Share programme.

Yucca Mountain is located in an inhabited area—the first house is 22 km away—characterised by a very dry climate, with approximately 19 cm rainfall per year of which 95% evaporates or is absorbed by the vegetation. Yucca Mountain is 1500 m high and is expected to house galleries excavated in the side of the mountain, 300 m under the crest and 300 m above groundwater. This mountain is formed of tuff, a highly porous volcanic rock with oxidising power, which however has the property of retaining radioelements. As regards the presence of water at the site, the absence of any rising from the groundwater has been demonstrated, but risks of water percolation, especially owing to the heat released by wastes, make it necessary to prevent the corrosion of packages by choosing particularly resistant materials or claddings[30].

Clay, for its part, represents a medium with a complex chemical and crystallographic structure whose material properties are well known but which had not been used for any large-scale underground facility before the construction of the Mol laboratory in Belgium. The Boom clay at Mol has proven to be not the expected paste but a hard rock. The same applies to the Callovo-Oxfordian clay at Bure, which is also a hard non-porous rock of relatively high density. Both Boom clay and Callovo-Oxfordian clay are barely permeable at all.

Situated at Campine, north-east Belgium, the Mol laboratory is located at - 225 m in a layer of Boom clay[31] covering several hundred square kilometres and oriented south-east - north-west. The base of the layer is located at - 1000 metres in the south-east and at - 400 metres in the north-west.

The Bure laboratory, for its part, will be located at - 490 m in a layer of Callovo-Oxfordian clay whose thickness varies from 100 m in the south-west to 160 m in the north-west, at an average depth of 450 m and with a surface area of a hundred or so square kilometres.

At both Mol and Bure, the clay therefore comes in the form of an underground layer which potentially represents an encapsulating *'safe'* for possible wastes, provided its confinement properties are scientifically demonstrated.

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[30] The installation of titanium shields above the canisters of spent fuels is one of the solutions studied.

[31] Boom clay is a silty clay with a high pyrite and glauconite content.

3. The delay in the construction of the Meuse/Haute-Marne laboratory has been partly compensated by the knowledge acquired internationally

Research by the ANDRA on clay has considerably advanced even before exploration of the Bure site.

In effect the ANDRA has been a stakeholder, since the beginning of the 1990s, of various scientific or technical projects undertaken at the Mol underground laboratory in Belgium, excavated from Boom clay, and at the Mont Terri laboratory in Switzerland.

Boom clay is different from the Callovo-Oxfordian clay at Bure, particularly by its higher ductility and yet its study is of interest on account of its more extreme characteristics. The Opalinus clay at Mont Terri is also a useful analogue but it too is less favourable than the Bure clay.

By conducting research in these two laboratories, the ANDRA acquired generic knowledge on clay and specific know-how on particular clays. This allowed it to advance rapidly as soon as clay samplings from Bure could be studied in the laboratory. It was also able to prepare methods and measuring equipment which were operational as soon as the Bure chamber and shafts were placed in service.

3.1. Many experiments have been carried out at Mol, Belgium

Since 1987, France has used the possibilities offered by the underground HADES laboratory at Mol to advance with the scientific demonstration of the possible feasibility of underground disposal in clay.

Various experimental methods characterising the properties of clay, especially geochemical, geomechanical and thermal, have been developed at Mol.

These methods were then tested and perfected at Mont Terri whose clay is closer to that of Bure.

In the very unlikely hypothesis of a break in waste packages, it is important to determine what mechanisms could lead to a dissemination of radioelements in the medium.

A set of experiments has led to the determination of the chemistry of the interstitial waters of clay, and highlighted the balance of interstitial waters with the rock, as well as the nature of hydrous transfers. The migration process in Boom clay is mainly a process of diffusion with very low transport speeds[32].

Similarly, the influence of heat has been studied to determine the extent to which the properties demonstrated at natural temperature could be modified by the heat released by waste packages.

A positive element is that on examining the properties of clay close to a shaft ten years after its drilling, it could be seen that in the same way that fractures fill in, the hydraulic properties of clay are restored after ten years, a new balance being created after the excavation. This point is particularly important because the mechanical behaviour of clay is sensitive to water content variations.

New knowledge was also acquired concerning engineering work in clay, particularly the excavation of galleries and their sealing. The excavation of the new gallery at Mol made it possible to check the performances of a tunnel boring machine, and test the tunnel support method using concrete blocks with a key, which are more advantageous than concrete arches. Similarly, arch deformation or sliding methods were developed, and methods measuring the effort at the rock / arch interface, and the convergence of the mountain range.

3.2. Scientific and technical mastery has been acquired at Mont Terri

The Mont Terri laboratory is located in a geological medium similar to that at Bure and has allowed very important work to be performed for the design of experiments and tests which were then carried out at the Meuse/Haute-Marne laboratory.

The Opalinus clay at Mont Terri is a good analogue of the Callovo-Oxfordian argillites studied at Bure. In both cases they are materials having the aspect of a clay but the mechanical properties of a hard rock. The main difference between the two types of argillites is that the silty argillites of Mont Terri are folded vertically and overlapping,

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[32] The permeability is 10^{-12} m/s, i.e. approximately 30 µm/year

whereas those of Bure are tabular and without tectonic constraints. But their ages and respective chemical compositions are equivalent.

The main experiments conducted at Mont Terri concern the following fields[33]:

- Geochemistry of fluids circulating in argillites;
- Diffusion and migration of radioelements in rock: establishment of experimental set-ups, measurements and tests of models in Opalinus clay then transposed to Callovo-Oxfordian clay;
- Thermal behaviour of the medium submitted to a hot source;
- Construction techniques of anchoring keys in the clay[34].

85% of the experiments performed at Mont Terri would be transposable to Bure. This will be particularly the case with the experiments conducted on the damage to the Opalinus clay during the boring of the shaft or galleries. The issue of damage to rocks is particularly important insofar as disruptions can cause permeability and allow water circulation. What is tolerable in a civil engineering work, for example the Channel Tunnel, where leaks are regularly filled with resin injections, is not tolerable where the disposal of radioactive wastes is concerned. That is why experiments were carried out at Mont Terri on the efficacy of the use in the damaged zone of drains filled with bentonite.

The IRSN (Institut de radioprotection et de sûreté nucléaire – Institute for Radiological Protection and Nuclear Safety) is also carrying out research at Mont Terri as the provider of technical support to the nuclear safety authority. Unlike its subsurface laboratory at Tournemire, the Mont Terri laboratory allows it to use radioelements as tracers. The research performed in the clay at Tournemire and in that at Mont Terri mainly concern the fracturing and fissuring of rock, its hydraulic behaviour, modelisation of the transport of radioelements with the phenomena of absorption or transfer in interstitial water, microbiology of the medium owing to the possible presence of archeobacteria reactivated

[33] Hearing of Mr Jacques DELAY, Deputy Laboratory Director, Head of the Scientific Department, Meuse/Haute-Marne underground research laboratory, ANDRA, Mont Terri, 10 September 2003.
[34] The Mont Terri 3.5 million € budget for 2003-2004 is covered to 47% by the ANDRA.

by the opening of galleries, and forced ventilation techniques in galleries and their influence on rock saturation and desaturation[35].

Therefore, thanks to the work started at Mol and then pursued at Mont Terri, a series of in situ experiments could be set in place at Bure, as soon as the chamber at - 445 m was available.

This way, the two years of delay in building the laboratory—one year due to the late issue of the administrative license to commence the work, and the other caused by legal proceedings following a site accident—have been almost compensated.

4. Research has led to very many gains, even if uncertainties remain to be cleared regarding the feasibility of a disposal facility in the clay at Bure

The in situ experimentation chamber in the clay layer at Bure at a depth of - 445 m and of a total length of 40 metres became operational only at end November 2004. Since then, and taking into account the experience accumulated at Mol and Mont Terri, many scientific experiments have been rapidly performed.

Two remarks must however be made.

First, experiments at Bure started much earlier from the surface with a major programme of drillings in the major shaft and the auxiliary shaft.

Second, even if the data acquisition rate is going to be very rapid during 2005—especially as the depth level of the galleries should be reached at the end of the first quarter and some galleries should be delivered by mid-2005—it will however be impossible to complete, before end 2005, various important experiments for the qualification of the clay layer in terms of its confinement properties.

Advanced scientific organisation has been set in place around the Meuse/Haute-Marne laboratory and since a short while in situ.

A convincing set of scientific results has been produced. Bearing in mind the time available, this data and these analyses, which have

[35] Hearing of Mr Helmut PITSCH, manager of the modelisation and transfer validation laboratory, IRSN, Mont Terri, 10 September 2003.

nevertheless already been produced in abundance, are not sufficient with regard to the pursued goal and must be checked over time.

4.1. Pluralistic and world-class scientific work has been accomplished at Bure

The conditions and procedures of high-level fundamental scientific research have been implemented for the study of the Bure site. A pluridisciplinary approach calling on the best organisations has been implemented to characterise the Bure clay. This approach is organised according to the internationally recognised procedures of fundamental research.

An Orientation and Follow-up Committee (Comité d'orientation et de suivi) has been set up with an advisory capacity alongside the ANDRA but its opinions have been acted upon. This committee groups thirteen French and foreign members belonging to the academic world or to major research bodies and is chaired by the Research Director of the BRGM (Bureau de recherches géologiques et minières – Office for Geological and Mining Research). It assesses the design of experimental programmes as a whole and the interpretation of results.

Research alliances (GdR – groupement de recherche) have been created grouping high-performance teams, such as FORPRO for the study of deep geological formations[36] (CNRS and ANDRA), PARIS for the physico-chemical study of actinides in solution (CNRS, ANDRA, CEA and EDF), and MOMAS for mathematical modelisation and simulations (CNRS, ANDRA, BRGM, CEA, and EDF).

This way, for the FORPRO programme, a high number of teams of mixed research units—CNRS/universities, IPG (Institut de Physique du Globe – Geophysical Institute) and 'grandes écoles' (leading higher education schools)—have been involved, grouping 200 researchers, engineers, and doctorands and post-doctorands. A multidisciplinary approach has also been applied, combining geochemistry, geophysics, petrophysics, geomechanics and microbiology.

[36] The main research topics of the FORPRO GdR are as follows: transfers of solutes in a clayey medium of low permeability and evolution of the latter over time; origin, age and chemical composition of underground waters; past or present pathways taken by waters in the medium of the underground laboratory and their impact on the long-term behaviour of a disposal site; responses of the geological medium to mechanical, thermal or chemical disruptions; modelisation of the evolution of a geological site at various time scales.

In all, more than 80 academic laboratories are associated in the work carried out within the framework of 7 'excellence alliances' on precise topics and with, per product, nearly 30 theses orally defended in 20 different universities.

The quality of the work performed has also been attested by peer reviews made by the NEA-OECD in 2001 according to an adversarial examination procedure meeting international standards and conducted by a panel of independent scientists and experts from several countries[37].

The orientation and scientific assessment procedures applied by the ANDRA for the Meuse/Haute-Marne laboratory are undeniably those of high-level fundamental research[38]. The high level of this research is evidenced by the high number of scientific publications related to the study of Bure clay.

4.2. High-level scientific methods and equipment have been used at the Meuse/Haute-Marne laboratory

Advanced methods are used to study the Bure clay layer.

From the surface, a large number of vertical drillings have been made at the site of the laboratory and within a radius of 20 km around it[39]. The clay layer has been crossed in two directions by means of diverted or directional drillings. In all 15 km of drillings have been made. Drillings cores of a length of 4.2 km including 2.3 km in the clay were studied at the surface and loggings were made. These supply a continuous record of the variations of a physical or chemical parameter in terms of depth, in accordance with oil industry measurement technologies.

3D seismic methods, used during a geophysics campaign conducted in 2000, have also allowed a precise map of the Bure region to be drawn.

[37] The French R&D Programme on Deep Geological Disposal of Radioactive Waste: An International Peer Review of the Dossier Argile 2001, NEA-OECD, 2003.
[38] GdR scientific board, National Assessment Board, ANDRA scientific board, CNRS National Committee, Expert Orientation Committee (universe sciences), peer review A+ journals, Experts Committee of the VIth PCRD
[39] At the laboratory site: 7 drillings in the calcareous Oxfordian located above the clay layer. In a radius of 20 km: 6 platforms, 11 deep drillings, 5 drillings in the Dogger located below the clay layer and 6 drillings in the Oxfordian.

In addition, direct observation of the clay layer has been made since March 2004.

Complementarily to these advanced techniques and physico-chemical experimental methods, specific experimentation methods have been developed to provide answers to difficult but fundamental questions.

For instance, the CNRS has developed a method for the dating of underground waters on different time scales: under 100 years with krypton 85, or from 50,000 to 1,000,000 years with krypton 81[40]. Another example, two methods of 3D imagery to a depth of 5 m in the damaged zone allow the induced fracturing of the walls of galleries to be studied[41].

These methods, as a whole, have already significantly contributed to understanding the properties of Bure clay.

4.3. Clay is a medium guaranteeing the integrity of vitrified waste packages over several hundred thousand years

As confinement barriers of the first levels, waste matrixes and canisters play a decisive role in the safety of geological disposal.

The long-term behaviour of immobilisation matrixes and canisters can be studied using numerical models simulating the physico-chemical mechanisms governing the evolution of the materials used. To determine the laws of the latter, laboratory tests on samples in accelerated conditions are completed by the study of natural or archeological analogues. A decisive element is when water at the disposal site enters into contact with the waste packages, which takes place after approximately 1000 years.

The vitrification of high-level wastes—fission products and minor actinides—is a process chosen after observing that archeological

[40] These methods find applications in the study of climate change and in cosmochemistry.
[41] These two methods have applications in the study of volcanic or civil engineering risks, and in hydrogeology and sedimentology.

glasses are almost intact after several thousand years in seawater[42] and that basaltic glasses are barely damaged at all after one million years.

A comparison of the release speeds of radionuclides fixed in cements or bitumens or of the activation products of metallic alloys shows the superiority of vitreous matrixes[43].

The CEA has indeed established that, for cements used to condition certain intermediate-level long-lived wastes44, radioactivity is released as soon as water arrives, owing to the porosity of cement, in other words after 1000 years[45]. The use of bitumen as the immobilisation matrix leads to an improvement in performances, but 90% of the initial package is impaired after 10,000 years.

For hulls and end-fittings—intermediate-level long-lived wastes from fuel sheaths, which are compressed and inserted in stainless steel cylinders—radioactivity is released only far much later. In effect, as the radioactivity of these wastes results from elements activated in the metallic mass, their solubilisation does not occur until after approximately 100,000 years.

Lastly, the vitrified wastes used to condition high-level long-lived wastes have a very high retention capacity of radioelements. Glass matrixes not only have poor solubility in water but their surface becomes covered with protective gels after dissolution over a very low thickness[46]. According to the models realised by CEA, 'the lifespan of such a package is higher than 300,000 years'[47].

[42] L'aval du cycle nucléaire - Tome I: Etude générale (The back end of the nuclear cycle - Part I: General study), report by Messrs. Christian BATAILLE and Robert GALLEY, Members of Parliament, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 978, Senate no. 492.

[43] The process is as follows: calcination of the solution of fission products and minor actinides, then vitrification at 1100°C by mixing with frit and heating in an induction furnace, then pouring of the molten glass into a cylindrical canister in refractory steel. Radionuclides are part of the vitreous network, which explains the longevity of this conditioning.

[44] These are operational wastes compacted or immobilised in cement, or else they are liquid wastes embedded in cement.

[45] To relativise the scope of such a phenomenon, cement is used as the conditioning matrix only for wastes which, in all, represent a low share of total radioactivity.

[46] The reactional mechanisms relative to vitrified wastes are hydration and interdiffusion, hydrolysis of some elements (silicium, aluminium, iron), and the formation of a layer of gel and its densification which almost cancels the porosity.

[47] Mme Michèle TALLEC, hearing of 27 January 2005, Parliamentary Office for Scientific and Technological Assessment, National Assembly.

In short, while the performances of waste packages depend on the geological environment where they are emplaced, they are only one of the safety factors. The deep geological formation plays, as seen, a decisive role as a confinement barrier.

4.4. The physico-chemical properties of Bure clay contribute to good confinement

The Callovo-Oxfordian clay at Bure results from sedimentation in a shallow medium that occurred 155 million years ago, at a temperature of approximately 40°C. Since then the rock has not been disturbed.

No fault with a vertical slip greater than 2 m exists over 4 sq. km. There are only 38 microfractures over the 1400 metres of drillings cores resulting from diverted drillings, and these microfractures are without movement and without any influence on the hydraulic properties. The homogeneity of the layer has been proven over 200 sq. km but also on a metric scale and at molecular level.

Bure clay has very low porosity and water moves very slowly in it (3 cm in 100,000 years).

Independent of water movement, the transport processes of chemical elements, especially of radioelements, are also slow in it. With low porosity, Callovo-Oxfordian clay indeed has a high retention capacity. For instance, the most mobile anions (I, C1, Se) possibly released by waste packages would not reach the summit of the layer before 300,000 years. Mobile cations would reach the top of the layer in 10 to 20 million years and minor actinides, even less mobile, in more than a billion years[48].

Also, experiments demonstrate that the interface between Callovo-Oxfordian clay and the layer of calcareous Oxfordian topping it, form a difficult to cross barrier for cations.

This remarkable property further strengthens the confinement properties of the clay layer.

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[48] Clay particles are charged negatively on their surface, repelling anions and slowing down their progression by diffusion in the rock porosities. Cations for their part are adsorbed by clay.

4.5. The hydrogeology and seismic characteristics of the Bure site are favourable

To judge the confinement properties of a geological medium, it does not suffice to characterise the medium. The properties of the enclosing formations must also be determined, particularly as regards hydrogeology.

The limestones of the formations enclosing the Bure layer, in other words the Oxfordian which lies above and the Dogger which lies below, contain very little water. The vertical gradients are very low over the totality of the layer and almost nil at the site. Geochemistry has also demonstrated that transfers of elements are very slow in limestones: 10 km in one million years.

Seismology also represents an important topic and a subject of concern for some experts[49]. Reference has in particular been made to an earthquake which occurred in 1784 in Neufchâteau, thirty or so kilometres from Bure, and there was another seismic episode in 1992 a few kilometres from Bure.

Yet the reconstitution of ancient earthquakes of level 2 at the most makes it clear that the epicentre was at a distance of 70 km from the site. This zone belongs to the east of the Parisian Basin, a region of very low seismicity where the possible sliding speeds over regional faults are around 0.001 to 0.0001 mm/year. The Bure sector does not have any detectable neotectonic activity nor any significant local seismic activity.

Following the revision of the national seismic zoning plan, the Bure zone will moreover be classified in France's least seismic category[50].

Nevertheless the Bure facilities are dimensioned to resist a level 6 earthquake, in order to take account of the maximum physically possible earthquake of a magnitude of 6 that occurred 75 km away.

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[49] André MOUROT, Member of the CLIS, Bure, Public hearing organised by the Parliamentary Office for Scientific and Technological Assessment on 27 January 2004 at the National Assembly.
[50] Hearing of Mr Thierry TROUVE, Director of the prevention of pollutions and risks, Ministry of Ecology and Sustainable Development, 2 February 2005.

As the consequences of an earthquake are lessened as depth increases, it can be scientifically considered that sufficient precautions have been taken.

4.6. Experiments need to be confirmed in situ and uncertainties cleared as regards the damaged zone and the consequences of thermal gradients and gaseous emissions

As seen, many scientific experiments on the Bure clay were performed even before the excavation of the shafts and construction of the experimentation chamber, by using the possibilities offered by the Mol and Mont Terri laboratories, as well as by making use in the laboratory of the drilling cores or samplings made at a distance. Some experiments, especially the essential safety ones, must be validated in situ.

Further, the damaged zone, corresponding to the thickness of the rock disrupted by the excavation of shafts, galleries or engineered barriers, represents a potential weakness point for confinement which is ensured almost perfectly by clay, in the absence of any human intrusion.

An important matter however is to know the dimensions of the damaged zone with respect to the clay layer. According to the first observations made when excavating the shaft and the experimentation chamber at - 445 m, the damaged zone represents a third of the radius of an engineering work, in other words 1 m for a shaft with a 3 m radius. This dimension must be compared with the thickness of the clay layer, from 130 to 150 m, since the intact remainder of the clay layer will continue to act as a confinement barrier. The case of transversal engineering works should be addressed in greater depth, bearing in mind that engineered barriers can be designed so as to stop possible releases that take the course of the damaged zone.

The consequences of possible gaseous emissions from wastes conditioned in matrixes such as cement and bitumen must also be studied. What is the probability of such phenomena and what form could they take? What would their consequences be on clay or on engineered barriers, depending on whether disposal is of the reversible or irreversible type, after the backfilling of galleries?

Another question which must also be addressed in greater depth is that of the influence of temperature on the behaviour of clay in its mass and in the damaged zone. Radioactive wastes indeed emit heat. Once they have been emplaced in the clay layer, to what extent could they change its behaviour?

To settle the heat issue, several parameters can be used. First, it can be waited until waste packages have cooled by storing them at the surface. Second, the emplacement of packages in disposal galleries can be calculated so that the ambient temperature does not exceed a maximum value.

Although these problems are of an industrial order, it is nevertheless necessary to have precise scientific knowledge of the mechanisms of clay evolution depending on temperature, so as to set in place the management procedures for packages and to dimension disposal in an optimal manner.

4.7. The assessment of global safety remains to be completed

Within the framework of cooperation between the ANDRA, the CEA and EDF, a numerical modelisation of a radioactive waste disposal site was made to simulate its behaviour and evolution over time.

There are of course very many parameters to be taken into account: nature of the packages, chemistry of the medium, corrosion mechanisms, transport kinetics in the various geological media, involvement of water traces, etc. A major difficulty is naturally the interrelation between the various phenomena influencing the integrity of disposal.

The ALLIANCES simulation platform, a high-quality instrument, already allows thousands of calculation cases to be made and to assess various confinement evolution scenarios, including in the event of accidental or voluntary intrusion. To represent reality more faithfully, the models will however have to integrate the results of the ongoing or future physical experiments. Similarly, once the engineering choices have been made, they must be incorporated in the global model. In this respect, numerical models are expected to shed interesting light on the reversibility / irreversibility choices with respect to safety.

In reality, the assessment of safety depends largely on the finalisation of numerical models, which shall therefore precede any decision.

As the deep geological medium plays a decisive role for safety, a major decision is of course the choice between reversibility or irreversibility.

The Act of 31 December 1991 commissions research to study these two solutions on an equal basis. But, in actual fact, if practical considerations are taken into account, does this choice continue to really form a dilemma?

5. Reversibility is possible over a long period in good safety conditions

The respective advantages of the irreversibility and reversibility of the disposal of radioactive wastes are to be assessed from three viewpoints: technical, ethical and practical.

5.1. The safety arguments in favour of irreversibility do not appear decisive

Technically speaking, irreversibility entails the backfilling of the disposal site and therefore provides the best confinement possible. It also eliminates any need for monitoring once it has been proven that the geological formation ensures confinement over the very long term, in other words for several hundred thousand years.

The role of the various safety barriers is of major importance as shown *a contrario* by the Yucca Mountain example whose confinement properties are controversial. As laid down for this site by the US National Academy of Sciences, the safety of the site must be guaranteed for several hundred thousand years, the length of time corresponding to the radioactive dose peak of the longest-lived elements. Consequently, owing to the possible long-term migration of radioelements from the site in a specific direction, the Department of Energy is obliged to demonstrate the integrity of spent fuel canisters over this time scale, making it necessary to take costly measures against corrosion, insofar as tuff is a natural medium far more aggressive than salt or clay.

Also in a situation of irreversibility, the retrieval of wastes makes it necessary to re-excavate shafts and access galleries, which complicates the implementation of technical solutions which could ultimately allow radioactive wastes to be transmuted, even if conditioned, or energy content to be drawn from them. But irreversibility does not make it impossible to retrieve wastes since the same mining techniques used in building the site should be able to be used subsequently to re-excavate access.

In contrast, reversibility which, in its maximalist version, makes it necessary to leave shafts and galleries open, reduces the performance of the confinement of wastes and even the physical safety of disposal.

This solution however presents two decisive advantages. Reversibility theoretically makes it possible to rapidly detect the deterioration of packages and find a solution without delay. The other advantage is to facilitate the implementation of possible waste incineration technical solutions, since the retrieval of packages is facilitated in this hypothesis.

Technically, as regards safety, when the advantages of irreversibility and reversibility are compared they do not appear so much more in favour of irreversibility as could have been believed on the face of it.

5.2. Reversibility is imperative for ethical reasons

With respect to future generations, irreversibility settles the matter of responsibility. No burden is carried forward to future generations and the only obligation to be complied with in their respect is the transmission of information on the location and composition of the disposal site.

Reversibility in contrast does carry forward the onus of monitoring, in exchange for easier intervention on wastes.

In any case, with reversibility, the field of the technically possible remains open, which is essential for a positive perception of technical progress, national solidarity and confidence in the future.

In the December 1993 report of his mediation mission on the siting of underground research laboratories[51], Christian BATAILLE wrote; *'I feel reversibility is as much of a scientific as a moral guarantee. (...). It must therefore be clearly announced that the research*

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[51] Report to the Prime Minister, Mission de mediation sur l'implantation de laboratories souterrains, by Mr Christian BATAILLE, Member of Parliament, Documenation française, 1994.

programmes to be carried out in underground laboratories will prioritise the study of systems which shall subsequently allow reversibility of disposal. Taking account of the progress of science and techniques, and of progress in other research avenues, this characteristic will reserve the possibility and therefore the freedom of choice.'

All in all, irreversibility can appear as a kind of loss of confidence with respect to scientific progress and as an infringement of the integrity of the subsoil, even if the natural decline in the radioactivity of wastes brings it down to the level of a natural uranium deposit.

Whereas at the beginning of the 1980s irreversibility represented the choice of most countries, doubts are growing in number today regarding the opportunity of complicating the retrieval of packages and regarding the acceptability of such an approach by society.

Reversibility makes it possible to keep an obvious degree of flexibility and finally appears as a priority line of action.

Furthermore, analysis of the technical solutions for geological disposal demonstrates that there is undoubtedly room for solutions combining the advantages of both approaches and allowing this choice to be made at a future date.

5.3. In practice, the respective advantages of the two approaches appear combinable

On examining the technical solutions envisaged for geological disposal and on taking into account the time factor governing the actual operation of such disposal, it appears that the irreversibility-reversibility choice can be simplified.

A disposal site can apparently be technically designed to ensure reversibility while offering safety almost comparable to that of irreversibility.

Disposal architecture ensuring reversibility has therefore been developed on the basis of modular concepts leading to flexible management and evolution of design over time.

The deep site is organised as a network of access tunnels laid out in a grid pattern and also of disposal chambers set crosswise to the tunnels outside.

Primary packages (canisters of intermediate-level long-lived wastes and their envelope) are emplaced four by four in rectangular concrete canisters. Canisters of high-level long-lived wastes are, for their part, emplaced in cylindrical casks. Multipurpose handling devices are then used to place the two types of packages in disposal chambers separated from the access tunnels by a radioprotection lock chamber.

Therefore, management choices remain open at each step: maintenance as such, passage to the following step (construction, closure) or return back. The first level of reversibility is similar to deep storage and the last level is closure, which brings the safety level close to that of irreversibility[52].

Step by step reversibility also appears to be an interesting concept which allows for choices to be made over the long term, even deferring decisions over several generations, yet without generating high costs.

Coming in addition to the possibilities offered by engineering, the time factor should also allow reversibility to be ensured in the best conditions.

Activity in the nuclear field involves the long term.

The first high-level radioactive wastes were produced in the 1950s. The most recent of the EDF nuclear power plants, Civaux, should stop operating around 2040-2050 in the hypothesis of a 50-year lifespan. After the reprocessing of its fuels and a 40-year cooling period of vitrified wastes, geological disposal of the last high-level wastes from its operation should be made around 2100.

Other reactors, including at least the EPR at Flamanville, will operate longer into the century.

The ultimate decision to close the national disposal site will therefore lie with those responsible in the XXIInd century.

[52] Philippe STOHR, ANDRA, public hearing on 27 January 2005, Parliamentary Office for Scientific and Technological Assessment, National Assembly

In short, it is therefore important to select the technical options optimising safety while leaving the choices open.

The first engineering studies carried out by the ANDRA show that, subject to confirmation, this possibility is not utopian.

6. Why a second laboratory in a deep geological formation is not necessary

In its Article 4, the Act of 30 December 1991 lays down that 'the Government shall send each year to Parliament a report setting forth the progress of research on the management of high-level long-lived radioactive wastes and that of work conducted simultaneously as regards (…) study of the possibilities of reversible or irreversible disposal in deep geological formations, particularly thanks to the construction of underground laboratories (…).'

While various arguments are set forth to stipulate, demand or require the construction of a second underground laboratory, it does not however appear necessary for a set of reasons.

First, as Article 4 mentions 'underground laboratories' in the plural, compliance with the Act would require at least a second laboratory. However, attentive reading of Article 4 contradicts this assertion.

What the Act requires is, in effect: 'the study of the possibilities of reversible or irreversible disposal in deep geological formations'. Strict interpretation of the Act would impose the study of all geological formations, which would be totally impossible because unrealistic, bearing in mind the almost infinite number of configurations of the national subsoil. Similarly, as Article 4 continues by specifying 'particularly thanks to the construction of underground laboratories', a strict interpretation of the Act would also impose that for each of the countless possible geological configurations several laboratories be built, which would be totally unrealistic.

A flexible interpretation of the Act is therefore obviously required for various notions, especially as regards the use of: the plural in 'deep geological formations'; the adverb 'particularly'; and the plural in 'underground laboratories'.

In fact Parliament's will—expressed in particular by the Bill Rapporteurs, Mr Christian BATAILLE at the National Assembly and Mr Henri REVOL at the Senate—was that research should not focus on separation-transmutation and on long-term conditioning and storage, but that rigorous studies should be made on reversible or irreversible geological disposal, making use of all possible means, including in situ experiments. In actual fact, the Act does not stipulate either the study of several geological media or the construction of several laboratories for each of them.

Another type of argument put forward in favour of a second laboratory is formed by the reminder of the December 1993 conclusions of the mediation mission on the siting of underground research laboratories[53]. Four French departments were indeed proposed: Gard (clay), Haute-Marne (clay), Meuse (clay), and Vienne (granite). As three of the four proposals concerned clay, the multiple choice was aimed at diversifying the risks of failure at the end of the studies.

The situation is now entirely different since, although the studies are not completed and no decision has been taken on the feasibility of disposal, no negative finding has been advanced as to the confinement aptitude of the Marne/Haute-Marne clay layer and the scientific prospects are good.

Also the need to study several geological media is an additional element put forward for a second underground laboratory.

It should however be observed in this respect that the same people, who disqualified the properties of granite and advocated the abandonment of the project to build an underground laboratory in the granite in the Vienne department, are today demanding the opening of a second laboratory.

Particularly enlightening, the case of Switzerland supplies the conclusions of a comparison between clay and granite. Switzerland is indeed the only country to have built two underground laboratories, one in granite (Grimsel) and the other in clay (Mont Terri).

However, Switzerland has recently chosen to prefer clay.

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[53] Mediation mission, Mr Christian BATAILLE, Deputy, Nord, op.cit.

The Swiss policy for the disposal of high-level radioactive wastes comprises two parts: first, the conduct of generic research on the clay at Mont Terri and the granite at Grimsel and, second, the search for a technically suitable site that is well accepted locally.

The Mont Terri laboratory in the Swiss Jura is a clay behaviour studies centre, of major scientific and technical importance, primarily for Switzerland and then for the members of the international consortium cooperating on various projects. The laboratory forms a work base constituted by a set of galleries excavated from a motorway tunnel. It is not intended to become a disposal site. The studies performed at Mont Terri on the Opalinus clay concern in particular the hydraulic, mechanical or thermal behaviour of the latter, as well as the development of numerical models of key processes for safety.

Located at the centre of the Swiss Alps and to the south of Lucern, the Grimsel laboratory devoted to the study of granite is situated in a 1 km gallery parallel to the access tunnel to an underground hydroelectric power plant. Work performed at the Grimsel laboratory at the beginning of the 1980s was aimed at preparing the exploration and characterisation of the crystalline rocks of the north, north-east of Switzerland, as the use of a gallery appeared less difficult and costly than making many drillings.

After having been studied for nine years by the authorities, the conclusions of the studies on the suitability of crystalline media for the disposal of radioactive wastes were transmitted to the Federal Council in 1994. On their basis, it did not select crystalline media as priority media owing to the presence of faults and fissures allowing underground water circulation.

Consequently, the NAGRA, the national cooperative for the disposal of radioactive wastes, undertook research on the possible suitability of a 50 sq. km. zone whose subsoil contains Opalinus clay, located in the Weinland, a region situated to the north of a Basel-Zurich line. Scientifically, the demonstration of the feasibility of disposal in clay was based firstly on the research work performed at Mont Terri, then on the drillings at Benken and, lastly, on the 3D seismic data of the Weinland. At end 2002, the NAGRA demonstrated conclusively the feasibility of disposal in the Weinland near Zurich.

In September 2004, the federal councillor, Mr Moritz LEUENBERGER, felt that alternatives to the Weinland should also be presented by the NAGRA but that, in any case, safety should be the priority.

According to the Swiss Confederation, clay is the priority option for the geological disposal of wastes. Crystalline rocks merely form a secondary option.

Consequently, the following question arises. Can France take advantage of this experience or must it engage in heavy expenditure to reach the conclusion already reached by Switzerland: clays have more interesting properties than granite?

Moreover, the ANDRA will be in a position in 2005 to present a dossier analysing the advantages and disadvantages of granite, thanks to the work performed at Grimsel in Switzerland or at Aspö in Sweden, and also thanks to the exploratory drillings at various sites in the French subsoil.

In any case, the interest of a granite solution in France is greatly weakened by a basic cause. Unlike in Scandinavian countries or in Canada which have a stable granite shield, France has undergone the Alpine and Pyrenean tectonics generating many faults in the granite massifs.

It should be emphasised that the subsoil exploratory work which led to the selection of the Bure clay layer was highly effective since the properties of this clay appear, for the moment, to be of very high quality compared with any other medium.

7. Geological disposal should be operational in France between 2020 and 2025

Bearing in mind that research is not completed, it is difficult to determine the date by when geological disposal could be operational in France. However the construction schedules for this type of facility in other countries supply precious indications as to the administrative lead times and construction periods.

7.1. The dates of operational start-up are spread from 2010 to 2020 depending on the countries

Even though very specific, the case of the United States gives information on the length of the decisional process and that of the construction of a geological disposal site.

The Yucca Mountain site was chosen in 1987 whereas presidential and congressional approval did not come before 2002. The construction license application was to be transmitted by the DOE to the safety authority, the NRC, but that was finally postponed. The Yucca Mountain start-up date initially scheduled by the DOE was to be 2010, but most observers expect 2015 at the earliest.

In Sweden, the selection process for a disposal site is still ongoing. SKB expects to pursue its investigations on the two selected sites of Osthammar and Oskarshamn until 2007. By then one of the two sites will have been selected. Towards 2007-2008, the construction license application will be submitted by SKB to the safety authority, SKI, which will have two years to respond and propose a decision to the Government. The Government's decision is expected in 2010. Given construction lead times and those to obtain the final operating license, SKB expects the disposal centre to start up some time between 2015 and 2020 at the earliest.

In Finland, it was on 16 May 2001 that Parliament adopted the project for the construction of a geological disposal site on the Olkiluoto peninsula. The construction of a characterisation laboratory, known as Onkalo, on the Olkiluoto peninsula, began in 2004, and will serve to conduct research in situ over the period 2004-2010. The construction license cannot be issued before 2012 at the earliest, after rigorous examination of the detailed safety file by the Finnish security authority, STUK. Construction of the disposal site itself is expected after 2012. Start-up of the site is scheduled for 2020.

7.2. A geological disposal site could enter into operational service in France between 2020 and 2025

In the light of foreign experiences, it can be observed that detailed characterisation and engineering studies of a disposal site, and the safety analysis and examination of the safety file by the competent authority take at least five years. The site construction period strictly speaking lasts approximately ten years.

Do such lead times have any meaning as regards France?

Scientific experimentation could continue over a five year period, during which could also take place full characterisation of the Bure site as well as technological demonstrations of the engineering and of the equipment for the construction and operation of a disposal facility.

Drafting of the detailed preliminary draft project, establishment of the safety file of the future disposal site, consultation of the public and the period for examining the application are estimated as lasting approximately five years (total: ten years).

Lastly, after two years of additional studies with a view to invitations to tender and their analysis (total: twelve years), the construction period strictly speaking could last five years (total: seventeen years). The construction of disposal galleries could be made in phases, following excavation of the access shafts and the network of central tunnels, in the event of reversible modular disposal[54].

The start-up of a geological disposal site in the Bure layer could therefore take place some time between 2020 and 2025.

III.- *STRAND 3:* THE FEASIBILITY OF LONG-TERM STORAGE, ESSENTIAL TODAY AND TOMORROW, MUST BE DEMONSTRATED BY AN ACTUAL FACILITY

The study of long-term conditioning and storage forms the third strand of research pursuant to the Act of 30 December 1991.

The research commenced in 1991 obviously did not start from scratch. Since the beginning of the applications of civil nuclear energy, operators have striven to condition radioactive wastes to avoid any transfer into the environment. The quality and thickness of the metals

[54] In Sweden, it is estimated that there will be 40 km of underground galleries at a depth of - 400 m to store 4500 canisters of fuel spent in its 11 reactors, which are operated for an average length of 40 years. As regards France, the disposal galleries will be much shorter.

and concretes used to produce canisters are chosen so that their integrity is ensured over a long period. In short, while the techniques of conditioning high-level wastes in glass and intermediate-level wastes in bitumen or cement are old, they have been perfected thanks to the work carried out under the 1991 Act.

Storage facilities have been operational in France for many years at each nuclear power plant and at each research centre, as well as at the La Hague reprocessing plant. Storage is made, for instance: in pools at nuclear power plants or at the La Hague, as regards spent fuels; storage halls for high-level vitrified wastes at La Hague and at Marcoule; or storage tanks for wastes not yet conditioned.

Owing to their robust design and the safety margins adopted, the storage facilities currently operating in France can be run entirely safely for approximately fifty years. The experience gained from these facilities has served as the basis in elaborating new, better designed, longer-lived storage concepts aimed at providing additional flexibility for waste management.

Yet an actual long-term storage facility remains to be built.

1. Conditioning has progressed as regards matrixes and also canisters

Thanks to the research conducted since 1991, major progress has been achieved regarding waste characterisation methods, which are essential to optimise its management. New conditioning matrixes have brought higher performance. Lastly, the rationalisation of canisters and new practical solutions are being developed.

1.1. The fine characterisation of wastes allows their management to be optimised

Precise knowledge of the content of radioactive waste packages is essential to choose the most adapted management solution. This is particularly important when old wastes are retrieved for conditioning or reconditioning. By way of example, at its La Hague facility, COGEMA plans to retrieve, from 2005, the sludges stored at STE2 and the wastes stored in the HAO 115 & 130 silos, as well as the various wastes (resins, powdery graphite, solvents), stored in decantation tanks at the UP2-400 plant[55].

The two categories of methods are, on the one hand, so-called ‘intrusive’ methods in which, following a sampling, a set of physico-chemical analyses is made and, on the other hand, non-destructive methods based on imagery. The sensitivity of intrusive methods has been greatly improved. Also, the new combinations of imagery methods—radiography, neutron and gamma measurements—reduce the uncertainties as regards the physical content of packages and the quantification and localisation of radionuclides.

These new characterisation methods are aimed at optimising waste management.

1.2. New conditionings allows a reduction in volumes and higher durability of packages

Several significant results mark the evolution of conditioning techniques of low- or intermediate-level wastes generated by the processing of spent fuel at the La Hague plant.

Between the conception of conditioning processes and the year 2000, the total volume of low- or intermediate-level short-lived wastes, intermediate-level long-lived wastes and high-level long-lived wastes was divided by a factor of 10. While the volume of high-level long-lived vitrified wastes decreased little, in contrast there was a high reduction in intermediate-level long-lived wastes and low- or intermediate-level short-lived wastes.

This reduction in volume results firstly from a reduction in the volume of wastes from dissolution and separation operations as well as from the development of the dry method and optimisation of wet method processes. Secondly, the vitrification of effluents has replaced bituminisation. Lastly, a third boost in this direction has been provided by the compacting of hulls and end-fittings and technological wastes instead of using the techniques of embedding them in bitumen or reinforced concrete[56].

[55] National inventory of radioactive wastes and recoverable materials, ANDRA, 2004.

[56] In 1980, at the time of the conception of the conditioning processes implemented at the UP3 plant, the total volumes reached 3 cu.m /t reprocessed uranium, of which approximately 20% for

By placing compacted hulls and end-fittings in standardised CDS-C canisters made of the same stainless steel as the CDS-V vitrified wastes canisters, instead of concrete, progress is obtained in terms of package durability. The standardisation of dimensions also contributes significant gains in terms of ease of management and savings.

Another important contribution of research by the CEA and the CNRS is that new conditioning matrixes are being developed for each of the minor actinides (americium, neptunium and curium) and for long-lived fission products (iodine, cesium). The aim is to make it possible to condition products from separation.

1.3. New standardised canisters offer new storage or disposal possibilities

Standardisation and new technical solutions form the guidelines for work conducted on canisters since 1991.

Referring to standardisation, the ANDRA and the CEA have developed a rectangular-shaped reinforced concrete cask with four compartments into which can be fitted all existing types of primary packages of intermediate-level long-lived wastes[57]. These packages can easily be handled by their base like pallets and can indifferently be stored or emplaced in disposal sites.

Also cast iron casks should allow six packages of high-level vitrified wastes to be housed. Good impermeability is ensured in them by an electron beam welded steel cover.

The French option to place high-level long-lived wastes in canisters must however also be compared with the Belgian choices (concrete cask surrounded by carbon steel) or with the Swedish or Finnish choices (cast iron and copper cask for spent fuels).

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wastes embedded in bitumen, 55% for technological wastes embedded in blocks of concrete, 20% for cements containing hulls and end-fittings and 5% for vitrified wastes containing fission products and minor actinides. In 1995, the total volume was no longer more than approximately 0.9 cu. m /tU. Embedding in bitumen had been abandoned and the volume of concrete blocks containing technological wastes reduced by a factor of 10. Over the 1996-2000 period, the compacting technique of technological wastes and hulls and end-fittings led to a total volume of low- or intermediate level wastes of 0.7 cu. m /tU.

[57] CDS-C standardised canisters for hulls and end-fittings, CBFC2 canisters, ST3 bituminised sludge drums, EIP over-drums.

A new storage solution for spent fuels is also being developed.

In France, spent fuel storage precedes reprocessing and takes place in a pool in a nuclear power plant or at La Hague, for a four to six year period, to allow radiation and heat to decrease. The aim is to develop a dry storage solution adding flexibility to the management of reprocessing and solving the problem of MOX fuels whose reprocessing cannot be envisaged before several decades.

It is to be noted that Sweden does not perform reprocessing and stores its spent fuels in sub-surface pools at the CLAB at Oskarshamn for approximately thirty years.

A technological demonstrator of a dry storage canister has been made in the form of a cast iron metallic cylinder with four compartments.

Tests must still be performed on the durability of the materials.

2. Conceptual breakthroughs in long-term storage should allow a qualitative leap provided actual facilities are built

Nuclear operators consider that the lifespan of the existing industrial storage facilities, which have generated a high amount of experience feedback, could be easily extended to 100 years, provided safety demonstrations are made.

Nevertheless, long-term storage, the study of which is laid down by the Act of 30 December 1991, requires conceptual and technological leaps in order to be extended to 100-300 years.

2.1. A high amount of storage experience has been acquired

The nuclear sector has already accumulated much experience on the storage of high-level long-lived radioactive wastes[58].

[58] As a reminder, the stocks of spent fuels stored to decrease their radiation in pools at nuclear power plants or at La Hague, represented on 31 December 2002: 10,350 tonnes of fuel of the UOX standard type pending processing; 670 tonnes of fuels of a specific type (enriched processed uranium and MOX) whose processing was not started; 115 tonnes of fuels from the Superphenix breeder reactor, including 60 tonnes corresponding to new fuels not loaded owing to the close-down of this facility in 1997; and 49 tonnes of fuels from the old EL4 reactor at Brennilis. *In*

CDS-V packages of vitrified wastes from the processing of spent fuels are stored at the E-EVT7 facility at the La Hague plant[59]. At end 2002, there were nearly 7000 packages there, representing a volume of approximately 1000 cu. m, installed in double-envelope ventilated shafts for them to cool.

In the same way, the Marcoule centre has a vitrified waste packages storage facility comprising nearly 3000 packages representing a volume of 550 cu. m. placed in ventilated shafts for cooling. The multi-use interim storage site (EIP) at Marcoule also represents an interesting example for intermediate-level long-lived wastes from the cleanup of the Marcoule site.

Lastly, the CASCAD facility at Cadarache consists in dry storage, in shafts ventilated by natural convection, of spent fuels from the Brennilis power plant or from ship propulsion reactors. This storage facility is designed to last 50 years but appears capable of lasting much longer.

Referring to intermediate-level long-lived wastes—hulls and end-fittings from fuel sheaths—they are conditioned in CSD-C packages and placed in the La Hague facility called Entreposage de colis compactés (ECC—compacted packages storage). The STE3 storage hall at the same plant receives, for its part, the packages of bituminised wastes produced from the effluents processed in the STE3 unit. Plans have also been made to store powdery wastes in fibre concrete canisters in the EDT unit.

Dry storage techniques are therefore well proven in France. To design long-term durable facilities, can these well mastered techniques be extrapolated or, on the contrary, is it necessary to start from scratch?

2.2. The still distant aim is to have storage facilities with a 100-300 year lifespan

A 100-300 year lifespan for a storage facility supposes the durability, first of all, of the primary packages of wastes, then, of the canisters, and lastly, of the facilities themselves.

Inventaire national des déchets radioactifs et des matières valorisables, ANDRA, 2004 (National inventory of radioactive wastes and recoverable materials, ANDRA, 2004).

[59] The E/EVT7 unit can be extended close by, thanks to land reserved for this purpose.

Various problems are to be solved for the long term. The overall design of the facility must aim at robustness and passivity. The durability of concretes after a hundred or so years is for the time being an unanswered question. Metal corrosion, for its part, is a better mastered parameter. Heat released by packages can be managed by implementing natural or forced convection, but the management of possible gaseous emissions is a thornier issue. Lastly, the facility must ensure confinement of wastes in all circumstances by appropriate mechanical and chemical systems and it must also offer intrinsic resistance to external aggressions.

The CEA has detailed a sub-surface storage concept for high-level wastes, which appears to meet all the set conditions. Excavated on the side of a hill, this concept is composed of storage modules grouping 6 galleries, in the floor of which are bored 120 shafts of 17 m depth. Ventilation is ensured by the natural circulation of air between the lower ventilation tunnels bringing in fresh air at the foot of the shafts and higher ventilation tunnels ending in chimneys at the top of the hill. A demonstration gallery of a site of this type has been built at Marcoule for the intention of the public.

A concept which appears robust has been achieved but, as the National Assessment Board (CNE) says, in order further to develop it, a practical case corresponding to a specific site must now be addressed.

In short, the gains achieved by research on long-term conditioning and storage are undeniable. Their transposal into actual operational systems will be possible once additional efforts have been made.

IV.- *COMPLEMENTARITY OF THE THREE STRANDS:* RESEARCH WILL OPEN UP COMPLEMENTARY OPTIONS AFTER 2020-2025

When, in 1990, it was a matter of classifying the major fields of research to be performed for radioactive waste management, a distinction had to be drawn between, on the one hand, separation and transmutation and, on the other hand, the storage and disposal of wastes from reprocessing, without any additional operation on their structure or composition.

Quite rapidly, it appeared necessary however to differentiate between long-term storage, an interim solution, and geological disposal, a definitive solution. It also appeared necessary to pay special attention to conditioning, which is of very great importance for safety. As for separation and transmutation, it must shorten the waste management constraint from a few hundred thousand years to only a few hundred.

After fourteen years of research, what are the interactions between the three strands of the Act of 30 December 1991? Can it be envisaged to abandon research on one or several of the strands or, on the contrary, do the solutions corresponding to these three fields all remain essential?

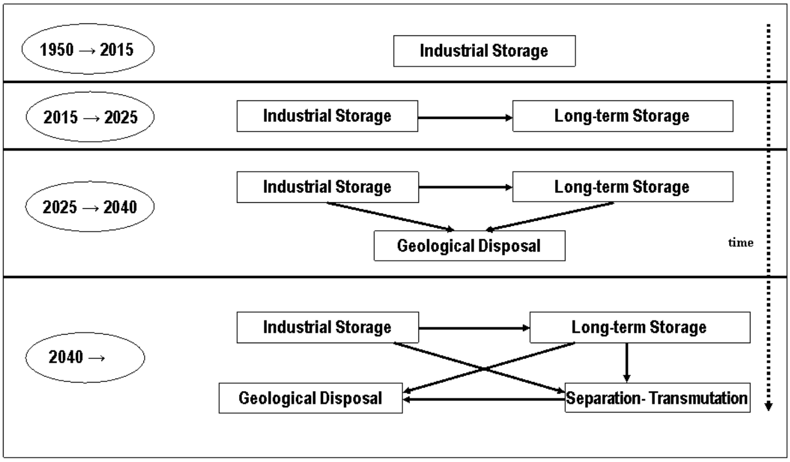
1. An actual solution exists: industrial storage

Since the origins of nuclear power and reprocessing, spent fuels have been stored pending reprocessing, and high-level radioactive wastes have been conditioned for the very long term in vitrified wastes and stored pending a definitive solution.

During the drafting of the bill on research on radioactive waste management, transmutation was proven theoretically but not in practice, and geological disposal was merely a general option without actual detailed studies.

One year before the end of the fifteen year period devoted to research under the Act of 30 December 1991, the feasibility of these management options is very probable and their respective operational start-up schedules are now known.

Diagram 4 : The new radioactive waste management options and their implementation schedule



The Act of 30 December 1991 therefore provides clear answers regarding the availability of the various management methods.

As seen above, possible geological disposal in France cannot enter into service until approximately 2040. In the meanwhile, the only management possibility is storage. From 2020 onwards, the choice will be between storage and disposal.

Finally, after 2040, the three options will be available.

2. Long-term conditioning and storage are pivotal to radioactive waste management but cannot suffice

Long-term conditioning and packaging obviously do not form a minor research strand.

Quite the contrary, progress in this field will serve to strengthen the conditioning techniques already used and will help cross a decisive threshold in terms of storage facility durability. It should be recalled in this respect that the safety level of the industrial storage facilities presently operating is high and that the main challenge of the long term is increasing the longevity of facilities.

In addition to safety, long-term conditioning and storage are essential to optimise in the long run the radioactive waste management system by granting it flexibility.

In particular, the existence of long-term storage facilities is a necessity for non-reprocessed special fuels—irradiated fuels non-reprocessed for the time being and spent MOX fuels whose reprocessing cannot be made until after a long waiting period, higher than the lifespan of industrial storage facilities.

2.1. Research on long-term conditioning and storage is perfecting the safety of the present means

Conditioning on its own puts up three confinement barriers to a possible migration of radioelements into the environment: the matrix, fuel sheath or canister and, lastly, the cask. Conditioning is therefore an essential safety parameter.

Similarly, progress which could result from research on storage can be integrated in the facilities planned for the medium term.

2.2. Long-term storage participates in optimising management

Long-term storage offers flexibility to optimise, in the future, the implementation of advanced separation, transmutation and the definitive disposal of transmuted wastes.

Long-term storage will introduce flexibility in the management of radioactive wastes, particularly by opening up the possibility of the deferred reprocessing of spent fuels, or else by making waiting periods possible, for instance for the cooling of packages of vitrified wastes, before definitive disposal.

Yet long-term storage represents only an interim management solution.

3. Geological disposal, essential today and tomorrow, must be reversible to leave the field open for technical progress

3.1. Storage can be only one step in radioactive waste management

The IAEA and many countries agree in feeling that a definitive solution is essential for high-level long-lived wastes as well as for spent fuels of whatever type, conventional or MOX-based.

From whatever viewpoint it is examined, long-term storage is not a satisfactory solution if the responsibility of the beneficiaries of nuclear power with respect to future generations is considered essential.

The industrial storage experience acquired at La Hague and at Cadarache for high-level wastes or for irradiated fuels with deferred reprocessing, demonstrates that it is possible to reach a satisfactory safety level. But even long-term storage supposes maintenance, surveillance and reconstruction, at more or less close intervals, of the facilities, without mentioning the possible obligation to recondition wastes.

Nor is storage the optimal solution in terms of radiological security, without mentioning safety, which cannot be ensured at the same level as in a geological layer.

These operational burdens for a lesser safety level cannot be transmitted to future generations.

Long-term conditioning and storage techniques must therefore be perfected. It is also necessary to advance towards the setting in place of definitive solutions.

3.2. Geological disposal must, in any case, allow easy retrieval of wastes

Whether it concerns storage, which is reversible per se, or disposal which is reversible upon option, reversibility first of all stands for a technical guarantee against possible deterioration of packages.

It is also a common sense solution because engineering can provide reversibility solutions which can compete, at least to a certain extent, with irreversibility in safety terms.

Lastly, reversibility stands for confidence in the future and in technical progress which in due time will no doubt provide a solution to more or less wipe out waste radiotoxicity.

4. Transmutation is a long-term goal which will not eliminate the need for disposal but will reduce its constraints

4.1. Transmutation will change disposal data by reducing the necessary intake capacities

France has made the choice of reprocessing, in the first place to take advantage of the energy content of the recoverable materials: plutonium formed in spent fuel and uranium not burnt there. By implementing this technique, France has reduced by a factor of five the volumes of high-level wastes.

If France had not made this choice, which has been confirmed since the origin whatever the political majorities, in what terms would the issue of the direct disposal of spent fuels have been raised?

The case of the United States sheds light on this question. The Yucca Mountain reversible disposal project has encountered considerable difficulties. After the site was chosen in 1987, Congress did not make a positive decision until 2002. As for start-up, scheduled for 2010, it does not appear probable before 2015, i.e. 30 years after the first decision. Also, the total expenditure incurred for site selection and development of the sole project stood at 6 billion US dollars at end 2004.

Can it be considered that when Yucca Mountain[60] starts commercial operation it will provide a definitive solution to the disposal of American spent fuels?

According to legislation today, Yucca Mountain's capacity for spent fuels from nuclear power plants is 63,000 tonnes[61], to be compared

[60] In its configuration of 2004, the Yucca Mountain project provides for the excavation of 56 km of disposal galleries and 39 km of access galleries, i.e. a total of 95 km.
[61] 63,000 metric tonnes of heavy metal (MTHM).

with the total of 40,000 tonnes of spent fuels already stored at end 1998 in power plant pools. At the end of their 40-year lifespan, the total amount will reach 90,000 tonnes. As many reactors will probably be licensed to operate up to 60 years, the volume of fuels unloaded will finally reach 120,000 tonnes. If nuclear electricity were to see its market share increase in the future, the United States would then need 21 Yucca Mountains in 2100.

Waste fuel processing, banned for the moment by law in the United States, would provide a solution by limiting the necessary capacities.

In effect, the thermal load of spent fuels makes it necessary to space out their disposal locations in the galleries[62]. In contrast, if fission products were separated and disposed of at the surface, geological disposal could be reserved for actinides whose volumes would be clearly lower. With the transmutation of actinides, disposal needs would be even lesser.

Turning to the French situation, it can be said by analogy that the separation of minor actinides and fission products in the future would lower even more the needs for geological disposal, since it would be reserved for long-lived radioelements. With the additional step of transmutation, disposal needs would be even lesser.

4.2. Because of its limits, transmutation does not eliminate the need for disposal

In the present state of knowledge, it is difficult precisely to determine the exact characteristics of the ultimate wastes of transmutation. Everything however indicates that these wastes will require geological disposal to ensure their safety.

According to the calculations made under the supervision of Professor RICHTER, the number of Yucca Mountain type disposal sites would be slashed from 21 to only one[63] by the transmutation of the long-lived radioelements contained in spent fuels unloaded from American power plants until 2100. However, even with a satisfactory transmutation

[62] During the first 60 years, the thermal load of spent fuel is due mainly to fission products. After 60 years, the thermal load comes from plutonium and minor actinides.

[63] Professor Burton RICHTER, Nuclear Energy Research Advisory Committee, DOE, February 2004.

rate of long-lived radioelements, it would be necessary to set up a disposal site as the lifespans of incineration products is still several hundred years.

According to all probability, disposal will be necessary in the future even if transmutation is industrially operational in around 2040.

But it is also essential for the high-level wastes already produced in 2005. Even if the dissolution of vitrified wastes is technically possible and economically bearable, their retrieval cannot indeed be made until after 2040, there being additional lead times for the dissolution operations of vitrified wastes and for the production of transmutation fuels.

Reversible geological disposal appears unavoidable for the high-level wastes today stored at Marcoule and Cadarache. It will also be a necessity for part of the high-level wastes generated between now and 2040.

Lastly, as the technological and economic unknown factors are low regarding geological disposal, it can be developed as a backup solution if transmutation could not move on to the industrial stage because of major technical and economic obstacles.

Conclusion:

The long lengths of time involved in the nuclear field are stymieing the political decision. However, in this field, the short-sightedness consisting in taking only the market constraint into account must be avoided.

As regards electronuclear production, the period in question is 1950-2050, the timespan between the construction of G2, G3 at Marcoule and the shut-down of the last power plants presently in operation.

As for the radioactivity of high-level wastes, the scale is hundreds of years for fission products and several hundred thousand years for minor actinides.

It was therefore particularly necessary to provide for a long period of research, which the 1991 Act did.

This research demonstrates that the three strands are more complementary than competing, particularly given the period over which they will enter into force. This period will probably be spread over time, disposal being operational in a decade or two and separation-transmutation taking longer to develop.

Permanent technical progress depends on research on radioactive waste management. The funding of research should be ensured in the future, regardless of budget vagaries.

It is our responsibility to set in place as fast as possible operational solutions corresponding to maximum safety.

CHAPTER II – *Political conclusions:* The general principles of a sustainable management of radioactive wastes can be defined by the 2006 Act

According to Article 4 of the Act of 30 December 1991 on research on radioactive waste management, ‘following a period which cannot exceed fifteen years from the promulgation of this Act, the Government shall send Parliament an overall assessment report on this research along with a bill authorising, where applicable, the creation of a disposal centre for high-level long-lived radioactive wastes (…).’

To group and analyse the results of the research they have carried out during the 15 year period, the Act players (CEA, ANDRA, EDF, AREVA) and the research bodies that have cooperated with them (CNRS, BRGM, UMR, etc.) are each going to transmit a summary report of their work some time during 2005. For their part, the Minister delegate for Research and the National Assessment Board shall make an analysis and submit recommendations to the public authorities.

Although the 1991 Act does not provide for the consideration of a bill by Parliament except in the event of the creation of a geological disposal centre, the Rapporteurs feel that, in any case, it is essential that lessons be drawn from the research performed during the fifteen years and that a new Act should prolong the impetus given to research by the 1991 Act and allow practical breakthroughs in radioactive waste management.

In the rest of this report, ‘2006 Act’ shall therefore stand for the future legislation which should be laid before Parliament by the Government in the very first months of 2006 to prolong the dynamic progress started in 1991 in the field of radioactive waste management.

I.- *DISCLOSURE AND DEBATE:* DISCLOSURE ON THE RESULTS OF RESEARCH ON RADIOACTIVE WASTE MANAGEMENT MUST BE IMPROVED AT ALL LEVELS: LOCAL, NATIONAL AND INTERNATIONAL

A debate on any scientific and technical question presupposes that the results of a research process should be available and brought to the knowledge of all the participants.

This remark was made several times by the international participants and especially the Swedes at the hearings organised by the Rapporteurs on 20, 27 January and on 3 February 2005.

The need for transparency also appears in the Act of 30 December 1991 which created two bodies participating in this disclosure mission.

As stated by Article 14 of the Act of 30 December 1991, *'At the site of each underground laboratory, a local disclosure and follow-up committee (CLIS) shall be created.'* The Act also created a National Assessment Board (CNE).

In the same way that the research conducted has been assessed scientifically and technically, an analysis must now be made of the extent to which these bodies created by the Act have reached their aims and if it is necessary to further improve the system.

Lastly, after the creation of many local disclosure and cooperation bodies by legislation and by regulations, the question may be raised as to the relevance of a greater sharing of the acquired institutional experience, leaving aside any question of the creation of a single type of local information committee.

It will also be necessary to examine if additional means can be employed in the future to improve the conditions of democratic debate by further improving disclosure on research on radioactive waste management, particularly by greater participation of the Act players in this essential mission.

Considerable progress has undeniably been made by the Act players/producers of wastes (EDF, CEA, AREVA), research bodies

(CEA, CNRS, universities), Parliament, public authorities, territorial authorities and stakeholders, to improve the disclosure of their work, but additional efforts are necessary.

1. The CLIS at the Meuse/Haute-Marne laboratory must operate in keeping with the mission it was assigned by the Act

The Bure local disclosure and follow-up committee (CLIS) was created pursuant to the Act of 30 December 1991. For several years, it may have moved away from the operation set forth by the Act but since a short while appears to have returned to practices more in conformity with its mission[64]. The time lost in this respect is to be regretted; improvements to be made to this structure are to be examined.

Several deviations from the Act have been observed in the operation and in the structure of the CLIS.

The Act assigns the presidency of the CLIS at the Meuse/Haute-Marne laboratory to the prefect of the Meuse. The efficacy of the presidency of the CLIS has been shown to be defective on several occasions and in several fields.

While the Act neither provides for nor bans the creation of a vice-presidency, it appears that the election of its first incumbent did not take place in satisfactory conditions. Also, parliamentary participation has not been managed so as to ensure an effective presence, some parliamentarians having even renounced participating.

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[64] Article 14 continues as follows: ‘this committee shall comprise in particular: representatives of the State, two Members of Parliament and two Senators, appointed by their respective assembly; elected representatives from the territorial authorities consulted on the occasion of the public inquiry; members of environmental protection associations; agricultural unions; representatives of professional organisations; and representatives of personnel working in connection with the site as well as the license holder.

This committee shall be composed, for at least half, by elected representatives from the territorial authorities consulted on the occasion of the public inquiry. It shall be presided by the prefect of the department where the laboratory is located.

The committee shall meet at least twice a year. It shall be informed of the aims of the programme, the nature of the work and the results obtained. It can refer matters to the National Assessment Board mentioned in Article 4.

The committee shall be consulted on all questions relating to the operation of the laboratory having effects on the environment and neighbouring communities. It can hold hearings or get second expert opinions from approved laboratories.

The establishment and operating costs of the local disclosure and follow-up committee shall be borne by the alliance set forth in Article 12.

Also some meetings have been marked by sitting incidents, indicating a sometimes defective organisation, and by untimely changes in the agenda, reproved by many speakers invited to speak before the assembly. The poor climate of the meetings has finally dissuaded many members of the CLIS from participating in it, leaving the field open to the sole opponents of the laboratory.

All in all, for too long a period, the CLIS was transformed into a body where only the opponents to the laboratory expressed their views, instead of playing its disclosure and debate role. During their meeting with the members of the CLIS bureau on Friday 3 December in Bar-le-Duc, the Rapporteurs noted a worrisome lack of disclosure on strands 1 and 3 of the 1991 Act research.

Today, a vice-president more representative of the population and of the elected representatives has been appointed. The president of the CLIS, for his part, has been notified of the importance of his role for the correct operation of this body. But precious time has been lost for serious and above all dispassionate consideration of the questions posed by the construction and operation of the laboratory.

Lastly, the conditions in which a second expert's counter-report was commissioned from an external body raise various questions on the amount of the contract and the method of obtaining candidatures, which was not very effective since only one appears to have been recorded, that of the IEER, which was awarded a contract of a very high amount[65]. The IEER (Institute for Energy and Environmental Research), a North-American body, admittedly has a broad corporate name but in fact specialises in proliferation and plutonium, which is only somewhat related to the issues of the safety of an underground laboratory[66]. The choice made may therefore indeed appear surprising, whereas geology and safety specialists are not lacking in Europe and in the United States. Also, unlike other external assessments of the work by the ANDRA, the

[65] 180,000 €

[66] The IEER's website states: 'The Institute for Energy and Environmental Research (IEER) began work in 1987. Our focus has been mainly on two areas: ozone layer depletion and energy-related climate issues; and environmental and security aspects of nuclear weapons production and nuclear technology. To that end, IEER has: evaluated releases of radioactive materials into the environment near nuclear weapons plants; assessed the global health and environmental effects of nuclear weapons and testing; provided technical support to grassroots groups concerned with the effects of nuclear weapons production; conducted many technical training workshops on nuclear-weapons-related issues for grassroots activists; and initiated national and international outreach and education on plutonium disposition.'

IEER report was not submitted to a peer review—the international standard. By taking care, by means of its various reports, to ensure sufficient funding, Parliament did not however desire lax use of public funds.

Generally speaking, it lies with the public authorities to ensure that in the future the mission assigned to the CLIS is scrupulously respected.

The bill on transparency and safety in nuclear matters[67], tabled with the Bureau of the Senate, gives in its Article 6, a legislative status to local disclosure committees (CLI – commissions locales d'information). According to the governmental text, *'at any operation site of one or several basic nuclear facilities, a local information committee shall be set up with a general disclosure and assessment mission concerning nuclear safety and radiation protection relative to said facility.'*

As it is not a basic nuclear facility, the Meuse/Haute-Marne facility is not concerned by this provision. However, in any case, the specific nature of the CLIS should not be changed in a period when it is more necessary to ensure its correct operation than to drastically alter its structure.

2. The term of the National Assessment Board (CNE), which has played a largely positive role, should be extended

Article 4 of the Act of 30 December 1991 set up a National Assessment Board (CNE) tasked with establishing each year a report which the Government sends to Parliament and which relates the progress of research conducted in France on the management of high-level long-lived wastes as well as that of research and developments abroad.

The CNE is composed of: six qualified personalities including at least two international experts, appointed on an equal footing by the National Assembly and by the Senate, on proposal by the Parliamentary Office for Scientific and Technological Assessment; two qualified personalities appointed by the Government, on proposal by the Higher Board for Nuclear Safety and Information (Conseil supérieur de la sûreté

[67] Projet de loi no. 326 (2001-2002) relative à la transparence et à la sécurité en matière nucléaire, recorded at the Presidency of the Senate on 18 June 2002.

et de l'information nucléaire); and four scientific experts appointed by the Government, on proposal by the National Academy of science (Académie des sciences).

Set up in April 1994, the CNE published its first report in June 1995 and its tenth report in June 2004. Its global assessment report is expected in 2005 and will accompany, according to the terms of the Act, a bill authorising, where applicable, the creation of a high-level long-lived radioactive wastes disposal centre.

Tasked mainly with drawing up each year the results of research, for the intention of the Government and Parliament, the CNE has brilliantly accomplished its role and has in addition become a stimulator of the Act players and a source of inspiration for research orientations, given the eminent qualifications of its members.

Such an evolution of its role was only natural and is also found in the operation of the similar body in the United States, the US Nuclear Waste Technical Review Body (NWTRB).

The CNE's existence is related to the 15-year research period of the 1991 Act, and should now be extended beyond 2006.

3. Disclosure made by the Act players should be still further improved

Several players of the research pursued under the Act of 30 December 1991 have significantly increased their disclosure effort in recent years.

The document *'Stratégie et programmes des recherches'* (Research strategy and programmes) drawn up under the Act of 31 December 1991 is a summary report of the work by the follow-up committee on research on the back end of the cycle (COSRAC – Comité de suivi des recherches sur l'aval du cycle) and is prepared by the Minister delegate for Research. This annual document drawn up in cooperation with the Act players provides technical information. It can be regretted that educational presentations have not been drawn from it. The same remark also applies to the reports by the CNE.

The main player of strands 1 and 3, the CEA has only recently launched a policy of public information, of a considerable scale. Since

2002, a special issue of its magazine, Clefs, on radioactive wastes has been published along with well-informed pages on its website. Also, in April 2005, the Visiatome centre is scheduled to open at Marcoule, providing information to the public[68].

The ANDRA, for its part, has made a remarkable contribution to the transparency of information on radioactive wastes by establishing the national inventory of radioactive wastes and recoverable materials, published at end 2004. Also, a visits policy has been set in place at the disposal centre in La Manche at Beaumont-Hague, the Aube disposal centre at Soulaines-Dhuys, the very low-level wastes disposal centre at Morvilliers in Aube, as well as at the Meuse/Haute-Marne underground research laboratory at Bure. At each of its sites, buildings receiving the public have been constructed and guided visits set in place.

Once the underground laboratory has been set up, public visits must be organised.

In this respect, the underground laboratory at Aspö in Sweden forms a model of interaction with the public. Located at a depth of 460 m, this laboratory serves above all to test all the technologies which will be used in the construction and operation of the future granite geological disposal site. Several thousand people visit this facility each year[69].

Also, following the example of the very broad dissemination which the Swedish SKB makes of its future triennial research programmes, the ANDRA could broaden even more the information it provides on its needs and its research results, so as to make the national or international scientific community even more aware and in order to increase the number of those responding to its invitations to tender.

To improve even more the information of the public, numerical technologies provide new real time or close-in-time possibilities. Following the example of what was done for a while at the La Hague facilities, the placing in service of a webcam at the Bure site, and at the site of the Phenix reactor or in the laboratories at Marcoule, would demonstrate what work is actually done. Also an annual audiovisual appraisal should also be made for each of the three strands and placed on line on the websites of the Act players.

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[68] The Visiatome at Marcoule is a *'discovery and information centre on radioactivity and its evolution.'*

[69] Construction of the Aspö laboratory started in 1990 and was completed in 1995.

Lastly, it is essential that the 1991 Act players organise regular communication with the elected representatives of the territorial authorities concerned by research on separation-transmutation (Languedoc-Roussillon and Provence-Alpes-Côte d'Azur regions [Gard and Bouches-du-Rhône departments]), geological disposal (Champagne-Ardenne and Lorraine regions [Haute-Marne and Meuse departments]), and long-term storage (Languedoc-Roussillon and Provence-Alpes-Côte d'Azur regions [Gard and Bouches-du-Rhône departments]).

4. The National Public Debate Committee (CNDP) has been set up to address actual construction projects, which are premature for the time being

Before debating a scientific and technical subject, it is necessary to have validated results on which the discussion can take place. The fifteen years of research pursuant to the Act of 30 December 1991 provided their crop of results. However the Rapporteurs have observed that they are very insufficiently known by all the stakeholders.

As previously seen, disclosure on research results is an essential step, particularly as regards elected representatives and populations concerned by wastes management: Marcoule, Cadarache, ANDRA disposal centre, and Meuse/Haute-Marne laboratory. This disclosure is cruelly lacking. The first task of the public authorities is to ensure they strengthen its provision as a matter of urgency.

Referring to public debate, the Act of 27 February 2002 on local democracy has introduced new possibilities based around the Commission nationale du Débat Public (CNDP – National Public Debate Board).

According to Article 134 of the Act, *'the CNDP, an independent administrative authority, is tasked with monitoring the public's compliance with participation in the process of the elaboration of construction or equipment projects in the national interest by the State, territorial authorities, public establishments and private persons, which come under categories of operations whose list is determined by decree at the Conseil d'Etat, provided they present high economic stakes or have significant impacts on the environment or spatial development.'*

Public debate entrusted to the CNDP must therefore be centred on an actual construction project.

Therefore a referral by the Government to the CNDP on *'general options regarding the management of high-level and intermediate-level long-lived radioactive wastes'* does not correspond to the CNDP's purpose, insofar as that is a general debate on a general issue and not on a construction or equipment project in the national interest.

It should be observed in this respect that the CNDP's intervention regarding a specific project for the construction of a disposal site, which alone would be in keeping with its purpose, would be premature since research on the confinement properties of Bure clay is not completed. It should also be remembered that a national debate was organised in 2003 on energies, and nuclear issues were largely addressed then.

In accordance with the 1991 Act, it lies with Parliament to conduct a debate on the general principles of wastes management in France. These general principles alone can be covered by the 2006 Act. This debate must remain an eminently political debate conducted by the Representatives of the Nation.

Only Parliament has the legitimacy to conduct a debate on the question of national interest represented by the pursuit of studies on facilities related to radioactive waste management: Generation IV fast reactors, accelerator-driven subcritical reactors, geological disposal, long-term storage.

II.- *RESEARCH:* PARLIAMENT MUST CONTINUE TO INSTIGATE RESEARCH ON THE THREE STRANDS AND SET TIME MILESTONES FOR IT

Over the 1992-2002 period as a whole, the financial and budget resources allocated to research on radioactive waste management, pursuant to the Act of 30 December 1991, amounted to 2.224 billion €, of which 33% for strand 1, 39% for strand 2 and 28% for strand 3[70]

[70] Stratégie et programmes de recherches sur la gestion des déchets radioactifs à haute activité et à vie longue (Research strategy and programmes on the management of high-level long-lived radioactive wastes), Technology Directorate, Ministry delegate for Research, 2003 edition.

As seen in chapter I, considerable progress has been accomplished in knowledge on radioactive wastes and in the methods applying to their management, even if, in most fields, research is still incomplete.

The finalisation of research is therefore essential. Consequently, priority research orientations for the years ahead must be identified and it must be determined whether the financial and human resources of the past period are sufficient or must be strengthened.

It must also be determined in what direction the purview of the Act of 30 December 1991, whose contribution has never been challenged, could still be improved within the framework of the 2006 Act.

1. Research on separation and transmutation must be pursued in cooperation

The degrees of progress in research on separation, on the one hand, and transmutation, on the other hand, are undeniably very different. For separation, it would be possible, at end 2005, to speak of technological demonstration at almost industrial scale by 2015-2020 if the industrial investments could be envisageable by then. In contrast, the date of industrialisation for transmutation is much more distant as it is related to the development of a new generation of nuclear reactors or a new system concept.

In any case, the funding requirements for research in the two fields are very high in the future, whether it be a matter of current expenditure or investment expenditure. Cooperation between national research bodies and international cooperation must therefore be strengthened.

1.1. The industrialisation of advanced separation requires heavy investments which could however generate disposal savings

During the year 2005, the CEA is going to test, on a kilogramme scale, the separation methods is has developed on the gramme scale. To do so, the world-unique Atalante facility can suffice.

To eventually implement on an industrial scale the separation techniques building on the present techniques, some experts feel that an additional plant of the type of the UP3 plant at La Hague should be constructed. However, for economic reasons, it appears inevitable to wait for the refurbishment of the La Hague facilities in around 2040, in order to implement the separation of minor actinides and fission products which would then be integrated in the processing-recycling process.

In any case, the investment corresponding to the implementation of separation could be partly funded by the resulting savings as regards disposal.

The parameter determining the size of an underground disposal site is in effect thermal load. If waste packages release much heat, they must be spaced out so that the rock is not damaged by the rise in ambient temperature. On the contrary, if their thermal load is low, waste packages can be stored side by side, which decreases the size of galleries.

It should be noted that, for three hundred years following the unloading of spent fuels, two short-lived radioelements, cesium and strontium, are responsible for most of the thermal load. Advanced separation could allow deep disposal to be reserved for minor actinides and long-lived fission products. Short-lived fission products (strontium and cesium) could, on the contrary, be stored at the surface at far lesser cost.

1.2. The programmed shut-down in 2008-2009 of Phenix will complicate research on transmutation

Playing a key role in research on transmutation, the Phenix fast reactor will however have to be shut down in 2008, which raises the problem of the availability of replacement instruments to continue research in this field.

Of a nominal power of 250 MWe, the Phenix sodium-cooled fact reactor located at Marcoule, began commercial operation in 1974. Burning a plutonium- and uranium-based fuel, this reactor, which has a very compact heart of one cubic metre, allows the irradiation, for test purposes, of fuel matrixes as well as of radioelements regarding which it is desired to study their capture or fission (breaking apart) behaviour under the action of fast neutrons. Phenix is currently playing in France an essential role for the strand 1 experiments pursued under the 1991 Act.

Phenix was shut down from 1994 to 2003 for renovation and safety re-assessment work which cost 250 million €.

It has been demonstrated that the sudden stops in the reactor that were recorded before modernisation could not have resulted from positive reactivity[71]. Also, thanks to considerable technological progress allowing the sodium opacity obstacle to be overcome, the reactor safety examination could take place properly. New methods of monitoring structures by ultrasounds and by optics have been successfully developed and, by examining the vessel, it could be demonstrated that it complied with seismic rules in force.

Operational safety was ensured, so the DGSNR (Direction générale de la sûreté nucléaire et de la radioprotection – General directorate for nuclear safety and radioprotection) authorised Phenix to start up again in 2003 on the basis of a maximum power of 145 MWe—lower than the nominal power—corresponding to the use of two cooling loops out of three. However, Phenix's activity is limited to six last operating cycles before definitive shut-down of the facility.

The end of the first of these six cycles was in August 2004, following an operating phase during which the reactor availability rate was 94%. At end 2004, ten transmutation experiments were under way in the heart of Phenix and there was also much international cooperation with the United States and Japan.

Phenix's last cycle is scheduled for the beginning of 2009 when expert evaluation of the facility and its dismantling shall commence.

As for a possible prolongation of Phenix's activity, the modernisation costs and those entailed by re-assessing safety, in other words bringing Phenix into compliance with the levels which would be required of a new facility, would be prohibitive.

To continue transmutation experimentation after the shut-down of Phenix, the CEA plans to make use of international cooperation. It intends to access the Japanese fast neutron reactor at Monju, provided

[71] The most plausible explanation is the stacking of fuel assemblies at the heart causing the machine to automatically stop.

the latter has started up again and is in operation at the end of the decade, or else the Russian reactor BN-600.

However will these two reactors indeed be operational in 2009, will they be accessible to international cooperation, and will making use of machines located on the west coast of Japan, at Tsuruga, or in Russia, at Beloyarsk in Western Siberia, present the same flexibility as that of a reactor at Marcoule?

1.3. Transmutation by Generation IV reactors requires intense international cooperation

Launched at the initiative of the US Department of Energy (DOE), the Generation IV International Forum, which groups ten countries[72], has already managed to select six priority families for the development of nuclear power with 2040 in mind.

The rules of international cooperation for precompetitive research in this field are based on a sharing of intellectual property in proportion to the R&D contributed. They were adopted in 2004, meaning that an inter-governmental agreement should be signed some time in 2005. It should also be possible to transpose these rules to the construction of a demonstrator.

Yet the financial effort to be made for the development of six families is enormous and the burden for a given country will be all the higher if its choice is less shared with others.

France, for its part, is focussing on the family of gas-cooled fast neutron reactors, which appears to be one of the most promising for commercial electricity production and for the reduction of radioactive wastes thanks to the simultaneous transmutation of minor actinides in electricity producing reactors.

The CEA has the best scientific and technical assets to be the world leader of this technology. Its budget must however allow it to be dynamic in the fission field which should not suffer from the efforts made in the fusion field (ITER). In any case, joints efforts are required

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[72] Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, Switzerland, United Kingdom, United States.

on the part of the State, the national producer of reactors, AREVA, and the producer of nuclear electricity, EDF.

Another condition, intense international cooperation will have to apply around gas fast reactors. If, owing to its potential industrial applications not only for the production of electricity but also for thermochemistry and the production of hydrogen, the family of very high temperature reactors (VHTR) were to win the day, it would then be necessary to reconsider the present French priorities for tomorrow's nuclear energy, presently focussed on gas fast reactors.

1.4. The building of a European ADS demonstrator is a goal to be taken further

As previously seen, accelerator driven systems are of special interest to their designers regarding waste transmutation. What avenues should be taken in the future for the development of this technology?

Grouped within the European programme EUROTRANS, the ongoing design work must not only be finalised but must also lead to practical tests, which only a complete ADS model will allow.

The TRADE project proposed by ENEA (Italy) with support from the CNRS, the CEA, and ANSALDO, had the interest of addressing, from the safety angle, the study of the dynamic behaviour of a subcritical nuclear reactor connected to an accelerator. It was a matter of checking the extent to which a subcritical reactor can be operated in an entirely safe manner from start-up to shut-down, particularly despite the connection—which had in fact never been tested—between an accelerator and a nuclear reactor and despite the retroaction effects of thermal neutrons. This project has unfortunately been abandoned by ENEA which was to propose its 1 MW_{th} power TRIGA research reactor connected to a commercial cyclotron.

The horizon in Europe, and even worldwide, is therefore represented by the MYRRHA project borne by the SCK-CEN (Belgium) and supported in France by the CNRS, which has recently announced the creation of a partnership with the latter, by the CEA and EDF.

The MYRRHA project is an intermediary demonstrator of a 50 MW accelerator-driven subcritical system, with an estimated cost of 500 million € over 10 years.

The technical feasibility of this machine is being studied by many international, European or American teams. Its financial feasibility could be envisaged with support from the European Union within the EURATOM framework.

The remaining questions, particularly on the power of the machine which various experts feel would be too high for a first practical ADS facility, must be answered before investment is launched.

All in all, the financial effort made in strand 1 by waste producers, pursuant to the polluter-payer principle, represents on average 66 million € per year.

Precise programming of research activities will be essential in the years ahead. In any case, the CEA and the CNRS will have to acknowledge that transmutation has high ranking priority. Wide-scale international cooperation is essential but cannot exempt France from making a major effort.

2. Demonstration of the safety of the performances of geological disposal must continue for longer

At end November 2004, the experimentation chamber at - 445 m in the Bure argillite layer was made available to scientists, marking a clear acceleration in the acquisition of knowledge on this layer. Experiments started from the surface by the study of drilling cores and were continued by measurements made during the excavation of the shafts. The aim is to obtain a precise understanding of all the mechanisms determining the safety of a possible disposal site.

Applying and completing international recommendations, especially those of the ICPR (International Commission on Radiological Protection) and the IAEA, French regulations on the safety of geological disposal is already precisely defined. Fundamental safety rule no. III.2.f defines *'the goals to be adopted for the study and work phases for the definitive disposal of radioactive wastes in deep geological formations in order to ensure safety after the disposal operation period.'* Rule no. III.2.f specifies the fundamental safety goal of disposal[73], the safety-

[73] Regarding radioprotection criteria, fundamental safety rule no. III.2.f states: *'individual dose equivalents shall be limited to 0.25 mSV/year for prolonged exposures resulting from certain or very probable events (...)'; 'assessments shall be based on a modelisation of the evolution of disposal, particularly of barriers, and on a modelisation of the circulation of underground waters*

related design bases of disposal, and the methodology of the demonstration of disposal safety.

The very precise directives of the fundamental safety rule make a detailed demonstration necessary, which will require a set of complex measurements and engineering studies. The ANDRA's scientific and technical programme is aimed at this goal and will grow richer with the experimentations and counter estimations.

As previously seen, the Local Disclosure and Follow-up Committee (CLIS) at the Meuse/Haute-Marne laboratory had a study carried out by the American institute, the Institute for Energy and Environmental Research (IEER), which sent it its report in December 2004, on the basis of the scientific results obtained until September 2004. Examining seven major issues[74] related to the safety of a possible disposal site, the report emphasises various scientific and technical questions important for safety and recommends great attention be paid to them.

Therefore, according to the study, fundamental knowledge will have to be considerably increased as regards rock mechanics and the influence of the thermal load of wastes packages on their properties. The report underscores the importance of studies of the fractured EDZ (excavation damaged zone), of the coupling of caused fractures with natural fractures, and of the consequences of the possible production of gases in these fractures. Similarly, the sealing of disposal galleries is deemed to be decisively important for safety. Lastly, the report draws attention to the increased safety which could result from a revised design of waste canisters, bearing in mind the uncertainties introduced by the damaged zone.

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and of the transfer of radionuclides'; 'for a period which shall be equal to at least 10,000 years, the stability (which covers a limited and foreseeable evolution) of the geological barrier must be demonstrated'; 'beyond this stability period of the geological barrier, uncertainties as to the stability of the disposal site increase progressively with time; the radiation level of wastes will have considerably decreased. Majorant quantified estimations of individual dose equivalents shall then be made. They shall possibly be completed by more qualitative appreciations of the results of these estimations, with regard to the evolution factors of the geological barrier so as to check that the release of radionuclides does not lead to an unacceptable individual dose equivalent.'

[74] Chapter I: Dose rules and scenarios (including climate change) - Chapter II: Rock mechanics - Chapter III: Thermal aspects and the construction of burial structures - Chapter IV: Source term and near field - Chapter V: Hydrogeology - Chapter VI: Mineralogy and geochemistry of the host formation - Chapter VII: Seismology and deformation.

Anyway, it is obviously planned that the ANDRA will answer these questions, which in any case form only part of its study programme.

The completion of the auxiliary shaft and the start-up of excavation of the link gallery will complete the chamber at - 445 m and will increase the possibilities of scientific or technical experimentation in the months ahead.

Despite the acceleration of in situ studies, it is however clear that the year 2005 will not suffice to obtain all the necessary results. It will be necessary to plan a prolongation of the period to gather data required by safety assessment. This period may also be used to perform the geological characterisation of all the zone and carry out the necessary technological demonstrations for reversibility and the handling of packages.

Over the 1992-2003 period, strand 2 research expenditure amounted on average to 80 million € per year. It would be surprising if the amount of necessary expenditure decreases significantly in the next ten to fifteen years before the possible opening of a disposal centre at Bure.

3. The demonstration of long-term subsurface storage should be made rapidly

During the presentations made to the Rapporteurs on 16 and 17 December 2004 at Marcoule and Cadarache, as well as during the public hearing on 3 February 2005, two concepts were presented for surface or subsurface storage, on the one hand, of spent fuels or high-level long-lived wastes and, on the other hand, of intermediate-level long-lived wastes.

Referring to the storage of intermediate-level long-lived wastes, several parameters were identified as particularly important. A concrete canister that can receive four primary packages has been developed using a high-performance concrete guaranteeing its resistance over time and ensuring the evacuation of radiolysis hydrogen[75]. Despite the precautions taken, a concrete canisters surveillance strategy must be established. Also, will passive natural ventilation suffice to ensure, on the one hand,

[75] This container also serves as the basis for the design of reversible geological disposal.

the evacuation of gases possibly emitted by wastes and, on the other hand, a sufficiently low hygrometry?

Insofar as these parameters depend on the natural medium, it appears essential to build an actual facility, which should be technically possible given the sums allocated to research in this field.

The subsurface concept presented refers to a hill-side structure. To increase the siting possibilities, it appears preferable to replace it with shallow storage. This way, various large-surface nuclear sites, such as various CEA research centres, could be the site of the subsurface storage required by management of intermediate-level long-lived wastes in France.

The amount of financial resources allocated to strand 3 (long-term conditioning and storage) stood in all at 724 million € over the 1992-2003 period, in other words 66 million € as an annual average.

In the future, the same amount could be allocated to strand 3, for the time necessary to build the subsurface storage facility. The corresponding sums could then be allocated for their greatest share to strand 1 research, bearing in mind the investment needs for fast reactors and ADS, and to strand 2 to complete the studies on geological disposal.

4. Parliament should continue to instigate research and set time milestones to analyse the results

According to all the experts and all those heard at the public hearings on 20, 27 January and 3 February, the Act of 30 December 1991 has played a decisive role in the development of research on radioactive wastes in France.

The mechanisms of the Act have proven their efficacy at all levels.

The 1991 Act formalised research on radioactive wastes, which undoubtedly contributed to it being conducted successfully. State subsidies and funding from waste producers were awarded without too much difficulty, which meant that research programmes took place smoothly. Therefore research should be pursued within the framework of legislation.

The differentiation of research into three major fields clarified the goals pursued, while allowing well defined responsibilities to be assigned to the various research bodies in question. This classification should be continued for the same reasons.

The setting in place of a rendezvous in 2006, after 15 years of research, for a global assessment of the latter, has also proved to be a very useful mechanism.

In the future, however, closer time milestones could be imagined to analyse the results obtained.

Dates could be imagined in this respect based on the schedule of the most important decisions concerning the three research strands. On these dates, the Government could send a specific information report to Parliament.

These specific reports would complete the annual report which the National Assessment Board would continue to send each year to Parliament through the Parliamentary Office, as laid down by the 1991 Act.

Also, the 2006 Act could provide for an automatic referral to the Parliamentary Office for Scientific and Technological Assessment every two years for it to examine the progress in research.

Lastly, as stated by several directors of research bodies, it would be useful to draw the lessons of the operation of research alliances (GdR) in order to revamp or modify their status so as to broaden and facilitate cooperation possibilities between public or private research bodies.

III.- *SPIN-OFF:* LOCAL AND NATIONAL EXPLOITATION OF THE 1991 ACT RESEARCH IS A FIELD TO BE TURNED TO ACCOUNT AT THE SCIENTIFIC, UNIVERSITY AND INDUSTRIAL LEVELS

The scale of research investments made for wastes management (2.2 bln € over the 1992-2003 period) and the high technical level of the results obtained require their local and national exploitation from a scientific and technical viewpoint and also from a university and industrial angle.

1. The exploitation of research is a priority at the facilities of the most advanced countries

As previously seen, Finland's geological disposal site will be located on Olkiluoto peninsula in the borough of Eurajoki, 220 km to the northwest of Helsinki. On the edge of the Baltic Sea, this is a highly industrialised region.

The town of Rauma, located approximately 20 km from the site, is one of the main centres of the paper industry worldwide. Also, two BWR reactors have been operated since 1979 and 1980 at Olkiluoto, where the EPR is being built and is scheduled to start-up in 2009.

Finnish geological disposal will therefore be situated in an area with high industrial activity where the disposal site will form merely one additional facility. Also the Olkiluoto nuclear power plant possesses, in its precincts, its own subsurface disposal site for low- or intermediate-level wastes from its operation.

The very favourable context of the future disposal site and the already real economic spin-off of nuclear energy do not prevent the company POSIVA Oy, tasked with wastes management, from planning to locate there an additional activity, namely the construction of a containerisation plant close to the Olkiluoto disposal site, which is programmed for the 2012-2020 period at the same time as the construction of the geological disposal site.

The same approach will probably be adopted in Sweden.

Two sites, it is known, are still competing for geological disposal, the Osthammar zone and that of Oskarshamn. The Oskarshamn zone comprises the nuclear power plant with three boiling water reactors operated by the company OKG AB, as well as the CLAB, a spent fuels subsurface storage site. The Aspö underground laboratory has also been built close to Oskarshamn. In addition, an encapsulation laboratory where canister welding methods are being developed, has also been built at Oskarshamn. Lastly, among the sites studied for the siting of the spent fuel containerisation plant, Oskarshamn appears particularly well placed.

2. Research on each of the three strands must be exploited at the place where it was performed and further afield

As recalled above, 724 million € were spent on research on separation-transmutation over the 1992-2003 period and 888.5 million € for research on geological disposal. This research must be exploited to benefit the national economy and also the French departments concerned.

As for the level of the technologies employed, radioactive waste management is equally advanced as the nuclear power industry. The disposal sites of very-low or low- or intermediate-level short-lived wastes are presently operational and implement high-level techniques and organisation methods.

Considerable gains have also been made within the framework of the 1991 Act research as regards the scientific and technical progress made in various fields: synthesis or chemical separation methods, design of nuclear fuels, geological exploration or dating methods, modelisation of complex systems, and transmutation or reversible disposal engineering. The corresponding know-how can be transposed into other industrial fields and must be transmitted by higher education.

The scientific, university and industrial development of the departments where research on radioactive wastes is performed is a necessity in order to make research pay and also to show national solidarity with regard to the local populations concerned who are entitled to something in return for their contribution to solving a matter of national interest.

In this respect, two examples in France can be mentioned. In the Gard and Bouches-du-Rhône departments, there is a strong logic to develop activities based on research performed under the 1991 Act. These departments have had nuclear research facilities or nuclear power plants for a long time and so, at Marcoule or Cadarache, there does not appear to be any psychological obstacle to the exploitation of research investments. In contrast, bearing in mind their very recent involvement in the nuclear field, the Haute-Marne and Meuse departments must benefit from voluntaristic activities for scientific, university and industrial development which, on the one hand, take account of the desires already clearly expressed and the projects already devised by the local authorities and, on the other hand, are based on strong initiatives taken by the State and nuclear operators.

2.1. Strand 1 research is currently being exploited at Marcoule

The research on separation performed by the CEA at Marcoule required major progress in the synthesis of new molecules that can be used for extraction. Thanks to the development of molecules resisting radiations and capable of differentiating radioelements—minor actinides—with very close properties from one another, considerable know-how has been acquired in molecular synthesis, extraction techniques and process engineering.

A national separative chemistry institute is therefore being created at the Marcoule site by the CEA in conjunction with the CNRS and the University of Montpellier. As a chemistry cluster already existed in the Languedoc-Roussillon region, specialisation appeared to be the best avenue. Various industries—for instance pharmaceuticals, cosmetics, and perfumery—which make particular use of molecular synthesis and extraction techniques, may find in this new institute a useful partnership for their development.

2.2. Scientific and technological clusters must be created around the Meuse/Haute-Marne laboratory, with the essential aid of waste producers

In cooperation with the Universities of Troyes and Nancy, an approach of the same type has been launched by the ANDRA with regard to the Meuse/Haute-Marne laboratory so as to take advantage, for scientific purposes, of the know-how implemented or developed in the construction and, soon, the use of this laboratory. A multitude of projects was proposed at the outset. Following a prudent and responsible approach, four, then three scientific and technological cluster projects were finally selected to exploit the gains from research in a prospective and dynamic manner.

The first validated project concerns the creation of an underground experimentation centre at a depth of 100 to 200 metres. For use by underground excavation professionals and managers of underground premises, this centre would allow equipment to be tested and specialists to be trained. This project has received the backing of a Ministry and EDF.

The second project is for the creation of a technological demonstrator monitoring waters by continuous measurements made by optical fibres. This project met with the interest of the company Schlumberger.

The third project relates to the creation of an ecological data bank grouping samplings taken during the creation of the laboratory.

These are ambitious projects for the scientific, technological and university development of the Meuse, and their costs appear reasonable. The aim of the promoters of these centres is that they should have regional and national, and even European influence.

Financially speaking, it is essential and normal that the major operators of the nuclear sector contribute to their funding. The directors of public interest groups (GIP – groupements d'intérêt public), in particular, feel that it is does not lie with them to fund the studies relating to their creation. Moreover, the French departments are not structured to ensure the prime contractorship of such projects.

Also, the Lorraine region intends to grant a priority place in its technological development to energies, materials and nanotechnologies. For its part, the General Council of the Meuse has recently chosen biofuels, new materials and mechanics.

To decide between the orientations of the Lorraine region and those of the Meuse department, only the State appears to have the necessary authority and means.

2.3. Radioactive waste management, by its high technological level, must have a dynamic effect on the economy

The Act of 30 December 1991 laid down financial and economic accompanying measures for the siting of the Meuse/Haute-Marne laboratory[76]. The structures created for this purpose—a public interest

[76] Article 12 of the Act of 30 December 1991 sets forth that: *'a public interest group can be set up in the manner laid down by Article 21 of Act no. 82-610 on orientation and programming for technological research and development in France, with a view to conducting accompanying*

group (GIP) per department—operate well in the Haute-Marne and in the Meuse and participate usefully in equipping them with infrastructures. However, it is essential to go beyond the strict aspect of financial aids in order to trigger the dynamics of economic development made possible by the high technological level of radioactive waste management.

On the basis of an amount of resources of 58 million € over the 1999-2006 period, the Haute-Marne GIP shares its aids between aid for local development (20% of the total)[77], participation in major projects (30%)[78], and aid for economic development (50%)[79]. According to the constitutive convention of the GIP Objectif Meuse, 20% of the accompanying package is allocated to activities in the zone close to the laboratory and 80% is spread over the department. The contributions by the ANDRA have been received on time, unlike those of EDF.

In any case, the resources of these two GIPs must evolve towards a resource of the professional tax type[80].

Three *cantons* (territorial units)—two in the Meuse and one in the Haute-Marne—have also benefited from the *Grand Chantier* procedure, which has led to a programme of developments amounting to approximately thirty million €[81].

Besides, it has been laid down by the Government that each of the GIPs shall receive an annual amount of 9.15 million € over a 15 year period[82]. These sums must be paid. In any case it is necessary to ensure continuity of the financial accompanying measures for the laboratory for fifteen full years, irrespective of the rise in taxation related to possible disposal.

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activities and managing equipment that can promote and facilitate the setting up and operation of each laboratory.'

[77] Road works, renovation of housing and highways, etc.

[78] Rollout of mobile telephony networks, broadband networks, renovation of colleges, etc.

[79] Economic zones, innovative investments, environmental protection investments.

[80] For a power plant with two 1300 MW nuclear units, approximately 15 million € per year of professional tax is paid to the borough where it is sited and to the departmental fund.

[81] 52 boroughs in all are concerned with a total population of 9,500 inhabitants.

[82] The explanatory memorandum of the Act of 30 December 1991 states that the annual contribution to the license holder to create the laboratory shall be sixty million francs (9.15 million €). In 1997, the Minister for Industry acceded to the request made by the two departments of Haute-Marne and Meuse to each benefit from this sum, on the grounds that the laboratory is located in the Meuse but only a few kilometres from the Haute-Marne.

In addition to these useful aids, a voluntaristic approach is now needed to site, in the area, industrial activities related to the nuclear power sector.

Obviously scientific and technological cluster projects cannot come to fruition if ‘structuring’ economic activities are lacking. Industrial traditions exist in both departments—metallurgy, electrical industries, agri-food industry, wood, paper industry—where new activities could find moorings.

A project like that of an underground laboratory must be managed by the State over the long term and according to a spatial and economic development logic and not a strictly accounting logic.

An interministerial committee with a permanent secretariat should be set up. Its regular meetings would allow overall follow-up to the issue. Clear directives would then be given to the Representatives of the State. In any case, the ANDRA cannot be left alone on the front in the Meuse and Haute-Marne, whereas its project is of a national scale.

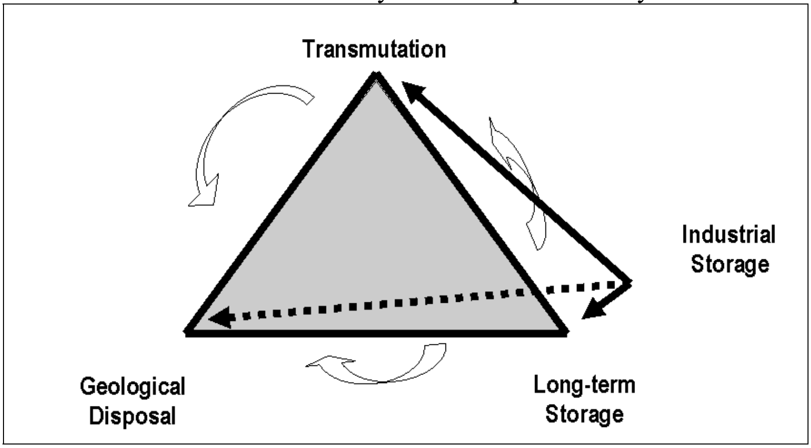
Lastly, the 2006 Act should provide for an annual Government report being transmitted to Parliament on the economic development of the areas concerned by radioactive waste management.

IV.- *MANAGEMENT METHODS:* THREE DECISIONS IN PRINCIPLE, FORMING A THREESOME, FROM THE USE OF TRANSMUTATION, TO GEOLOGICAL DISPOSAL AND LONG-TERM STORAGE, SHOULD BE TAKEN BY PARLIAMENT, ALONG WITH A SCHEDULE OF DECISIONS FOR THE PUBLIC AUTHORITIES

The research conducted pursuant to the Act of 30 December 1991 has highlighted the dynamic of scientific and technical progress in the field of radioactive waste management. This dynamic will lead, as previously seen, to the development in the decades ahead of methods improving safety.

It lies with legislation to take note of the dynamic complementarity of transmutation, geological disposal and long-term storage.

Diagram 5 : The threesome of the three radioactive waste management methods and their dynamic complementarity



Consequently Parliament should clearly state that transmutation is the ultimate goal of waste management and that, as such, forms a fully-fledged research field to be funded recurrently.

A decision in principle regarding the use of geological disposal must also be taken by Parliament, while leaving the responsibility for its implementation to the executive, within the framework of a schedule defined by legislation.

Lastly, a decision in principle to use long-term storage must be taken so that France can make progress on the basis of its experience of industrial storage so as to have enduring and flexible instruments for radioactive waste management.

1. A decision in principle taken by Parliament could affirm separation-transmutation as the ultimate goal of radioactive waste management

A decision in principle concerning the use of separation, the prerequisite for transmutation, could be taken by the 2006 Act. In the wake of the substantial results already obtained, general aims could be set, such as for instance the date of 2015 for the end of the complementary studies, particularly those related to the GANEX process for the grouped extraction of minor actinides from fission products. Similarly, the date of 2025 could be chosen as the aim for the completion of industrialisation tests. Lastly, the date of 2040, corresponding to the refurbishment of the facilities, could form the aim for operational start-up of separation.

As for transmutation, the main results of the research conducted pursuant to the 1991 Act are that transmutation is scientifically demonstrated and that two channels can be envisaged for its industrial implementation in around 2040, namely Generation IV fast reactors and accelerator driven subcritical reactors.

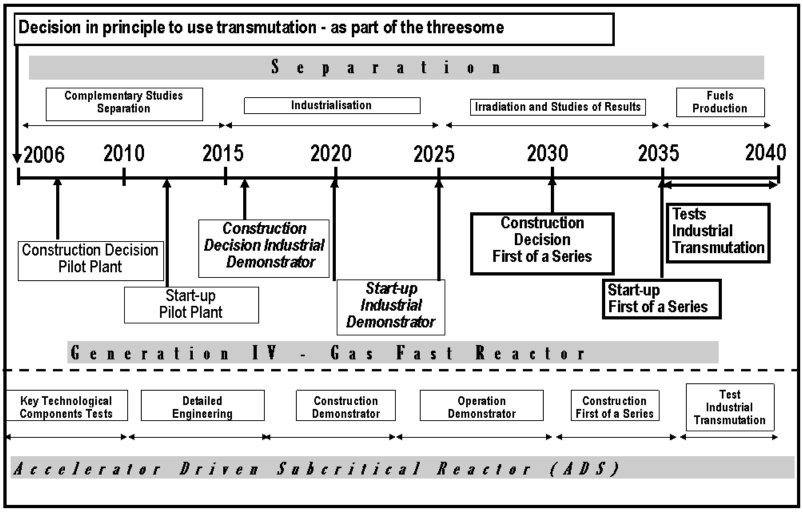
Research on these two technical solutions is of critical importance for the energy supply. Generation IV reactors should in fact boost uranium reserves, produce ultimate radioactive wastes in lesser quantities and should be utilisable to transmute light-water reactor wastes. For their part, ADS systems, apart from the progress which their development would allow in various techniques, form a technological guarantee for the incineration of radioactive wastes.

Generation IV and ADS therefore represent the long-term horizon of the nuclear power industry. Parliament must stress their importance by setting forth a research obligation in this field, which should be prioritised and which should be complied with, whatever the other constraints of research bodies, especially public ones, regarding their aims and funding.

Apart from the goal of operational start-up of transmutation in 2040, interim goals could be set.

The following diagram shows the estimated dates for some of the steps in the process that can lead to industrial implementation of transmutation. It is based on the optimistic hypothesis that the two avenues of Generation IV reactors and ADS systems would not encounter any technical obstacles compromising their feasibility nor any financial obstacles making it necessary to abandon one or the other.

Diagram 6 : Possible goals for transmutation



In any case, subject to a study in greater depth, two dates could form plausible interim goals: one for the start-up of an industrial demonstrator in 2025 and the other for testing industrial transmutation on an industrial scale in a first-of-a-series facility in 2035.

2. A decision in principle to adopt geological disposal could be affirmed by Parliament

2.1. Geological disposal is the choice, most often enshrined in legislation, of a whole set of countries

Geological disposal is a technical solution for radioactive waste management which several countries have chosen, either in practice (Sweden) or in an official manner by placing it on the statute book (Finland, United States).

Switzerland is in favour of geological disposal

Adopted in March 2003, the new Swiss Act on nuclear energy entered into force in February 2005 along with its implementing regulations.

In the wake of the rejection of the two initiatives 'Moratoire-plus' and 'Sortir du nucléaire' of May 2003, this Act confirms the role of nuclear energy in Switzerland and facilitates the construction of a geological disposal site which shall be monitored for an extended period and shall be kept reversible during this period in economically reasonable conditions.

Geological disposal was selected by the Swedish Government

To define its radioactive waste management and spent fuels policy, Sweden, which does not make use of reprocessing, has implemented a pragmatic approach invoking the subsidiarity principle.

Four principles having legislative value have been adopted by Parliament: nuclear operators are responsible for disposing of wastes and spent fuels; disposal expenditure must be covered by a tax on electricity production; the ultimate responsibility for wastes and fuels lies with the State; and disposal of foreign wastes in Sweden can be only exceptional.

Pursuant to these principles and to mutualise their resources, the four Swedish nuclear operators founded the company SKB tasked, on their behalf, with taking charge of the management and disposal of wastes and fuels.

Further to the principles validated by Parliament, the 1984 Act on nuclear activities defines the safety rules to be observed in all nuclear activities, including waste disposal[83]. This same Act introduced the obligation for nuclear operators to establish and carry out a research and development programme for the disposal of wastes and spent fuels which must be submitted every three years to the Government.

The ordinance of 1984 on nuclear activities designates SKI as the national nuclear safety authority, tasked in particular with assessing the

[83] The other fundamental Swedish act on nuclear energy is the 1998 Act on protection against ionising radiations.

research programme. Approving and possibly amending this programme are reserved for the Government itself.

Drawing the consequences of the successive R&D programmes, SKI enacted in 2002 a long-term safety rule on the disposal of spent fuels and radioactive wastes, which addresses in particular the qualitative requirements of a multibarrier system and the time scale for assessing safety[84].

All in all, intervention by the Swedish Parliament regarding the use of geological disposal has focussed on setting forth general principles and passing an act on the safety of nuclear activities. The choice of geological disposal will therefore come from the Government on proposal by SKB and after assessment by the safety authority SKI.

Geological disposal is Finland's choice enshrined in law

In Finland, as early as 1983, the Act on nuclear energy decided a research programme on radioactive waste management and set for the year 2000, subsequently postponed until 2001, the ultimate date for a practical decision on the construction of an underground disposal site.

Pursuant to the Act, the reason for this choice is the 'overall good of Finnish society' according to which 'solving the issue of radioactive wastes cannot be carried forward to future generations.'[85]

Belgium has adopted a prudent approach which does not exclude geological disposal

Belgium is still seeking definitive solutions for wastes as a whole—low- intermediate- or high-level.

A prudent approach has been adopted with, as the first goal, the construction of a definitive disposal centre for low-level radioactive wastes, which has not yet led to an actual facility but which was well under way at end 2004 in the borough of Dessel.

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[84] The assessment of safety must concern the period during which confinement barriers are necessary to isolate radioelements or delay their dispersion, and in any case at least 10,000 years.
[85] Interview with the MP, Mikko IMMONEN, Helsinki, 3 November 2003.

As for high-level radioactive wastes, Belgium has greatly advanced regarding knowledge of the properties of the deep clay layer at Mol, which is studied by means of an underground laboratory.

It has not yet been decided to build an underground disposal site.

The adoption of geological disposal in the United States is laid down by law

The United States, for its part, has built the first geological disposal site in service worldwide—the Waste Isolation Pilot Plant (WIPP)—for low-level transuranic wastes of military origin and has opted for geological disposal for spent fuels.

It was in 1979 that the US Congress decided the creation of the WIPP and construction started in 1982 near Carlsbad in New Mexico, at a depth of 655 metres in a salt layer. Beforehand, in 1957, the US National Academy of Sciences had deemed that salt was the most promising option for the disposal of radioactive wastes, particularly owing to the total absence of water in such a medium. In accordance with the law, the WIPP is used for low-level but long-lived transuranic military wastes, for a total volume defined at the outset. These wastes come from the reprocessing of nuclear materials and the production or dismantling of atomic weapons at 15 to 20 military nuclear facilities spread throughout the United States.

The geological disposal of spent fuels was, once more, decided by law in the United States.

The 1982 Nuclear Waste Policy Act (NWPA) is aimed at *'encouraging the development of disposal sites for high-level wastes and spent fuels, establishing a research, development and demonstration programme on the disposal of these materials and promoting other goals.'* Title II of said Act authorises the Secretary of State for Energy to grant credits for the construction, operation and maintenance of a laboratory studying underground disposal.

Pursuant to this Act, the DOE elaborated general principles published in 1984 on the criteria for choosing candidate disposal sites. Then the Secretary of State for Energy drew up a first list of five sites on the basis of these principles and subsequently recommended the three sites of Deaf County in Texas, Hanford in Washington State, and Yucca

Mountain in Nevada[86]. Faced with the escalation of costs and ever longer lead times, the US Congress, by an amendment to the NWPA, instructed the DOE—tasked with setting in place a practical solution—to limit characterisation studies to the sole Yucca Mountain site. Eventually, it was in 2002 that the Secretary of State for Energy proposed the choice of Yucca Mountain to President Bush, which choice was approved by Congress, which overruled the veto of the State of Nevada by an overwhelming majority.

The geological disposal option is confirmed in Germany

While the Atomic Energy Act in Germany, of which the first version dates back to 1959, has been amended on several occasions, especially by the Act of 26 April 2002 on the 'programmed phase-out of commercial electrical nuclear energy, the initial option of geological disposal has never been challenged.

In actual fact, according to the German Act, all radioactive wastes of whatever level and lifespan, must be disposed of in deep geological formations. Whereas waste producers are responsible for all the other operations of the fuel cycle, it is the federal Government which has responsibility for disposal.

As the reprocessing of spent fuels is banned from July 2005, the choice of disposal will also concern irradiated fuels which will be unloaded from power plants and not reprocessed from that date onwards and until 2020-2032, the date of the shut-down of the last German power plant according to the agreement signed with industry in June 2000.

For the whole range of radioactive wastes as well as for irradiated fuels, Germany therefore emphasises the decisive advantages of geological disposal. The Ministry for the Environment, competent in nuclear safety matters, even intends to set up a single disposal site grouping all categories of radioactive wastes and spent fuels, but this orientation is challenged, particularly by nuclear operators.

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[86] Nuclear department of the French embassy in Washington, July 2004.

2.2. Local decisions accepting disposal are a matter for elected bodies in nearly all countries

In Sweden, municipalities have a tradition of independence which is well anchored in history. But a subtle dialectic has emerged between them and the national interest. Only two boroughs, Mala and Storuman, in the north of Sweden, among the eight selected, refused to continue to participate in the feasibility study process for a disposal site[87]. However, this refusal is ascribed to precipitation and the absence of information and concertation with the local populations, which characterised the approach of the time.

As Finnish legislation has not provided for local referendums, it was the municipal council of Eurajoki (5,800 inhabitants), the borough where the selected site of Olkiluoto is located, which took the local decision to accept, after a vote of 20 for and 7 against. The municipal council of the neighbouring town of Rauma (37,000 inhabitants), for its part, voted in favour unanimously.

As for the creation of an underground laboratory in France, the Act of 30 December 1991 lays down in its Article 6 that *'any project to set up an underground laboratory shall give rise, before any preliminary research work is started, to formal consultations with the elected representatives and populations of the sites concerned, as laid down by decree.'* According to the provisions of decree no. 93-940 of 16 July 1993, at the same time as the public inquiry, the regional, general and municipal councils concerned were consulted for their opinion. The results of the public inquiry and of the consultations with the local authorities were part of the dossier drawn up to apply for a license.

This consultation procedure to obtain the opinions of the populations and local elected representatives apparently functioned satisfactorily for the setting up of an underground laboratory.

Is the decentralisation reform likely to introduce new procedures for the consultation of the population?

[87] Sweden has an original municipal referendum mechanism: 5% of voters can ask for a referendum to be organised but the municipal council is under no obligation to organise one

A local referendum can be organised by the deliberative assembly of a territorial unit[88] on any draft deliberation settling an issue within the competence of said unit[89]. Can it be considered that the issue of radioactive wastes is within the competence of territorial units? It does not appear so.

In effect, as the constitutional reform of decentralisation was expressly directed towards the subsidiarity principle, the competences of territorial units are those which can best be implemented at their level. This is not the case for radioactive wastes. Not only do radioactive wastes result from national electricity production and research, but their management is optimal only at the national level.

As was the case with the project for a laboratory, it lies with the elected representatives of the territorial units to reach a decision, where applicable, on a possible project to build a disposal centre in the Bure clay layer.

2.3. Parliament could take a decision in principle to adopt geological disposal, the Governmenthaving to take a decision at the latest by 2016 on a possible application for a license to build a disposal site

The policy followed by Finland to set up a geological disposal site forms an example to be examined before making proposals for France.

In accordance with the Finnish procedure, the Government took the decision to adopt geological disposal in December 2000. This decision was ratified by Parliament[90] on 16 May 2001 by 159 votes for and 3 against.

According to this decision, it lies with the Government to take the procedure to its term on the basis of a forward schedule appended to the decision in principle[91]. Admittedly the detailed safety report on the

[88] According to Article 72 of the Constitution, the territorial units of the Republic shall be the communes, the departments, the regions, the special-status areas and the overseas territories to which article 74 applies.

[89] Institutional Act no. 2003-705 of 1 August 2003 on local referendums.

[90] *Eduskunta* in Finnish.

[91] Reminder of the dates already mentioned in the first chapter: the first step is the construction of a characterisation laboratory known as Onkalo, on the Olkiluoto peninsula, from 2004 on, which will serve to conduct in situ research over the 2004-2010 period. The construction of a

Olkiluoto geological disposal site will have to be transmitted to Parliament. But the construction and operation license will be a matter entirely for Government to decide, which will neither have to consult Parliament nor obtain its agreement.

This type of procedure respects the separation of powers but a guidance schedule was also adopted by Parliament, setting 2012 at the earliest as the date for the construction license but scheduling start-up of disposal in 2020.

France, for its part, by making the choice of reprocessing-recycling of spent fuels, has laid the essential bases for transmutation. However it appears, firstly, that long lead times are necessary for its implementation and industrialisation, secondly, that ultimate wastes will still result from transmutation, and lastly, that the long-term safety of long-term storage is lower than that of geological disposal.

The knowledge acquired thanks to the 1991 Act of course has its limits and shortcomings. But it is clear that complementary research, even performed over decades and with unlimited means, would not be likely to challenge the finding that geological disposal is essential, in the last analysis, as the final resting place for possibly transmuted wastes.

The 2006 Act must therefore take note of this scientific finding and take a decision in principle to adopt reversible disposal in a deep geological formation.

In compliance with the separation of powers and particularly with the prerogatives of the nuclear safety authority, the choice of the site is naturally a matter for the Government to decide.

It would however lie with Parliament to draft a desirable schedule for this decision.

A first condition is the setting in place of an in situ research programme at Bure that should be as complete as possible.

The lengths of experiments required in situ at Bure will be insufficient at end 2005 bearing in mind the delays. However, taking into account modern modelisation and numerical simulation means, it would

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containerisation plant and of disposal itself is scheduled for the 2010-2020 period. The site is scheduled to start up around 2020.

be pointless to wait decades to judge the experimentation results of very slow phenomena like the migration of radioelements in a rock such as clay—impermeable and with a high adsorption effect.

A 5 year period, from 2006, of additional experimentation and the drafting of a safety dossier would allow the Government to possibly authorise the ANDRA in 2011 to file with the safety authority an application for a license to build a disposal site in the Bure clay layer.

As the ANDRA started its research on the clay at Mol in 1992, the 15 year period of research laid down by the Act of 30 December 1991 would not only be met but exceeded.

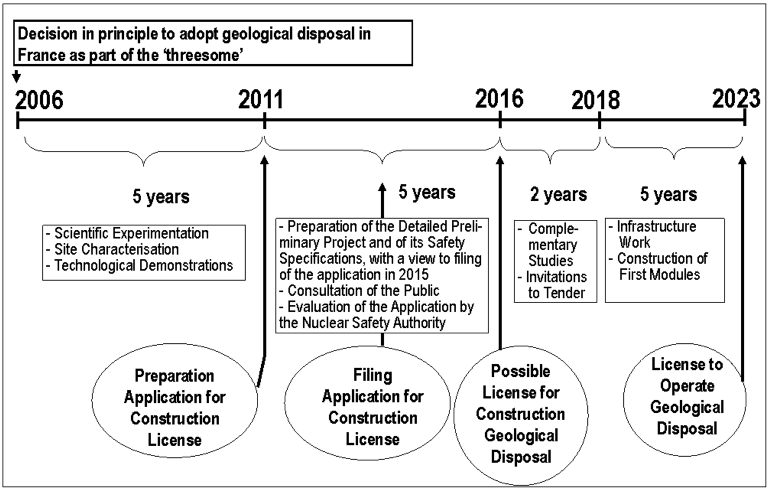
Bearing in mind the lead times for consulting the public and drawing up the ANDRA dossier, it could be aimed at for the Government to take a decision on the construction of a disposal site at the latest in 2016.

Supposing a license is granted, two years would have to be scheduled for possible complementary studies and for the organisation of invitations to tender and the openings of tenders, so the first digging could begin in 2018 and the first waste packages could be emplaced around 2023.

In any case, the parliamentary decision in principle would be superseded by decisions by the executive, with at least three important dates:

- 2011 for the authorisation granted to the ANDRA to prepare a license application dossier
- 2016 for the construction license, and
- 2023 for the license to operate (see following chart).

Diagram 7 : Guidance schedule on the decisions for a disposal site



In the meanwhile, the construction of a long-term subsurface storage site could have been started if not completed. Similarly, projects could have been finalised for transmutation, particularly in the field of dedicated systems such as ADS. Also 15 years would have been effectively devoted to research on the Marne / Haute-Marne laboratory and also on research strands no. 1 and no. 3.

Therefore the concomitant rollout of the three strands, which is strongly desired by the elected representatives of the Haute-Marne and the Meuse, would be confirmed, not only as it has been so for research, but also for practical developments.

3. The adoption of long-term storage could be an obligation laid down in legislation and combined with the development of a surface or subsurface site

'It is absolutely necessary to devise and then build long-term storage facilities'. This was one of the conclusions of the May 2001 report by the Parliamentary Office on the possibilities of long-term storage of irradiated nuclear fuels[92].

[92] Les possibilités d'entreposage à long terme de combustibles nucléaires irradiés, by Mr Christian BATAILLE, Parliamentary Office for Scientific and Technological Assessment, National Assembly, no. 3101, Senate no. 347, Paris, May 2001.

To assume its responsibilities with respect to future generations, France absolutely must have long-term storage, which alone will allow the indispensable flexibility in managing spent fuels, whether reprocessed or not, and radioactive wastes.

In effect, the development of such a facility would enable full-scale testing of the concepts resulting from research by the CEA on strand 3 of the Act of 30 December 1991.

Also its operation would enable centralised storage of intermediate-level wastes, including those from the dismantling and cleanup of former nuclear sites.

Lastly, such a facility would also enable long-term storage of UOX fuels, pending reprocessing, and of spent MOX fuels. Referring to conventional UOX fuels, EDF said they are all meant to be reprocessed[93], but the corresponding lead times could be high if EDF's plutonium needs for MOX production do not grow rapidly. As for spent MOX, reprocessing technique tests are conclusive at AREVA, but the cooling period, of approximately 60 to 80 years, is longer than the lifespan of industrial storage.

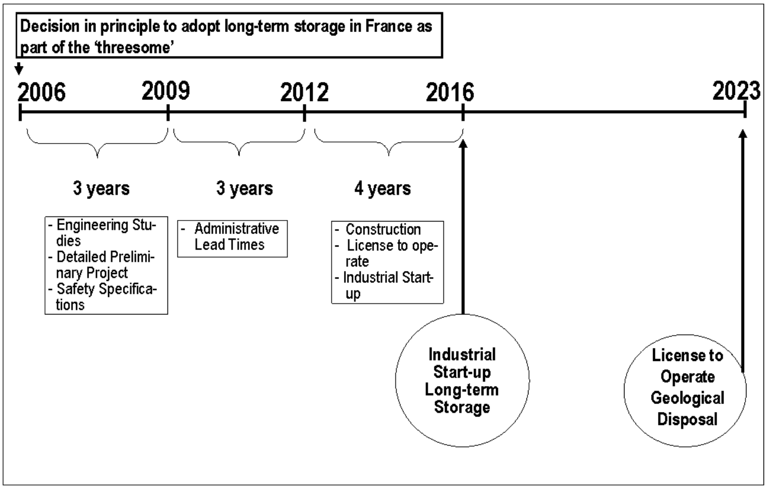
The present industrial storage facilities could become clogged, which should be planned for by creating additional capacities, which it would be judicious to build in the form of long-term storage sites.

Switzerland, with its ZWILAG storage centre, has provided the example of a surface facility with a lifespan expected to easily exceed 50 years.

In any case, it appears necessary to build a long-term storage facility in a relatively short timeframe, as made possible by the good progress in the preliminary studies conducted by the CEA (see diagram hereafter).

[93] Bernard DUPRAZ, Delegate Director General – production, engineering. Public hearing of 20 January 2005.

Diagram 8 : Guidance schedule for the development of a long-term storage facility

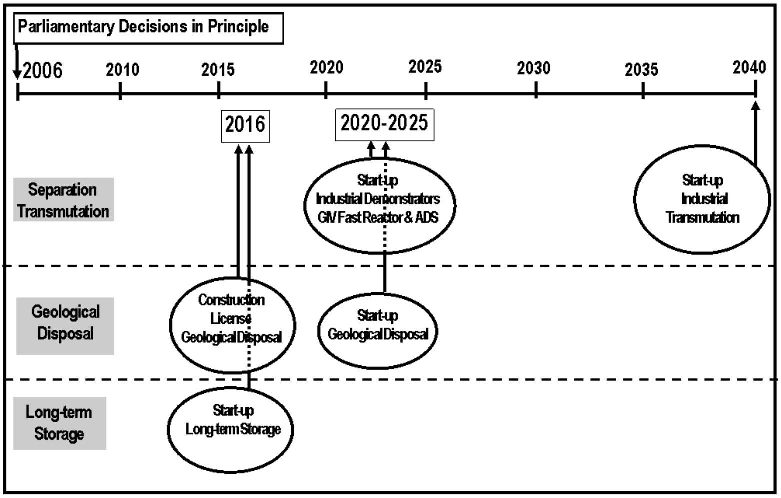


Following the example of the choices made in countries like Finland or Sweden, the construction of this surface or subsurface centralised storage facility should therefore be envisaged within a site already comprising basic nuclear facilities, in replacement of one of several of them after their decommissioning. The site should also be chosen to reduce transport to maximum extent.

That is why legislation could make it mandatory to develop a multi-purpose long-term storage facility, at the surface or subsurface, for start-up in 2016 at the latest. This facility could receive a diversified set of waste packages before the implementation of the final solution in their respect.

The major dates of radioactive waste management, set down in the 2006 Act as goals attached to the Parliamentary decisions in principle, are shown in the following diagram.

Diagram 9 : Major dates of radioactive waste management; goals set down by the 2006 Act



V.- *OVERALL LOGIC:* THE NATIONAL PLAN FOR THE MANAGEMENT OF RADIOACTIVE WASTES AND RECOVERABLE MATERIALS (PNGDR-MV)—THE ESSENTIAL GENERAL FRAMEWORK—SHOULD BE ENSHRINED IN LEGISLATION

In March 2000, the Parliamentary Office for Scientific and Technological Assessment proposed to the public authorities to study the feasibility of a national radioactive waste management plan.

The aim was to underscore in particular the volumes in question as well as the responsibilities of the various nuclear operators and to set goals integrating the results of the research conducted pursuant to the Act of 30 December 1991.

Five years later, the nuclear safety authority, the Directorate-General for Nuclear Safety and Radioprotection, has managed to develop a completed version of a National Plan for the Management of Radioactive Wastes (PNGDR – Plan national de gestion des déchets radioactifs), which results from work carried out internally and from the meetings of a working group grouping representatives of the public authorities, producers of all types of radioactive wastes, and several environmental protection associations.

The elaboration and application of a national radioactive waste management plan meet an international commitment by France and a need for exhaustivity and coherence in the management of radioactive wastes in France.

In order not to leave any shadowy areas in the management of radioactive wastes, it appears necessary to broaden the application scope of the PNGDR to recoverable materials (matières valorisables – MV), which leads to proposing the setting in place of the PNGDR-MV, the basis of which is formed by the national inventory of radioactive wastes and recoverable materials published by the ANDRA at end 2004.

The PNGDR-MV national plan shall provide a specific management solution for the various cases not addressed by the Act of 30 December 1991.

In any case, once the PNGDR-MV national plan for radioactive waste management has been finalised it should be appended to the 2006 Act on radioactive waste management.

1. The PNGDR-MV meets an international obligation and a national need for exhaustivity and coherence

Since June 2001, France has been a contracting party to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, adopted in 1997 at the IAEA.

France must therefore comply with Article 19, according to which: *'Each contracting party shall establish and maintain a legislative and regulatory framework to govern the safety of spent fuel and radioactive waste management.'*

The implementation of a national radioactive waste management plan would therefore bring France's situation into line with its commitment with regard to the other contracting parties, among which appear industrialised countries possessing nuclear facilities.

The PNGDR-MV would also meet a concern for coherence in the approach by the public authorities.

Definitive management solutions are already operational for low- or intermediate-level short-lived radioactive wastes and for very low-level wastes, thanks to the facilities set in place by the ANDRA at Soulaines-Dhuys and Morvilliers in the Aube, i.e. for 90% of the volumes.

The Act of 30 December 1991 concerns the quest for management solutions for high-level long-lived wastes[94] resulting from the Act of 30 December 1991.

According to the national wastes inventory, on 31 December 2002 high-level long-lived wastes admittedly represented 96% of the total radioactivity of wastes but only 0.2% of their total volume. This volume is only 1639 cu. m, i.e. a less than 12 m sided cube, out of a total of 978,098 cu. m.

Solutions must therefore be sought not only for radioactive wastes as a whole but also for various recoverable materials whose recycling periods are either long or else indeterminate for the time being.

After compilation by the ANDRA, in cooperation with waste producers, of the national inventory of radioactive wastes and recoverable materials, which was published at end 2004, the following question should be answered: have satisfactory practical management procedures been set in place as regards security or must they be developed?

Lastly, the PNGDR-MV is a necessity as part of an exhaustive approach to the management of radioactive wastes and spent fuels—the only possible approach as regards security.

2. The PNGDR-MV should provide solutions for radioactive wastes and recoverable materials as a whole

As part of this report it is impossible to address all types of radioactive wastes and define for each of them the appropriate

[94] According to the national wastes inventory, on 31 December 2002 high-level long-lived wastes admittedly represented 96% of the total radioactivity of wastes but, with 1639 cu. m, only 0.2% of their total volume (978,098 cu. m).

management approach. This work is precisely undertaken by the Directorate-General for Nuclear Safety and Radioprotection.

It appears necessary however to insist on the case of non-reprocessed irradiated fuels and that of spent MOX, as well as that of low- or intermediate-level long-lived wastes.

2.1. Spent fuels that are non-reprocessed or recyclable in the very long term should be catered for by a long-term disposal or storage solution

In its report of May 2001[95], the Office noted that *'EDF power plants now discharge each year 1050 tonnes of irradiated UO2 fuels and 100 tonnes of irradiated MOX fuels.'*

Out of the 1050 tonnes of UO2 fuels unloaded annually, 200 tonnes are not meant to be reprocessed after the essential four cooling years and are therefore stored for a longer length of time in the pools at La Hague. The 100 tonnes of MOX are also stored there for cooling for a 60 to 80 year period.

At the public hearings organised by the Rapporteurs in January and February 2005, EDF expressed its intention to reprocess the totality of its uranium oxide irradiated fuels, as well as eventually its MOX fuels.

The PNGDR-MV should help make the schedules adopted by EDF more specific and organise temporally the breakdown between industrial storage and long-term storage.

2.2. The case of intermediate-level long-lived wastes should be dealt with entirely transparently

In France, intermediate-level long-lived wastes are awaiting a solution. They however represent an important category of wastes, by their volume (4.6% of the total volume of wastes), by their overall radioactivity (3.9% of the total radioactivity), by their type of

[95] Les possibilités d'entreposage à long terme de combustibles nucléaires irradiés (The possibilities of long-term storage of irradiated nuclear fuels), by Mr Christian BATAILLE, Deputy, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 3101, Senate no. 347, May 2001.

radioactivity (most often mixed alpha, beta and gamma[96]) and by their radioactive decay, most often very slow. They differ from high-level wastes by their specific activity of around 100,000 to 100,000,000 becquerels per gramme, as against approximately ten or so billion becquerels per gramme for high-level wastes.

Intermediate-level long-lived wastes result mostly from reprocessing operations and represented at end 2002 a volume of 45,359 cu.m which is expected to reach 54,509 cu. m in 2020[97], in other words a 38 m side cube.

As stated in its Article 4, the research of the Act of 30 December 1991 concerns the management of high-level long-lived radioactive wastes and their reversible disposal in deep geological formations.

Technically, a geological disposal centre qualified for high-level long-lived wastes would also be qualified for intermediate-level long-lived wastes.

However this issue must be addressed in an entirely transparent manner.

In any case, to guarantee the reversibility of a storage site built primarily for high-level long-lived wastes, it should not be filled in with a high volume of intermediate-level wastes which represent merely 4% of the radioactivity of the total for wastes, as against 96% for high-level long-lived wastes.

Pending the advent of a very long-term solution, long-term storage could present advantages to centralise these wastes and to have the necessary time to set a definitive solution in place[98].

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[96] Alpha radiation, composed of nuclei of helium, is dangerous as it is very ionising, but it is easy to protect against it because it is not very penetrative. Bêta radiation, composed of electrons, is less ionising than alpha radiation but more penetrative. Gamma radiation, composed of high-energy photons, is the most penetrative of the three.

[97] According to the ANDRA inventory model, the total number of packages of intermediate-level long-lived wastes will cumulatively reach 192,872 over 40 years. Packages of bituminised sludges will stand at 103,492 (54% of the total), cemented wastes at 35,282 (18%) non-conditioned wastes in canisters at 11,760 (5%), and CDS-C stainless steel canisters for hulls and end-fittings at 42,338 (22%)

[98] Sweden has chosen subsurface definitive disposal for its low- or intermediate-level wastes, which are disposed of at the SFR-1 centre, a subsurface disposal centre located close to the Forsmark nuclear power plant at a depth of 60 m under the sea and 1 km from the coast, which comprises horizontal galleries for low-level wastes and a vertical silo for intermediate-level

2.3. The PNGDR-MV could also provide a management solution for low-level long-lived wastes

For their part, low-level long-lived wastes, mainly graphite wastes from old uranium graphite gas power plants, and from radium-containing wastes from processes or from the cleanup of sites, represented at end 2002 a volume of 44,559 cu. m which is expected to rise to 87,431 cu. m in 2020.

Owing to their low specific activity of approximately a few thousand becquerels per gramme, low-level short-lived wastes are undoubtedly a case for a relatively simple solution such as disposal at a depth of a few metres under the clayey ground of a surface site for instance.

3. The PNGDR-MV could be given a mandatory character by the 2006 Act

Following its drafting, which should be completed before end 2005, the national plan for the management of radioactive wastes and of recoverable materials (PNGDR-MV) should outline the management solutions for each category of wastes.

To form an effective instrument with regard to waste producers, the national plan for radioactive waste management must have a mandatory character.

It will therefore be necessary to integrate it, in one way or another, in the 2006 Act.

The PNGDR-MV could therefore form an annex to the 2006 Act referred to in a specific article stating that *'the orientations of the national plan for radioactive waste management appearing in the annex are approved.'*

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wastes. For intermediate-level wastes which will result from the dismantling of nuclear power plants, the same will apply since these wastes will be disposed of in an extension to the same SFR-1 centre. Intermediate-level wastes can be disposed of at a subsurface site in Sweden only because they are short-lived. If it is only a few tens of metres thick, the geological barrier does not suffice to guarantee very long-term confinement of long-lived wastes.

VI.- *FUNDING:* THE VERY LONG-TERM GUARANTEE OF FUNDING FOR RESEARCH AND FOR THE INDUSTRIAL MANAGEMENT OF RADIOACTIVE WASTES COULD BE STRENGTHENED BY THE CREATION OF A DEDICATED FUND

The new status of EDF, the main producer of radioactive wastes in France[99], as a stock company, makes it necessary to re-examine the funding procedures for research on the very long-term management of radioactive wastes as well as on the industrial management of the latter and to set in place a transition from the present system of balance sheet reserves towards a durable and independent system guaranteeing funding over a very long period.

Many European or American countries have already set in place management solutions whose advantages in terms of durability are far superior to the present French situation.

1. The Finnish or Swedish, if not American, mechanisms of dedicated funds are better adapted than the French system of reserves and earmarked assets

The nuclear industry is an industry of the long term as regards the electronuclear reactors and the fuel cycle and radioactive waste management.

The nuclear industry began in earnest in France in 1959 with the start-up that year at Marcoule of the first nuclear reactors, G2 and G3. EDF's latest electronuclear reactors should reach the end of their operation around 2040[100]. Once they have been shut down, reactors cannot start to be dismantled until ten years later, which defers until the

[99] EDF's share in the total stock of France's radioactive wastes at end 2002 amounted to 65%, including 84% of high-level long-lived wastes, 62% of intermediate-level long-lived wastes, 24% of low-level long-lived wastes, 70% of low or intermediate-level short-lived wastes and 38% of very low-level wastes.

[100] The lifespan of nuclear power plants presently in service is 40 years when they are built and could exceed 50 years in some cases.

second half of the 21st century the dismantling of reactors like Chooz-B or Civaux[101].

The fuel cycle itself extends over very long periods.

Nuclear fuels, which remain three to four years in the reactor, then pass approximately four years in a pool before being reprocessed.

Given their thermal load, vitrified waste packages from reprocessing do not appear suitable for disposal in a deep geological formation before at least forty years.

As previously seen, it does not appear that a possible geological disposal site can enter into service before 2025. Also, the last fuels will be unloaded from the N4 reactors around 2040. Bearing in mind the cooling times, the corresponding packages of vitrified wastes would not be disposed of before the end of the century.

Nuclear operators have for long taken the long term into account. In France, they set aside reserves in their accounts to meet the future expenditure on dismantling and management of their spent fuels (reprocessing) and their radioactive wastes (disposal)[102].

The practices of nuclear operators vary however greatly in this respect. Despite methodological difficulties regarding assessments, the present situation of the coverage of future costs cannot be considered satisfactory, particularly with regard to the solutions adopted by some countries.

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[101] Today's choice is that of rapid dismantling, i.e. starting 10 years after the shut-down of the reactor, unlike the previous options which consisted in waiting 25 to 50 years to take advantage of the radioactive decay of the contaminated materials.

[102] The State Audit Office (Cour des Comptes) assesses the burden of the future costs on the cost of electricity produced at 3.3 € / MWh, i.e. approximately 10% of the total production cost (30 € / MWh).

1.1. The levels of reserves vary highly from one operator to another

The present coverage of the future costs of dismantling and of the end of the fuel cycle varies between nuclear operators both concerning the levels reached and the financial practices chosen[103].

In the CEA's accounts, the gross reserves for dismantling and the processing of fuels stand at 11.1 billion €. Since 2001 on, a fund dedicated to the funding of dismantling and cleanup operations of civil facilities has been set up, the amount of which stood at 4.18 billion € at end 2003, including 1.17 billion represented by part of CEA's holding in AREVA.

The AREVA group has, for its part, earmarked in its year 2003 accounts gross dismantling reserves amounting to 8.4 billion € and gross reserves for the retrieval of wastes amounting to 3.8 billion €. Bearing in mind the contracts signed with foreign clients particularly for the UP3 plant, only 4.3 billion € are borne by the group. To fund these costs, AREVA constituted, after 1995, a portfolio of shares in quoted French companies, the value of which is estimated at 2.221 billion €. The value of this portfolio is expected to rise in the years or decades ahead, so as to cover the amount of the estimated gross costs.

The coverage of the reserves constituted by EDF by a portfolio of earmarked assets is very much lower than at AREVA.

In EDF's year 2003 accounts, the gross reserves for dismantling and the end of the fuel cycle amount to 48 billion €, including 23.570 billion € for deconstruction and 24.436 billion € for the end of the cycle[104].

The gross reserve for reprocessing spent fuels amounts to 14.7 billion €. As for the studies and construction of a deep disposal centre for high-level long-lived waste, the gross reserve for deep disposal amounts to 6.2 billion €. A gross reserve is also set aside for subsurface disposal of low-level long-lived wastes for an amount of 0.4 billion €.

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[103] Le démantèlement des installations nucléaires et la gestion des déchets radioactifs (The dismantling of nucelar facilities and radioactive waste management), Specific public report, State Audit Court, January 2005.

[104] Reprocessing and deconstruction of La Hague, removal and disposal of wastes, cleanup of Marcoule and other expenditure.

To ensure a minimum amount of future liquidity, EDF constituted at end 2000 a 1.2 billion € portfolio of earmarked assets, with the continuation of this process to the extent of 0.3 billion € per year over the 2001-2003 period.

According to the above-mentioned report by the State Audit Court, *'the earmarked assets were set aside only as a partial response to the issue raised. At end 2003, 2.3 billion € are to be related to a reserves total of 24.7 billion € in current value.'*

1.2. There are many methodological uncertainties and questions as to the availability of funds when the time comes

As already seen, there are still many technical uncertainties on the back end of the nuclear cycle and, as things stand at present, there are also high uncertainties as to the schedule of the dates of entry into force of the main radioactive waste management methods.

First, the cost of geological disposal is still controversial for several reasons. EDF's reserves are based on an estimate made in 1996, which had determined the cost of the disposal site at 14 billion €. This estimate is being updated to take account of the cost of disposal reversibility and also of the outstanding costs of experimentations and engineering until construction commences[105].

It should also be noted that the hypothesis on the end of the cycle made by nuclear operators to calculate their reserves is that of disposal in a deep geological formation.

While there are big technical uncertainties as regards separation and major ones regarding transmutation, a swifter than planned development of these techniques would obviously inevitably lead to an increase in the costs of the back end of the cycle, even if a partial compensation can be expected from a fall in disposal costs owing to the reduction in the volumes of wastes disposed of in deep repositories. Moreover, the calculations do not appear to also take into account the cost of long-term storage, which will prove indispensable to make the management of wastes more flexible and to cater for non-reprocessed irradiated fuels and spent MOX.

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[105] These study costs can be estimated approximately at 1 billion € (66 billion € over 15 years) on the basis of the ANDRA's present expenditure for the Meuse/Haute-Marne laboratory.

To these technical uncertainties are added uncertainties as to the construction schedules, which have a great impact on the financial estimates.

It was previously seen that for a disposal site at Bure to possibly enter into service will require technical and administrative lead times of twenty years, i.e. around 2020-2025, with operation continuing until the beginning of the next century. A theory has been put forward by some waste producers according to which its operation should be deferred or its entry into service should even be postponed.

In actual fact, if a discounting method is used to estimate the value of the disposal site operating expenditure, the results can vary considerably, which is normal given the chronological horizon.

Owing to discounting—a mathematical method used to compare expenditure made at various dates—remote expenditure expressed in present value is minimised with respect to close expenditure[106]. In order to improve the presentation of accounts in discounted value, there may therefore be a technical incentive to postpone expenditure in order to minimise reserves. Also the results are highly affected by the discounting rate. In this respect, the higher the discounting rate, the lower remote expenditure is in present value. It must therefore be regretted that the discounting rates chosen respectively by the CEA (2.5%) and by EDF (3%) are not the same.

In any case, discounting will probably become generalised in the future since European accounting standards impose the use of discounting for the consolidated accounts of quoted European companies[107].

A portfolio of unrisky or moderately risky assets close in amount to the reserves, like that constituted by AREVA, ensures good liquidity,

[106] Income and expenditure of a given amount, collected or made in the past or in the future, do not have the same value as an identical amount earned or spent today. For example, expenditure of 100 in 20 years time has a present value of 55, with a discounting rate of 3%. Why? Quite simply because a sum of 55 in today's value would reach the amount of 100 in 20 years if it were invested at a 3% interest rate. *In L'aval du cycle nucléaire – tome II: les coûts de production de l'électricité (The back end of the nuclear cycle – Part II: Costs of electricity production), by Messrs. Christian BATAILLE and Robert GALLEY, Members of Parliament, Parliamentary Office for Scientific and Technological Assessment, National Assembly no. 1359, Senate no. 195.*

[107] The IFRS 2005 European regulation imposes, from 2005, the application of IFRS international standards.

even if the value of a portfolio of securities is likely to fluctuate and if its sale—even partial—may depress values.

On the other hand, a real liquidity risk exists if the company's assets may not be sufficiently liquid, in due course, to be sold and to fund the required expenditure, and particularly since the earmarked assets are very much lower than the reserves constituted[108].

The French solutions in fact diverge from those adopted by some countries.

1.3. The practices in other countries appear more durable

Among the various nuclear countries studied by the Rapporteurs, only Germany, like France, makes use of the constitution of reserves in the balance sheet of nuclear operators to cover the future costs of spent fuel management.

The United States has set in place a tax on electricity production amounting to a tenth of a cent per kWh produced. This tax is paid into the overall federal budget. It then lies with Congress to pay to the Department of Energy (DOE)—responsible for implementing a final solution for spent fuels from commercial power plants—the funds required to reach that goal.

Other countries, like Finland and Sweden, have rendered secure the sums necessary for radioactive waste management over the very long term.

Already in its Act on atomic energy of 1957, Finland tied the issuing of a license for an operator to operate a nuclear reactor, to the constitution of reserves for radioactive waste management. As soon as its Loviisa reactors started industrial operation in 1977 and 1981, the operator IVO, which subsequently became Fortum Power and Heat Oy, formed reserves in its balance sheet. TVO (Teollisuuden Voima Oy), the operator of the Olkiluoto reactors made similar reserves from 1979 and 1982, the dates of the respective start-ups of two reactors at this power plant.

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[108] Totally or partly deductible from the taxable income, reserves for risks and costs represent an additional resource for a company.

This system of internal reserves at the two nuclear operators was challenged by the new nuclear act of 1988.

A guarantee fund was indeed created, known as the *'State fund for the management of nuclear wastes'*.

This fund does not pay the expenditure of the ongoing year incurred in radioactive waste management, which remains borne by the nuclear operators. It is merely aimed at guaranteeing the outstanding investment and management expenditure.

Contributions to the fund have been made progressively by a special provision on the first 25 years of operation of a nuclear facility. During this period, the operator has indeed been authorised to pay only a growing fraction of the future costs. Another provision also avoids burdening the financial situation of operators: these are authorised to re-borrow, at the market rates[109], up to 75% of the resources of the fund, in exchange for first-rank guarantees, the State for its part having access to the remaining 25%.

It is the Minister for Trade and Industry who determines the financial amount which each operator must immobilise in the State fund[110]. In any case, future costs are calculated on the basis of available technologies, at present prices, i.e. without the use of any discounting method whatsoever. The payments made by the operators are considered as deductible expenditure and possible reimbursements as taxable revenue.

The capital of the State fund stood at 1.2 billion € at end 2003. In 2001, management of the fund led to a profit of 47 million €, management costs amounting to 50,000 €.

Sweden, for its part, has set in place a dedicated fund aimed at covering the management costs of radioactive wastes and spent fuels and the dismantling of nuclear facilities. Its amount is estimated at 5.5 billion €.

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[109] Euribor rate + 0.15%.

[110] The State fund is governed by a board of four members, including a representative of the Ministry of Trade and Industry, a representative of the Ministry of Finance, and a representative of the Public Treasury. The fund chairman is presently a private sector personality. The funds has two auditors, one of whom is chosen by the nuclear operators. The fund is managed by a director, a secretary and an outside accountant, all working part-time.

As in Finland, nuclear operators began as of the 1970s to constitute reserves for the future costs of waste management and dismantling. The corresponding funds were transferred to a State fund in 1981, following the passing by Parliament of the Act on the funding of future expenditure relating to spent fuels. The aim of the fund is to finance all the expenditure on the management and disposal of spent fuel, as well on dismantling and disposal of wastes resulting from it. In this respect, the nuclear wastes fund covers the CLAB's expenditure (storage of spent fuels), transport expenditure, the Aspö laboratory, as well as SKB's research and development expenditure[111].

The fund is fed by payments made by operators in proportion to their nuclear production. For guidance purposes, in 1998 the tax amounted to between 0.44 and 1.76 €/MWh, depending on the reactor considered. It is the safety authority, SKI, which proposes each year to the Government the amount of the tax, on the basis of the estimated costs of managing spent fuels.

Since 1996, complementary guarantees have been added to the fund. Nuclear operators must indeed constitute additional guarantees so as to be in a position to complete the fund if it proves insufficient. Two cases are being referred to: first, early shut-down of nuclear reactors which would deprive the fund of resources and, second, unexpected expenditure before all spent fuels are disposed of in geological formations.

At end 1998, the total amount of the fund stood at 2.5 billion € once the payments of 1.15 billion € had been deducted for the benefit of the wastes manager. The main investment of the funds collected is made at the National Debt Office. However, investment of part of the sums is authorised at market rates.

All in all, it appears that the method of guarantees outside nuclear operators is a frequently used solution, but Germany is closer to the present French model.

France has already evolved in the direction of the constitution of a portfolio of assets earmarked by nuclear operators.

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[111] The management and disposal expenditure on operation wastes disposed of at the SFR-1 facility are directly borne by the nuclear operators.

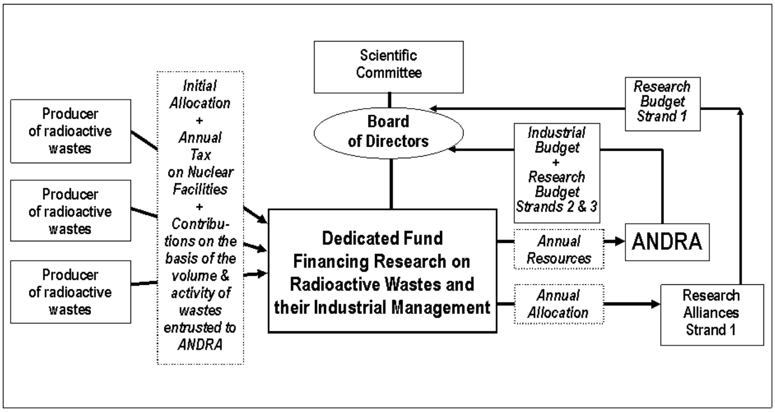
It would be useful to go further by setting up a dedicated fund, which would not only offer greater guarantees of durability but would also help clarify the funding of wastes management and strengthen the ANDRA by giving it greater autonomy with respect to waste producers.

2. The creation of a dedicated fund would help guarantee in the long term the management of radioactive wastes as well as research in this field

To guarantee the funding of wastes management over several decades if not several centuries, it could be useful to create a mechanism backed by the State, the durability of which is greater than that of any other human institution, including companies, especially when these, owing to a change in status, are subject to the short-term constraints of financial markets.

Compared with the present system of reserves constituted by EDF, AREVA and the CEA, a dedicated fund managed by the Caisse des dépôts and fed by waste producers would help identify the resources indeed available, making them yield a profit over time and granting the necessary continuity and foreseeableness to the funding of very long-term investments and of current expenditure at a very remote date.

Diagram 10 : A few operating mechanisms of a State fund for radioactive wastes



The dedicated fund called the FGDR (fonds de gestion des déchets radioactifs - fund financing radioactive wastes management) would be aimed at funding the industrial management of radioactive wastes and research in this field.

Among the industrial management expenditure borne by the fund, there would be not only the management of the low- or intermediate-level short-lived waste (Soulaines-Dhuys) or very low-level waste (Morvilliers) disposal centres and the surveillance of the latter and of the Manche disposal centre once they are closed, but also expenditure related to studies, engineering, construction, operation, shut-down and surveillance of any other disposal centre at the surface or in a deep geological formation and of any long-term storage centre.

The dedicated fund will also be tasked with funding research programmes on the management of radioactive wastes and spent fuels.

This fund, placed under the Caisse de dépôts which would ensure its financial management, would be managed by a board of directors whose members would be the director-general for nuclear safety and radioprotection, the director-general for energy and raw materials, the director of technology at the Ministry delegate for Research, and two Members of Parliament or two Senators appointed by the Parliamentary Office for Scientific and Technological Assessment. The board of directors would be assisted by a scientific committee whose members would be appointed by the Sciences Academy.

The dedicated fund would be fed by an initial allocation paid by waste producers in proportion to the reserves they would have constituted before the creation of the fund, and by annual allocations. Part of the initial global allocation would be transferred to the ANDRA as working capital. The ANDRA could negotiate the continuity and regularity of its funding. Calculated so as to exceed by a fraction to be determined the foreseeable annual payments by the fund, the annual allocations paid by waste producers would be proportionate to the tax on nuclear facilities and by a contribution on the basis of the expected yearly deliveries of wastes to the ANDRA.

In the middle of year y-1, the ANDRA would send the board of directors the global budget estimates for its industrial activities for a 5 year period, as well as its budget estimates for the research it intends to perform or have performed pursuant to strand 2 (reversible or irreversible disposal in deep geological formations) for which it would be responsible[112].

The dedicated fund would also be tasked with funding research performed pursuant to strand 1 (separation-transmutation) by research alliances grouping the bodies concerned.

A progressive switchover is possible from a system of reserves and earmarked assets set aside by nuclear operators to an external dedicated fund, as evidenced by the Finnish and Swedish examples.

In any case, the fund could receive an initial allocation paid by nuclear operators, representing 10 years of management and research expenditure.

3. The transfer of ownership of wastes cannot take place before several years when the very long term expenditure can be precisely identified

EDF's change in status from an industrial and commercial public establishment (EPIC) to a stock company increases the financial constraints—which after all are classical for listed companies—such as the transparency of accounts and the limiting of unrecorded obligations.

Some observers desire in advance to provide answers to the questions not yet asked by potential investors and therefore feel EDF should be relieved of its very long term costs relating to the back end of the fuel cycle, by transferring the responsibility for and ownership of its radioactive wastes in exchange for a balancing payment.

However, such an operation has not taken place in any country.

The main reason is that, despite the progress made in the design of the back end of the fuel cycle, it is still impossible to establish with certitude the dates of entry into service of the various technical solutions and calculate the future costs of the back end of the cycle.

By way of example, the US Department of Energy (DOE) is obliged to take back spent fuels from nuclear power plants. Yet, it is

[112] After examination of its requests by the board of directors, which could ask it for any useful complementary information, the ANDRA would receive the amount of its annual resources, on condition that it supply detailed justification of its expenditure by the following fiscal year.

specified that operators remain the owners of these fuels until they are disposed of in the Yucca Mountain galleries.

Therefore, referring to disposal in a geological formation, it is presently impossible to determine the exact dates of its entry into service and of its closure, the costs of its construction and particularly that of reversibility, as well as the costs of its partial or total closure and those of very long term surveillance.

Similarly, it is totally impossible to assess the costs of a possible retrieval of high-level wastes and of their transmutation, should the corresponding techniques be developed.

Consequently, it is impossible to estimate the balancing payment which could release each waste producer from its responsibilities as regards their management.

In short, it appears inevitable that financial analysts will develop, for companies with electronuclear facilities or offering processing and recycling services for nuclear fuel, new methods adapted to the uncustomary existence of obligations of out-of-the-ordinary length.

VII.- *THE NATIONAL AGENCY:* THE ANDRA MUST BE STRENGTHENED TO COPE WITH ITS FUTURE MISSIONS

With the national radioactive waste management agency, France has an original institution which appears particularly well adapted to the very long term tasks entrusted to it.

1. Neither the direct responsibility of the administration nor that of producers of wastes or of their emanations appear satisfactory solutions

The institutional systems adopted in the other countries for radioactive waste management differ from the French system in most cases.

The United States is characterised by direct administrative management by the Department of Energy (DOE) of spent fuels from commercial power plants as well as of military radioactive wastes. In exchange for collecting a tax of a tenth of a cent per kWh produced, the DOE assumes direct responsibility for the implementation of disposal solutions, which is not without posing many problems, the least of which is not the calling into question of its financial responsibility by nuclear operators, because of delays recorded in the collection of their spent fuels.

The case of Finland and Sweden is entirely different since, in these two countries, the nuclear operators have created a joint subsidiary, POSIVA Oy in Finland and SKB in Sweden, which take charge of the management of radioactive wastes and of spent fuels, while operators however keep their primary responsibility.

There is however a limit to this system insofar as it is the State which will assume the very long term responsibility for spent fuels and radioactive wastes once these have been respectively disposed of in a deep geological formation or in a subsurface site. The legal structure with which the public authorities will assume this responsibility is not yet known.

2. The ANDRA, as the national agency forming the right level of responsibility, could be usefully strengthened on the occasion of a broadening of its missions and a grooming of its status

The strengthening of the ANDRA is necessary to adapt its missions to the decades ahead and requires in particular a broadening of its missions and a simplification of its structures.

To rationalise the management of the various types of wastes, its missions should be extended to the management of radioactive wastes as a whole. In its Article 13, the Act of 30 December 1991, tasked the ANDRA with the long term management operations of radioactive wastes. Consequently, it is responsible *'for ensuring the long-term management of disposal centres either directly or through third parties acting on its behalf; and for participating in defining and contributing to research and development programmes on the long-term management of radioactive wastes, in cooperation especially with the Atomic Energy Commission (CEA).'*

In order to ensure coherence in radioactive waste management as a whole, it is essential to add to the ANDRA's responsibilities the construction and operation of long term storage sites.

It is also necessary to find a remedy for the pointless complexity of its decisional structures.

With the creation of a dedicated fund, the financial committee could be purely and simply suppressed, since most of its functions would be taken up by the fund board of directors.

The composition of the board of trustees also apparently needs to be corrected.

The length of the renewal process of the board of directors is a disadvantage seen in 1997-1998 and in 2004, which also should be solved.

Lastly, the chairman of the board of directors/managing director duality, brings along difficulties of competences and potential rivalities, as often seen in other public establishments.

In this respect, in return for the necessary adaptations to the context of an industrial and commercial public establishment, it appears that the best decisional structure would be the board of trustees / managing board structure. The chairman of the board of trustees could be a part-time job, with the chairman of the managing board exercising full management powers while benefiting from a body allowing dialogue and support and even external representation.

In order to increase the efficacy of its meetings, the number of members of the board of trustees could be considerably lowered, while taking into account the general organisational constraints of industrial and commercial public establishments

Following the creation of the dedicated fund, representation of waste producers on the board of trustees could be suppressed and the number of external personalities could be decreased.

In any case, the aim is to lighten ANDRA's a priori management constraints to put it in a position to assume a broadened range of missions while being more reactive.

CONCLUSION

Regarding radioactive waste management, the initial situation in France is good.

The case of low- or very low-level wastes is indeed now settled, thanks to the disposal centres at Soulaines and Morvilliers. The choice of reprocessing proves to be relevant, not only in terms of the optimisation of energy resources but also in terms of wastes management. Reprocessing indeed opens up the field of what is possible for the back end of the cycle and paves the way for decisive progress, namely a reduction in waste radiotoxicity now or in the future. Without reprocessing, there is only one possibility: definitive disposal of spent fuels, with considerably higher volumes and higher storage and disposal costs.

To what extent has the research conducted under the Act of 30 December 1991 allowed progress to be made regarding the essential issue of high-level long-lived wastes?

First, major scientific progress since 1991 on the ***separation*** of the most radioactive elements present in fuels allows it to be anticipated that separation should make it possible to maximise even more the advantages of reprocessing, already obtained by France, by permitting a differentiated and effective management of the various types of radioelements present in spent fuels. These new technologies to be industrialised will apply to future wastes.

Second, studies on ***transmutation*** have allowed progress in knowledge on this question. The feasibility of transmutation is today scientifically demonstrated thanks to the Phenix reactor and fast neutron reactor technology. Several approaches are envisageable for the future: Generation IV fast reactors and accelerator-driven reactors.

Referring to ***geological disposal***, the results of experiments in the European or American countries concerned are clear. Whatever option is chosen—reprocessing or direct disposal of spent fuels—and whatever the progress of research or of projects, none of these countries ignore geological disposal, owing to its very long term safety advantages over any other solution in the present state of knowledge.

According to the international agency, the IAEA, and according to many countries like Germany, Sweden Finland, Switzerland and the United States, geological disposal is the safest management method for radioactive wastes in the very long term. As for France and the Bure laboratory, results have been obtained confirming the confinement properties of the clay at the site and these will have to be completed.

From whatever viewpoint, long term storage is not a satisfactory solution, if the responsibility of the French with respect to future generations is borne in mind as it should be.

Referring to ***storage***, lengthy experience has been accumulated at La Hague and at Cadarache on high-level wastes. But storage, even for a long duration, supposes maintenance, surveillance and reconstruction, at more or less close intervals, of the facilities, without mentioning the possible obligation to re-condition wastes. This is not therefore the optimal solution as regards radiological security, without mentioning safety, which cannot be ensured at the same level as in a geological layer. This solution cannot therefore be chosen as the reference solution.

The research started by the 1991 Act shows that the three strands are more complementary than competing, particularly if their period of entry into force or into service is considered, which will probably be spread over time: storage more or less already exists; disposal can enter into service within two decades; and separation-transmutation will probably require a longer development period.

It lies with the present generation, after having enjoyed nuclear electricity, to set in place as swiftly as possible, operational solutions corresponding to maximum safety.

Radioactive waste management is a national issue which must necessarily find local responses. National solidarity must apply in both directions. Waste management must also be based on the polluter-payer principle: waste producers must assume all their financial, economic and social responsibilities.

The issue of a clear and durable funding of waste management is also raised, as well as those of the institutional and financial instruments which will undoubtedly have to be created or strengthened.

Regarding all these issues, the proposals by the Rapporteurs outline general principles which, no doubt, will subsequently have to be clarified, but which, taking advantage of the best international experiences, will have to be taken into account one way or another by the 2006 Act.

In this period of world uncertainty regarding energy supply and the cost of resources which is beyond France's control, nuclear energy provides stability and long-term guarantees which should be preserved.

A nuclear wastes management policy is a major condition to preserve this balance. It must be conducted equitably and transparently.

Yet all the precautions taken must not lead to immobility—it is necessary to manage to fit into the long term which is the characteristic of this dossier. Long nuclear timescales, often several decades, must not be out of step with the short political timescale, five years.

Lastly, the wastes policy must be addressed with lucidity as a link in an industrial chain.

Wastes are not the punishment which would be inflicted on us to punish us for our scientific audacity. Nor are they a problem decreed to be supposedly insolvable. If we got to the stage of affirming there is no solution, it could then be retorted that we have not wanted to find a solution.

This report sets out to demonstrate that, by politics and by law, responses to the nuclear wastes issue exist and are worth being developed.

Recommendations

Recommendation 1: **Disclosure** of the results of research on radioactive waste management must be improved at all levels: local, national and international.

Recommendation 2: **Research** on separation-transmutation and on reversible disposal in a deep geological formation must be pursued beyond 2006. Parliament must continue to instigate this research and set time milestones for it.

Recommendation 3: The **wealth of research** carried out under the 1991 Act **must be exploited** locally and nationally at the scientific, university and industrial levels thanks to the combined action of the public authorities and nuclear operators.

Recommendation 4: Within the framework of legislation, Parliament should lay down **three principles** for radioactive waste management, namely that France should: set separation-transmutation as the ultimate goal in this field and adopt reversible disposal in a deep geological formation and also long-term storage.

Recommendation 5: Parliament could set, as the **goals** for action by the public authorities, the dates of: **2016** for the start-up of long-term storage and authorisation to build a reversible disposal site in a deep geological formation; **2020-2025** for the start-up of a transmutation demonstration reactor and the start-up of geological disposal; and **2040** for industrial transmutation.

Recommendation 6: The **National Plan for the Management of Radioactive Wastes and Recoverable Materials (PNGDR-MV)** could, as the general framework for the management of radioactive wastes, be integrated in legislation.

Recommendation 7: The creation of a **dedicated fund** to finance research on radioactive wastes and their industrial management should be decided by Parliament in order to provide long-term guarantees to finance the necessary efforts. The fund would be placed under the responsibility of the State and would collect contributions from waste producers.

Recommendation 8: The **ANDRA's missions** on the disposal of radioactive wastes could be broadened to the long-term storage of all radioactive wastes and non-reprocessed spent UOX or MOX fuels.

Account of the review of the report by the Office on 15 March 2005

On 15 March 2005, the Parliamentary Office reviewed the report by Mr Christian Bataille, Member of Parliament, and Mr Claude Birraux, Member of Parliament, on the progress and prospects of research on the management of radioactive wastes.

Mr Claude Birraux, Member of Parliament and Rapporteur, said that this report follows a referral to the National Assembly Bureau at the initiative of the chairmen of the four National Assembly political groups. The report is published at the end of the 15 year research period defined by the Act of 30 December 1991 on the management of radioactive wastes. It is the eighth report the Office has drafted on radioactive wastes and was prepared by missions to six countries and visits to research centres in France, during which more than 250 researchers and persons in charge were questioned. There were also meetings with elected representatives and three full days of public hearings.

High-level long-lived radioactive wastes are expressly covered by the Act of 30 December 1991. They concentrate 96% of the total radioactivity of radioactive wastes produced in France, in a total volume, from the beginning of nuclear power to the end of 2002, of 1639 cu. m., with an increase of 110 cu. m per year. The total volume of intermediate-level long-lived wastes, which represent only 3.9% of total radioactivity, stood at 45,359 cu. m at end 2002, their increase being approximately 600 cu. m per year.

Mr Christian Bataille, Member of Parliament and Rapporteur, recalled that the Act of 30 December 1991 classified research in three strands: strand 1 on separation and transmutation, strand 2 on disposal in deep geological formations, and strand 3 on long-term conditioning and storage.

Mr Claude Birraux, Member of Parliament and Rapporteur, then added that separation is aimed at recovering, on the one hand, minor actinides whose radioactivity period is measured in hundreds of thousands of years and, on the other hand, fission products whose radioactivity period is approximately one thousand years. Separation has been demonstrated at laboratory scale and its industrial implementation now depends on the refurbishment of the La Hague facilities.

Transmutation, for its part, consists in neutron bombardment of the heavy nuclei of minor actinides to break them into lighter nuclei with a shorter radioactivity period, and has been demonstrated scientifically, mainly thanks to the experiments performed with the Phenix reactor. To perform transmutation industrially, Generation IV fast reactors and/or accelerator driven subcritical reactors will be needed. Their commercial start-up is expected by 2035 and industrial transmutation by 2040, owing to the necessary tests.

As explained by Mr Christian Bataille, Member of Parliament and Rapporteur, geological disposal aims at making use of an underground layer of rocks—such as clay, granite, salt or tuff—as a 'safe' encapsulating radioactive wastes or non-reprocessed spent fuels. The International Atomic Energy Agency (IAEA), the UN specialised agency, and also many countries (Belgium, Finland, Germany, Sweden, Switzerland, United States) consider it to be the safest method to manage radioactive wastes.

As part of strand 2 research, the ANDRA has accumulated many scientific results on clay, thanks to research conducted in the underground laboratories at Mol (Belgium) and Mont Terri (Switzerland), and, more specifically, on the clay at Bure (Meuse) by drillings from the surface and by in situ studies performed in the shafts and the Meuse/Haute-Marne underground laboratory chamber. The Bure Callovo-Oxfordian clay has favourable confinement properties, even if some studies are not completed.

In any case, geological disposal could start up in France around 2020-2025, taking account of the additional experimentation and additional study lead times, and also of the administrative lead times. Engineering studies show that such disposal could be reversible over a very long period.

Mr Claude Birraux, Member of Parliament and Rapporteur, then stated that major progress has been made regarding long-term conditioning and storage. Some of this progress has already been integrated in industrial processes, the volumes of high or intermediate-level wastes having been divided by ten since 1992. The durability of packages of vitrified wastes and of packages of fuel metallic structures exceeds a hundred or so thousand years. Also, long-term storage, whose designed lifespan is 100 to 300 years, as against 50 years for industrial storage sites presently in operation, could be operational around 2016, bearing in mind the design progress made.

Mr Christian Bataille, Member of Parliament and Rapporteur, explained that the research performed since 1992 defines management methods that are not competing but, on the contrary, complementary per se and over time. As it cannot apply to wastes already produced, transmutation, which will start up only after 2040, cannot reduce the radioactivity period of minor actinides to under a thousand years. Reversible disposal is therefore essential. Long-term storage is also necessary, especially for spent fuels non-reprocessed for the time being and spent MOX fuels whose cooling period is longer than the designed lifespan of the industrial storage facilities presently in service.

Referring to the political conclusions of the report, Mr Claude Birraux, Member of Parliament and Rapporteur, felt that improvements are essential regarding disclosure and debate. Created by the 1991 Act, the local disclosure and follow-up committee (CLIS) at the Meuse/Haute-Marne laboratory must make progress in the future regarding its mission of disseminating research results. Also created by the 1991 Act, the National Assessment Board (CNE) must be extended beyond 2006. The National Agency for Radioactive Waste Management (ANDRA) and the Atomic Energy Commission (CEA), for their part, could be assigned ambitious disclosure goals, particularly by organising visits to their facilities. Referring to the public debate, the referral of the general policy on radioactive wastes to the National Public Debate Board (CNDP) does not correspond to its essential mission which focuses on actual construction and development projects. As for dialogue with elected representatives, it must be improved as a matter of priority thanks to a better operation of the CLIS at Bure and local disclosure committees.

With reference to research, Parliament must continue to instigate it and set time milestones for it, so as to go further with the setting in place of solutions whose interest has been confirmed by the work conducted over the 1992-2005 period. Both for separation and transmutation, high investments will be essential, particularly to place Generation IV reactors and ADS systems in readiness. These investments must therefore be planned for and secured, especially for the CEA, which is facing major funding requirements. As for geological disposal, research must be fully completed in order to demonstrate the confinement properties of Bure clay and to provide the details of the disposal engineering concepts. Referring to long-term disposal, it requires the completion of studies with a view to the construction of an operational facility.

Mr Christian Bataille, Member of Parliament and Rapporteur, then stated that the wealth of research started under the 1991 Act is to be exploited owing to the scientific and technological breakthroughs it has allowed, for example in molecular synthesis, separative chemistry, geochemistry, geophysics, or engineering. A separative chemistry institute at Marcoule and scientific and technological clusters proposed by the departments of the Haute-Marne and the Meuse must be built with support from the State and the nuclear sector. Also, the financial accompanying measures introduced by the 1991 Act must be applied over all the planned 15 year period. Further, voluntaristic economic development must be set in motion in the departments concerned by radioactive waste management. In any case, radioactive waste management is a national issue which must necessarily find local responses. National solidarity must therefore apply in both directions.

Mr Christian Bataille, Member of Parliament and Rapporteur, then felt that the research performed in the three strands must now lead to the decision in principle to adopt the three management methods in the future. It should lie with Parliament to lay down transmutation as the ultimate goal of waste management, take a decision in principle regarding reversible geological disposal and decide the creation of a long-term surface or subsurface storage facility.

In compliance with the separation of powers, it would lie with the Government to implement these decisions as part of a schedule of goals appearing in legislation. In this respect, 2016 could be the aim for the operational start-up of long-term storage, 2020-2025 for the start-up of geological disposal and 2040 for industrial transmutation.

Mr Claude Birraux, Member of Parliament and Rapporteur, then addressed the issue of the overall logic of radioactive waste management. The National Plan for the Management of Radioactive Wastes (PNGDR) was recommended by the Parliamentary Office at the beginning of 2000 and is now being prepared. This plan defines management solutions for all radioactive wastes, so as to ensure exhaustivity and coherence in the management of wastes in France. The

PNGDR will also have to provide a solution to the problem of spent UOX fuels, non-reprocessed for the time being, and spent MOX fuels, which must cool for 60 to 80 years before reprocessing. It must also solve the question of intermediate-level long-lived wastes, which are not expressly covered by the 1991 Act. In any case, the PNGDR, which should therefore be called PNGDR-MV (MV = recoverable materials) should be integrated in the 2006 Act.

Mr Christian Bataille, Member of Parliament and Rapporteur, said that it was necessary to guarantee the funding of research and waste management in the long term. In this respect, the 2006 Act could specify the setting in place of a dedicated fund for radioactive waste management (FGDR), placed under the responsibility of the State, and fed by contributions paid by waste producers and based on the tax on basic nuclear facilities.

This dedicated fund would be tasked with financing not only the ANDRA for its industrial activities and its research, but also research performed for separation and transmutation by other partners (CEA, Centre national de la recherché scientifique [CNRS], universities). It would make it possible to programme the necessary effort in an independent manner and over the long term. Lastly, Mr Christian Bataille felt that the ANDRA's structures should be simplified and its responsibilities broadened by granting it—in addition to the management of waste disposal—responsibility for long-term storage, so as to guarantee coherence in decisions and to minimise costs for the community as a whole.

In the discussion, Mr Henri Revol, Senator and president of the Office, congratulated the Rapporteurs for their clear, exhaustive and objective report and presentation. The measures recommended to the public authorities are precise and constructive. He emphasised the contribution made by Phenix to research on transmutation and felt that, in the development of Generation IV and ADS reactors, the Superphenix breeder reactor could have provided capital experience, which is confirmed by the technological and financial waste represented by its shut-down.

Mr Claude Gatignol, Member of Parliament, emphasised the volume of the quantity of information contributed, and complimented the Rapporteurs for having proposed solid scientific conclusions and also a political vision of the decisions to be taken. At a time when energy represents a strategic field for the 21st century and Germany and Spain are questioning themselves on the means to exit their nuclear moratorium, he recalled that during the public hearings organised in preparation of the report, eminent foreign scientists, including the Nobel prize winner Burton Richter, emphasised the interest of the 1991 Act and the high capacity of French researchers. Parliament can continue to play a decisive role in radioactive waste management thanks to the Rapporteurs' proposals, particularly on disclosure, the dedicated fund, and the strengthening of the ANDRA, which require a parliamentary debate.

Mrs Marie-Christine Blandin, Senator, also congratulated the Rapporteurs for the wealth and the interest of their work, and felt that there is no solution for waste management and that the research which is still necessary is likely to monopolise the funds for energy research. She put forward that waste transport would be increased by the implementation of the three management methods recommended by the Rapporteurs. It was preferable, she felt, to dispose of radioactive wastes on the spot. She also deemed necessary the creation of an authority tasked with disclosure, and asked for clarifications on military wastes.

In response, Mr Claude Birraux, Member of Parliament and Rapporteur, insisted on the need for international cooperation both for Generation IV reactors with the GIF international forum and for ADS systems with the Belgian MYRRHA project. As for disclosure, he referred to the provisions of the Act on transparency which proposes the creation of a high authority modelled on one of his legislative proposal. In another respect, the Office has devoted one of its reports on nuclear safety to the issue of transport; the report underscores in particular that waste canisters are dimensioned with very high safety margins.

For his part, Mr Christian Bataille, Member of Parliament and Rapporteur, emphasised that, while this report has special importance in the run-up to the 2006 Act, he did not intend to propose its text or supply all the solutions for radioactive waste management. Debates between the stakeholders will still be necessary, for instance on intermediate-level wastes. Military wastes are, for their part, stored in particular at Marcoule and Cadarache in interesting storage modules. As for funding, it is necessary to get out of the present situation, in which waste producers negotiate the research to be performed and, instead, set in place a democratically and transparently managed dedicated fund financing research on waste management.

Mr Daniel Raoul, Senator, congratulated the Rapporteurs for the quality of their study and emphasised the importance of disclosure, a task which the local committees are not managing to entirely assume. Owing to their involvement in the subject, nor do the CEA and the ANDRA appear capable of taking charge of this task. Hence the idea of the creation of a high authority, a mechanism which however presents the disadvantage of dispossessing Parliament of its prerogatives too often.

In response to requests for clarification on the funding and the missions of the dedicated fund, expressed by Mr Daniel Raoul, Senator, and by Mrs Marie-Christine Blandin, Senator, Mr Christian Bataille, Member of Parliament and Rapporteur, said that the proposed dedicated fund could be fed by already collected resources and by new contributions, within the framework of more democratic scrutiny. It should fund, he added, not only waste management but also research.

Mr Jean-Claude Etienne, Senator, deemed that the report makes many proposals and suggestions useful for Parliament and approved in particular the proposal for the construction of a long-term storage facility managed by the ANDRA, which he considered essential for non-reprocessed spent fuels.

Mr Christian Bataille, Member of Parliament and Rapporteur, repeated the fact that the three management methods—separation-transmutation, reversible geological disposal, and long-term storage—are complementary. In reality there is not only a need to pursue research, but also for Parliament to take decisions in principle in order to concretise solutions: long-term storage can start up in 2016 and disposal by 2020-2025.

In response to a question by Mr Jean-Yves Le Déaut, Member of Parliament, on the durability of the Bure laboratory beyond 2006, Mr Christian Bataille, Member of Parliament and Rapporteur, said that research must be continued at Bure, public funding must cover the initially planned fifteen year period, and a decision in principle must approve the prospect of disposal in France.

In the following debate on the operation of local disclosure committees and on the importance of nuclear disclosure, Mr Daniel Raoul, Senator, felt that a disclosure body should be invented under Parliament's responsibility. Mr Jean-Yves Le Déaut, Member of Parliament, recommended the creation of a scientific information observatory placed under the authority of the Parliamentary Office. Mr Claude Gatignol, Member of Parliament, proposed the organisation of meetings of the Parliamentary Office in the regions concerned by radioactive waste management.

At the end of the debate, the report was adopted by all the members of the Office present, except for Mrs Marie-Christine Blandin, Senator, who voted against.

ANNEX 1 : PRESENT AND FUTURE STOCKS OF RADIOACTIVE WASTES IN FRANCE

Radioactive wastes are generated by defence, research, and electronuclear production activities. Already more than 90% of their volume can be dealt with by definitive disposal. This amount will reach 95% in 2010 when solutions for low-level long-lived wastes will become operational.

However, solutions still remain to be found for high-level and intermediate-level long-lived wastes representing approximately 5% of the volumes but more than 95% of the radioactivity of the wastes counted in the ANDRA's national inventory.

It is precisely the aim of the Act of 30 December 1991 on research on radioactive waste management to promote the setting in place of solutions for high-level wastes.

Table 2: The specific activity criterion to differentiate radioactive wastes

Type of waste	Specific activity (becquerel per gramme - Bq/g[113])
Very low-level	< 100 Bq/g
Low-level	100 < < 100 000 Bq/g
Intermediate-level	100 000 < < 100 000 000 Bq/g
High-level	~ 10 000 000 000 Bq/g

Table 3 : The lifespan criterion

Type of waste	period[114]
Very short-lived	< 100 days
Short-lived	< 30 years
Long-lived	> 30 years

On the basis of the two criteria of specific activity and lifespan, radioactive wastes are classified in France in five main categories.[115]

[113] Le Becquerel est l'unité du nombre de désintégration par seconde.

[114] La période ou temps de demi-vie est le temps au bout duquel le nombre de radioéléments présents initialement est divisé par deux.

[115] By convention, a short lifespan corresponds to a period of half-life under 30 years. A long lifespan corresponds to a period over 30 years.

Table 4 : Origin and destination of radioactive wastes in France
(source: National inventory of radioactive wastes – ANDRA)

On 31 December 2002	Description	Origin	Destination
High-level Long-lived	- Vitrified Fission Products and Minor Actinides	- Reprocessing - Research	Under Study (Act of 30 December 1991)
Intermediate-level Long-lived	- Fuel Sheaths - Bituminised Effluent Sludges - Cemented Solid Wastes	- Reprocessing - Research	Under Study
Low-level Long-lived	- Graphite Wastes (NUGG Reactors) - Radon emitting Wastes	- Dismantling - Wastes from Processing or Cleanup	Ongoing Construction for Start-up in 2010
Low- or Intermediate level Short-lived	- Solid Wastes - Cemented Wastes - Resins	- Operation, Maintenance, Dismantling of Research or Industrial Facilities	- La Manche on surface Disposal Centre, under surveillance since 2003 (527,000 cu. m) - Aube Disposal Centre, opened in 1992 (Capacity : 1 million cu. m)
Very low-level	- Debris, scrap iron -Special Industrial Wastes	- Dismantling	- Morvilliers Disposal Centre in the Aube (Capacity : 650,000 cu. m)

Table 5 : Main categories of radioactive wastes in France
(source: National inventory of radioactive wastes – ANDRA)

On 31 décembre 2002	Volume	as % of the total volume of wastes	as % of the total radioactivity of wastes
High-level Long-lived	1,639 cu. m	0.2 %	96.05%
Intermediate-level Long-lived	45,359 cu. m	4.6 %	3.87%
Low-level Long-lived	44,559 cu. m	4.5 %	0.01%
Low- or Intermediate level Short-lived	778,322 cu. m	79.6 %	0.07%
Very low-level	108,219 cu. m	11.1 %	~ 0

Table 6 : Annual volumes of wastes

Type of Waste	Volume End 2002	Reference	Annual Volume	Reference	% Total Radioactivity
High-level Long-lived	1,639 cu. m	Cube–12 m side	110 cu. m/year	Cube–5m side	96.0%
Intermediate-level Long-lived	45,359 cu. m	Cube–36 m side	600 cu. m/year	Cube–8,5 m side	3.9%
Low- or Intermediate level Short-lived	778,322 cu. m	Cube–92 m side	28,000 cu. m/year	Cube–30 m side	0.1%

By comparing the quantities of nuclear wastes and industrial wastes produced annually, it can be seen that the former form only a minor share.

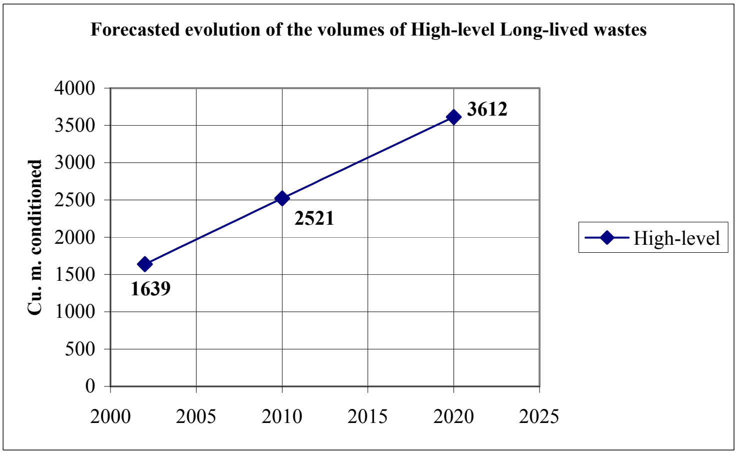
The annual quantity of special industrial wastes produced in France per inhabitant is 300 kg, including 100 kg of toxic chemical wastes, as against 1 kg of nuclear wastes. In this quantity of nuclear wastes, only 5 g are high-level wastes.

High-level wastes in 2002 : 96% of the total radioactivity in 1639 cu. m

High-level long-lived wastes result mainly from the reprocessing of spent fuels and represent the very low volume of 1639 cu. m at end 2002, i.e. 0.2% of the total. On the other hand, these wastes concentrate most of the total radioactivity of all radioactive wastes, i.e. 96%. Concentrating radioactivity in a low volume is one of the advantages of the reprocessing of spent fuels.

According to the ANDRA, the total volume of high-level wastes should not increase by more than a factor of 2.2 between now and 2020 (see following table).

Diagram 11 : Forecasted evolution of the volumes of high-level long-lived wastes between now and 2020
(source: National inventory of radioactive wastes – ANDRA)



Wastes come in the form of a glass matrix in a stainless steel canister and are for the time being stored at the site of La Hague and Marcoule, pending a definitive solution which is the central objective of the research performed under the Act of 30 December 1991.

Intermediate-level long-lived wastes

Intermediate-level long-lived wastes represent 4.6% of the total volume of radioactive wastes compared with 3.9% of their total radioactivity. Their volume stood at 45,359 cu. m at end 2002. They are mainly wastes from reprocessing processes, espcially hulls and end-fittings from fuel sheaths. Intermediate-level wastes conditioned represent only 36% of their total and are stored for the time being at the sites of Marcoule and La Hague, pending a definitive solution within the framework of the Act of 30 December 1991.

Low-level long-lived wastes represent a volume of 44,559 cu. m, approximately equal to that of intermediate-level long-lived wastes. Low-level long-lived wastes correspond to 4.5% of the total volume and 0.01% of the total radioactivity of radioactive wastes as a whole. They are awaiting a disposal solution.

Diagram 12 : Forecasted evolution of the volumes of intermediate-level long-lived wastes and low-level long-lived wastes between now and 2020 (source: National inventory of radioactive wastes – ANDRA)

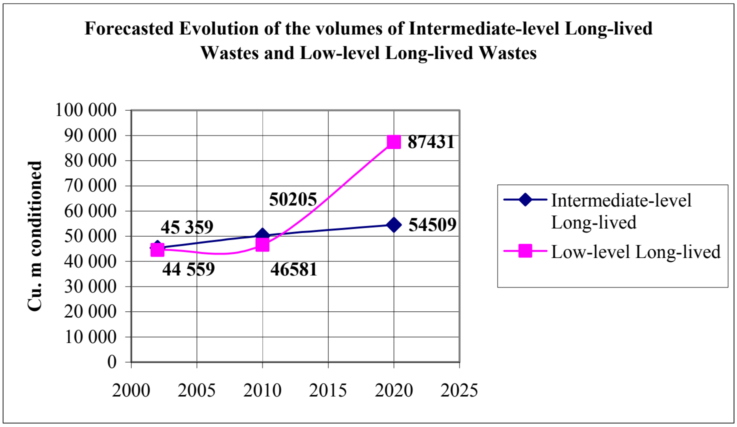


Diagram 13 : Forecasted evolution of the volumes of low- or intermediate-level short lived wastes and of very low-level wastes between now and 2020 (source: National inventory of radioactive wastes – ANDRA)

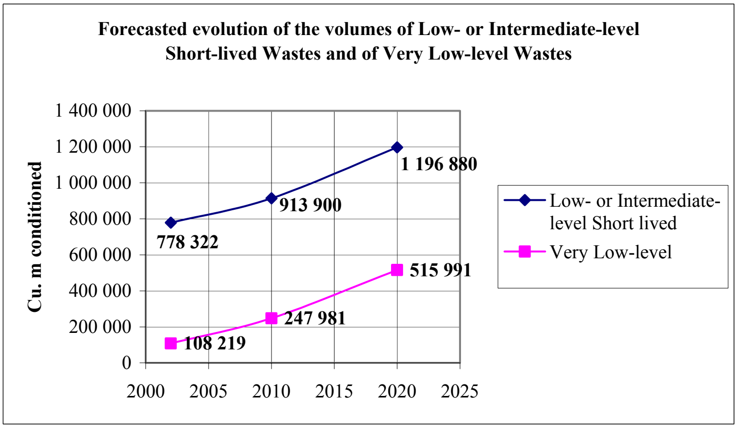
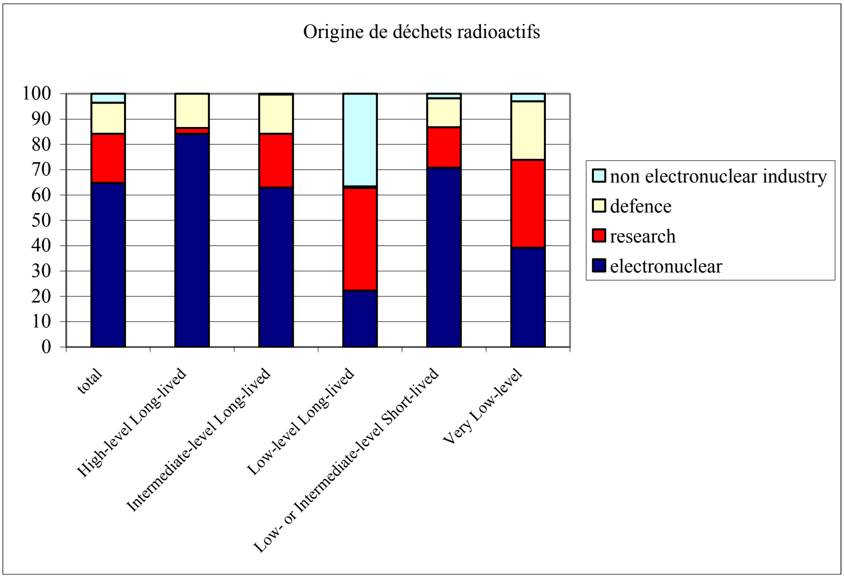


Diagram 14 : Sectoral origin of radioactive wastes on 31 December 2003, as a % of the equivalent total volume conditioned for each category of wastes (source: National inventory of radioactive wastes – ANDRA)



EDF is by far, in France, the main producer of radioactive wastes with 64.8% of the total volume. For high-level wastes, EDF's share reaches 84.2%.

ANNEX 2: MAIN CHARACTERISTICS OF THE RADIOELEMENTS PRESENT IN RADIOACTIVE WASTES

Table 7 : Main characteristics of the radioelements present in spent nuclear fuel[116]
(source: CEA)

Radioelement	Isotope	period	Radioactivity et Radiotoxicity	% of the total of the radioelement considered
I. Major Actinides				
Uranium	U 235	7,0. 10^7 years	alpha, gamma, very high (gr.I)	0.7%
	U 236	2,3. 10^7 years	alpha, high (gr.II)	0.5%
	U 238	4,5.10^9 years	alpha, gamma, low (gr.IV)	98.7%
Plutonium	Pu 238	88 years	alpha, gamma, very high (gr.I)	3%
	Pu 239	24 100 years	alpha, gamma, very high (gr.I)	52%
	Pu 240	6 600 years	alpha, gamma, very high (gr.I)	25%
	Pu 241	14,4 years s	bêta, alpha, gamma, very high (gr.I)	12%
	Pu 242	3,7.10^5 years	alpha, gamma, very high (gr.I)	8%
II. Minor Actinides				
Neptunium	Np 237	2,1. 10^6 years	alpha, gamma, very high (gr.I)	100%
Americium	Am 241	433 years	alpha, gamma, very high (gr.I)	63%
	Am 243	7370 years	alpha, gamma, very high (gr.I)	37%
Curium	Cm 244	18 years	alpha, neutrons, very high (gr.I)	91%
	Cm 245	8500 years	very high (gr. I)	6%

[116] Uranium oxide fuel – irradiation rate: 45 GW/t – after a cooling period of 5 years.

Radioelement	Isotope	period	Radioactivity et Radiotoxicity	% of the total of the radioelement considered
III. Short-lived Fission Products				
Strontium	Sr 90	28 years	bêta, forte (gr.II)	-
Cesium	Cs 137	30 years	bêta, gamma, moderate (gr.III)	-
IV. Long-lived Fission Products				
Zirconium	Zr 93	$1,5.10^{6}$ years	bêta, high (gr.II)	-
Technetium	Tc 99	$2,1.10^{5}$ years	bêta, low (gr.IV)	-
Palladium	Pd 107	$6,7.10^{6}$ years	bêta, low (gr.IV)	-
Iodine	I 129	$1,6.10^{7}$ years	bêta, gamma, low (gr.IV)	-
Cesium	Cs 135	$2,3.10^{6}$ years	bêta, low (grIV)	-

ANNEX 3 : ACT No. 91-1381 OF 30 DECEMBER 1991 ON RADIOACTIVE WASTE MANAGEMENT RESEARCH

Official gazette of 1 January 1992
ACTS

Act no. 91-1381 of 30 December 1991
on research on radioactive waste management research (1)
NOR: INDX9100071L

The National Assembly and the Senate have adopted,
The President of the Republic promulgates the Act of which the content follows:

Art 1. - High-level long-lived radioactive wastes must be managed in a manner respecting the protection of nature, the environment and health, while taking into consideration the rights of future generations.

Art. 2. - After Article 3 of Act no. 76-663 of 19 July 1976 on environmental-protection classified installations, an Article 3-1 is inserted which reads as follows:

'Art. 3.1. - The underground disposal in deep geological layers of dangerous products, of whatever nature, shall be subject to an administrative license. This license can be granted or prolonged only for a limited period and can therefore set forth the conditions of disposal reversibility. Products must be retrieved before expiry of the license.

The conditions and guarantees according to which some licenses can be granted or prolonged for an unlimited period, by derogation from the provisions of the preceding paragraph, shall be defined in a subsequent Act.'

Art. 3. - The disposal in France of imported radioactive wastes, even if reprocessed in the national territory, shall be banned after the technical lead times required by reprocessing.

Art. 4. - The Government shall send each year to Parliament a report stating the progress of research on the management of high-level long-lived wastes and of the work conducted simultaneously as regards the:

- Search for solutions allowing the separation and transmutation of the long-lived radioactive elements present in these wastes;

- Study of the possibilities of reversible or irreversible disposal in deep geological formations, particularly thanks to the construction of underground laboratories;

- Study of long-term conditioning and storage processes for these wastes at the surface

This report shall also mention the research and constructions made abroad.

Following a period which cannot exceed fifteen years from the promulgation of this Act, the Government shall send Parliament an overall assessment report on this research along with a bill authorising, where applicable, the creation of a disposal centre for high-level long-lived wastes and setting forth the regime of restrictions and subjections relating to said centre.

Parliament shall refer these reports to the Parliamentary Office for Scientific and Technological Assessment. These reports shall be disclosed to the public.

They shall be drawn up by a *Commission nationale d'évaluation* (National Assessment Board), composed of:

- Six qualified personalities including at least two international experts, appointed on an equal footing by the National Assembly and by the Senate, on proposal by the Parliamentary Office for Scientific and Technological Assessment;

- Two qualified personalities appointed by the Government on proposal by the Higher Board for Nuclear Safety and Information; and

- Four scientific experts appointed by the Government on proposal by the Sciences Academy.

Art. 5. - The conditions in which are set in place and operated the underground laboratories aimed at studying deep geological formations where high-level long-lived radioactive wastes could be disposed of or stored shall be determined in Articles 6 to 12 hereunder.

Art. 6. - Any project to set up an underground laboratory shall give rise, before any preliminary research work is started, to formal consultations with the elected representatives and populations of the sites concerned, as laid down by decree.

Art. 7. - The research work prior to the setting up of laboratories shall be executed in the manner laid down by the Act of 29 December 1892 on damage caused to private property by the execution of civil engineering works.

Art. 8. - Without prejudice to the application of Act no. 76-663 of 19 July 1976 on environmental-protection classified installations, the setting up and operation of an underground laboratory shall be subject to a license granted by decree at the Conseil d'Etat after: an impact study; obtaining the opinions of the municipal councils, general councils and regional councils concerned; and a public inquiry organised according to the procedures set forth by Act no. 83-630 of 12 July 1983 on the democratisation of public inquiries and environmental protection. This license shall be combined with specifications.

The applicant for such a license shall possess the necessary technical and financial capacities to fulfil such operations.

Art. 9. - The license shall grant its holder, within a perimeter defined by the original decree, the exclusive right to carry out surface and underground work and to dispose freely of the materials extracted during said work.

The owners of land situated within this perimeter shall be indemnified by amicable agreement with the license holder, or as applies in expropriation matters.

All or part of this land can be expropriated in the public interest for the benefit of the license holder.

Art. 10. - The licensing decree shall also set in place, outside the perimeter mentioned in the previous article, a protective perimeter within which the administrative authority can ban or regulate work or activities likely to compromise, on the technical level, the setting up or the operation of the laboratory.

Art. 11. - Radioactive sources can be temporarily used in these underground laboratories with a view to experimentation. Storage or disposal of radioactive wastes shall be banned in these laboratories.

Art. 12. - A public interest group can be set up in the manner laid down in Article 21 of Act no. 82-610 of 15 July 1982 on orientation and programming for technological research and development in France, with a view to conducting accompanying activities and managing equipment that can promote and facilitate the setting up and operation of each laboratory. Apart from the State and the license holder mentioned in Article 8, this group can be joined as of right by: the region and the department where the main access shaft to the laboratory is located; the boroughs where part of the territory is less than ten kilometres from this shaft; and any inter-borough cooperation body aimed at promoting economic development of the area in question.

Art. 13. - The *Agence nationale pour la gestion des déchets radioactifs* (National Agency for Radioactive Waste Management), an industrial and commercial public establishment, shall be created. Placed under the authority of the Ministry for Industry and the Ministry for Research and the Environment, this agency shall be tasked with the long-term management operations of radioactive wastes, and particularly with:

- Participating in defining and contributing to research and development programmes on the long-term management of radioactive wastes, in cooperation especially with the *Commissariat à l'énergie atomique*;

- Ensuring the long-term management of disposal centres either directly or through third parties acting on its behalf;

- Designing, locating and building new disposal centres, bearing in mind the long-term prospects of the production and management of wastes and performing any studies necessary for this purpose, especially by building and operating underground laboratories to study deep geological formations;

- Defining, in compliance with the safety rules, conditioning and disposal specifications for radioactive wastes;

- Listing the state and location of all radioactive wastes located in the national territory.

Art. 14. - At the site of each underground laboratory, a local disclosure and follow-up committee shall be created. This committee shall comprise in particular: representatives of the State, two Members of Parliament and two Senators appointed by their respective assembly; elected representatives from the territorial authorities consulted on the occasion of the public inquiry; members of environmental protection associations; agricultural unions; representatives of professional organisations; and representatives of personnel working in connection with the site as well as the license holder. This committee shall be composed, for at least half, by elected representatives from the territorial authorities consulted on the occasion of the public inquiry. It shall be presided by the prefect of the department where the laboratory is located. The committee shall meet at least twice a year. It shall be informed of the aims of the programme, the nature of the work and the results obtained. It can refer matters to the National Assessment Board mentioned in Article 4. The committee shall be consulted on all questions relating to the operation of the laboratory having effects on the environment and neighbouring communities. It can hold hearings or get second expert opinions from approved laboratories.

The establishment and operating costs of the local disclosure and follow-up committee shall be borne by the alliance set forth in Article 12.

Art. 15. – A Conseil d'Etat decree shall set forth, as and when required, the implementation criteria for this Act.

This Act shall be implemented as a State Act.

Done in Paris on 30 December 1991.

By the President of the Republic:
FRANCOIS MITTERAND

The Prime Minister
EDITH CRESSON

The Minister of State, Minister for the Economy, Finance and the Budget
PIERRE BEREGOVOY
The Minister of State, Minister for the Civil Service and Modernisation of the Administration
JEAN-PIERRE SOISSON
The Minister for Research and Technology
HUBERT CURIEN
The Minister for the Environment
BRICE LALONDE
The Minister delegate for Industry and Foreign Trade
DOMINIQUE STRAUSS-KAHN

(1) Preparatory work: Act no. 91-1381.
National Assembly:
Bill no. 2049;
Report by Mr Christian BATAILLE, on behalf of the Production Committee, no. 2115;
Debate on 25 and 27 June and adoption on 27 June 1991.
Senate:
Bill adopted by the National Assembly, no. 431 (1990-1991);
Report by Mr Henri Revol, on behalf of the Economic Affairs Committee, no. 58 (1991-1992);
Debate and adoption on 6 November 1991.
National Assembly:
Bill, amended by the Senate, no. 2319;
Report by Mr Christian BATAILLE, on behalf of the Production Committee, no. 2231;
Debate and adoption on 25 November 1991.
Senate:
Bill, adopted with amendments by the National Assembly at the second reading, no. 110 (1991-1992);
Report by Mr Henri Revol, on behalf of the Economic Affairs Committee, no. 127 (1991-1992);
Debate and adoption on 11 December 1991.
National Assembly:
Bill, amended by the Senate, at the second reading, no. 2450;
Report by Mr Christian BATAILLE, on behalf of the joint committee, no. 2464;
Debate and adoption on 17 December 1991;
Senate:
Bill, adopted by the National Assembly;
Report by Mr Henri Revol, on behalf of the joint committee, no. 169 (1991-1992);
Debate and adoption on 18 December 1991.

ANNEX 4: FINANCIAL RESOURCES ALLOCATED TO RESEARCH PURSUANT TO THE ACT OF 30 DECEMBER 1991

Diagram 15 : Evolution of the financial and budgetary resources allocated to research under the Act of 30 December 1991
(Source: Technology Directorate, Ministry delegate for Research, *'Stratégies et programmes de recherches sur la gestion des déchets radioactifs à haute activité et à vie longue'. – édition 2003)*

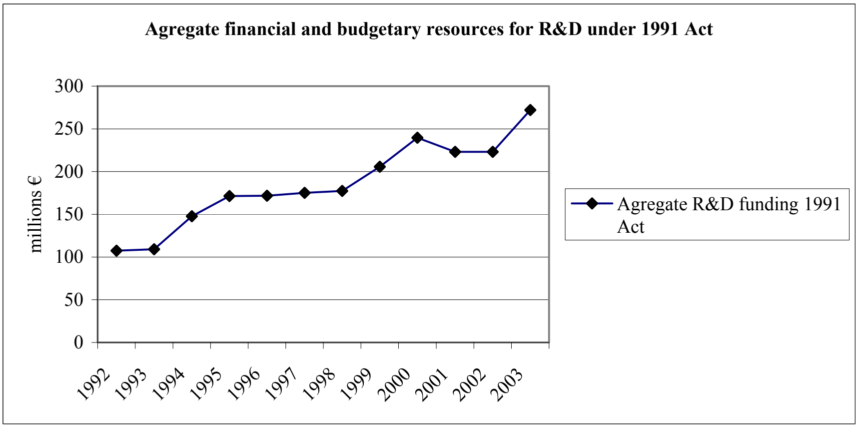


Diagram 16 : Breakdown, according to the three research strands, of the aggregate financial and budgetary resources for research conducted pursuant to the Act of 30 December 1991
(Source: Technology Directorate, Ministry delegate for Research, *'Stratégies et programmes de recherches sur la gestion des déchets radioactifs à haute activité et à vie longue'. – édition 2003)*

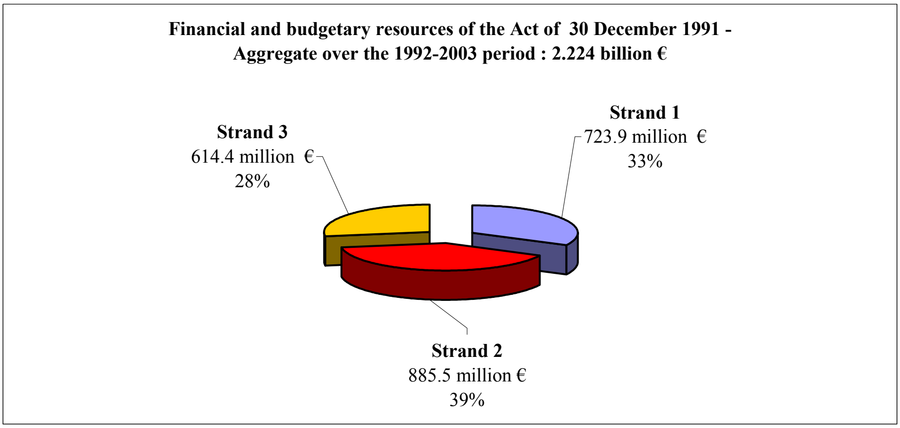
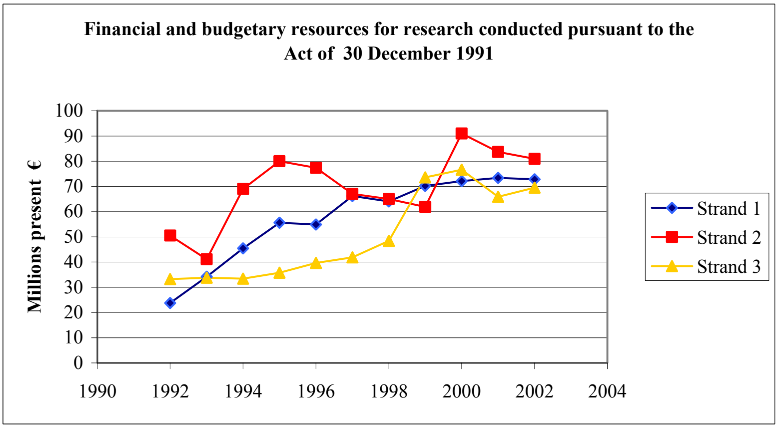


Diagram 17 : Annual evolutions of the financial and budgetary resources for research conducted pursuant to the Act of 30 December 1991
(Source: Technology Directorate, Ministry delegate for Research, *'Stratégies et programmes de recherches sur la gestion des déchets radioactifs à haute activité et à vie longue'. – édition 2003)*



ANNEX 5: LIST OF PERSONALITIES MET ON THE SPOT OR AT PRIVATE HEARINGS

EUROPEAN COMMISSION	
Mrs Loyola DE PALACIO	Vice-President
GERMANY	
French embassy in Germany	
His Exc. Claude MARTIN	French Ambassador in Germany
Miss Caroline BAHU	Sectoral Attachée-Economic mission
Mr Marcel BERVEILLER	Councillor for science and technology
Mr Nicolas CONDETTE	Scientific Attaché
Mr Thierry LE COCQ	Commercial Attaché
Parliament (Deutscher Bundestag)	
Mr Kurt-Dieter GRILL	MP
Mrs Ulrike MEHL	MP
Dr. Wolf-Dieter GLATZEL	SPD Group
Mr Christoph BENZE	Green Group
Mrs Michaele HUSTEDT	
Ministry for the Environment (BMU)	
Mr Alexander SPINCZYK-RAUCH	MinDirig - Unterabteilung RSIII
Dr. Michaël PAUL	Oberregierungsrat - RSIII
Dipl. Ing. Dieter MAJER	Ministerialdirigent
Dr. Wolf Diter THINNES	Regierungsdirektor
Ministry for the Economy and Labour (BMWA)t	
Dr. Dorothee MÜHL	Ministerialdirigentin
Dr. Horst SCHNEIDER	Ministerialrat - Division IX B3
DBE	
Mr Jürgen BEHRENS	Betriebsleiter
Mr Frank-Holger KOCH	Betriebsleiter
Mr Michael RIPKENS	Geschäftsfürher
E.ON ENERGIE AG	
Mr Gerald HENNEHÖFER	Generalbevollmächtiger
EnBW	
Mr Manfred VOLKER HABERZETTEL	Konzernbevollmächtigter
IPA	
Mrs Karina FORSTER	Managing Director
RWE AG	
Mr Volker HECK	Liaison Office Berlin
Dr. Klaus PETERSEN	Leiter Kernkraftwerke
BELGIUM	
ESV Euridice GIE	
Mr Frédéric BERNIER	Scientific Manager
Mr Marc DEMARCHE	Site Manager
ONDRAF	
Mr Jean-Paul MINON	Director General
SCK-CEN	
Mr Hamid Aït ABDERRAHIM	Director Reactor Physics & MYRRAH Department
Mr Paul GOVAERTS	Director General
Mr Franck DECONINCK	Chairman of the Board of Governors

Mr Philippe LALIEUX

UNITED STATES

US Congress	
Senator Pete DOMENICI	United States Senate
Mr Peter J. VISCLOSKY	Member of Congress
French Embassy	
Mr Jean-David LEVITTE	French Ambassador
Mr Régis BABINET	Nuclear councillor
Mr Cameron GRIFFITH	Congressional Affairs Liaison
Bisconti Research, Inc.	
Ms Ann BISCONTI	President
City of Las Vegas	
Oscar B. GOODMAN	Mayor
City of Las Vegas - Office of Business Development -	
Mr Jimmie PEGUES	Sr Economic Development Officer
Clark County, Nevada	
Ms Irene NAVIS	Planning Manager
Mr Engelbrecht VON TIESENHAUSEN	Comprehensive Planning
COGEMA, Inc.	
Mr Frédéric BAILLY	Manager, Spent Fuel Management Strategy
Mr Jacques BESNAINOU	Executive Vice President
Mr Ian HUNTER	Vice President, Government Operations
EDF International North America	
Ms Catherine GAUJACQ	President
Electricity Innovation Institute	
Mr TJ GLAUTHIER	President & Chief Executive Officer
Framatome ANP, Inc.	
Mr Nils BRECKENRIDGE	Manager Strategic Analysis & Marketing
GF Energy, LLC	
Mr Roger W. GALE	
Idaho National Engineering and Environmental Laboratory	
Dr Kemal PASAMEHMETOGLU	Director for Fuels
King Publishing Group	
Mr Llewellyn KING	Publisher & Editor-in-Chief
Lawrence Berkeley National Laboratory	
Mr Gudmundur S. BODVARSSON	Director - Earth Sciences Division
Lawrence Livermore National Laboratory	
Ms Cynthia ATKINS-DUFFIN	Chief of Staff - Energy & Environment Directorate
Mr Ronald W. COCHRAN	Laboratory Executive Officer
Mr Joseph C. FARMER	Directorate Senior Scientist
Mr William G. HALSEY	Nuclear Fuel Cycle - Focus Area Leader
Mr Tom ISAACS	Director - Office of Policy, Planning & Special Studies
Mr Frank M.G. WONG	Division Senior Scientist - Materials Science & technology Division
Los Alamos National Laboratory	
Mr John D. IMMELE	Deputy Director, National Security
Los Alamos AFCI Program Office	
Mr Michael W. CAPPIELLO	AFCI Los Alamos Program Manager
Los Alamos Neutron Science Center	
Mr Paul W. LISOWSKI	Division Leader
Los Alamos National Laboratory - Nuclear Technology Applications	

Mr Dana C. CHRISTENSEN	Office Director
Los Alamos - ANSCE Division Office	
Mr Richard L. SHEFFIELD	Senior Advisor
Natural Resources Defense Council	
Mr Thomas B. COCHRAN	Director, Nuclear Program
Nuclear Energy Institute	
Mr Marvin S. FERTEL	Senior Vice President
Ms Angelina S. HOWARD	Executive Vice President
Mr Alan NELSON	Senior Project Manager Licensing
Stanford Linear Accelerator Center	
Professor Burton RICHTER	Paul Pigott Professor in the Physical Sciences
Stanford University	
Mr Franklin M. ORR	Director, Global Climate and Energy Projet
The Lundquist Group, LLC	
Mr Andrew D. LUNDQUIST	President
US Department of Energy - Office of Nuclear Energy	
Ms Margaret S.Y. CHU	Director, Office of Civilian Radioactive Waste Management
Mr Carter D. SAVAGE	Office of Nuclear Energy, Science and Technology
Mr Paul T. DICKMAN	Senior Technical Policy Advisor Office of Civilian Radioactive Waste Management
Mr Frank GOLDNER	Office of Nuclear Energy, Science and Technology
Mr R.Shane JOHNSON	Associate Director for Technology and International Cooperation Office of Nuclear Energy, Science and Technology
Mr John L. WENGLE	Senior Advisor, Office of Civilian Radioactive Waste Management
Mr William MARTIN	Chairman, NERAC
Ms Elizabeth F. O'MALLEY	Intern'al Programs
US DOE - Carlsbad Field Office	
Mr Llyod L. PIPER	
Mr Dennis S. HURTT	Public Affairs Manager
US DOE Yucca Mountain Project	
Mr Robert A. LEVICH	International Programs
US DOE - Office of Civilian Radioactive Waste Management	
Mr Allen B. BENSON	Manager, Public Relations
U.S. Nuclear Regulatory Commission	
Mr Edward McGAFFIGAN, Jr.	Commissioner
Dr. Carl J. PAPERIELLO	Deputy Executive Director Office of the Executive Director for Operations
Ms Kathryn L. WINSBERG	Legal Assistant to Commissioner Edward
Mr Howard J. FAULKNER	OIP
United States Senate Committee on Energy	
Mr Peter LYONS	Counsellor
Berkeley University, College of Engineering	
Mr A. Richard NEWTON	Dean
Berkeley University - Nuclear Engineering	
Mr Joonhong AHN	Associate Professor
Mr Per PETERSON	Professor, Chair
Mr Paul A. WITHERSPOON	
US Nuclear Waste Technical Review Board	
Mr Mark D. ABKOWITZ	Member
Ms Paula N. ALFORD	Professional Staff - International Liaison
Mr William D. BARNARD	Executive Director
Mr David M. DIODATO	Senior Professional Staff
Ms Karyn D. SEVERSON	Director, External Affairs

White House Weekly

Ms Linda GASPARELLO	Associate Editor

FINLAND

Finnish parliament	
Mr Mikko IMMONEN	Member of Parliament
Mr Pekka NURMINEN	Secretary, Economy Committee
Mr Eelis ROIKONEN	Counsellor
French Embassy	
Mr Jean-Jacques SUBRENAT	Ambassador
Mr Laurent BERGEOT	Economic and Trade Councillor
Mrs Carole CUNISSET	Sector Manager
Mr Jean-Christophe MARGELIDON	Cooperation and Cultural Action Counsellor
Eurajoki Municipal Office	
Mr Altti LUCANDER	Member of the Municipal Council
Ms Hanna TUOMINEN	Town Clerk
Ministry for Trade and Industry	
Mr Jussi MANNINEN	Deputy Director General
POSIVA	
Mr Veli-Matti ÄMMÄLÄ	Project Director
Mr Timo SEPPÄLA	Director of Public Relations
Rauma Town	
Mr Vesa HEINO	President of the Municipal Council
Mr Pentti KOIVU	Mayor
Mr Hannu KUISMIN	Town Clerk
Mr Eero LAINE	President of the Board of Directors
Mr Tomi SUVANTO	Deputy Mayor
STUK	
Dr. Julius LAAKSONEN	Director General
M. Karl-Heinz HELLMUTH	Senior Advisor - Waste Management
TVO	
Mr Martti KÄTKÄ	Senior Advisor
VTT	
Professor Mikko KARA	Executive Director
Professor Seppo VUORI	Deputy Director of Research on Nuclear Energy
M. Rauno RINTAMAA	Materials and Structural Integrity

SWEDEN

Swedish parliament	
Ms Marie WAHLGREN	Member of Parliament
French embassy	
His Exc. Mr Denis DELBOURG	Ambassador
Mrs Jacqueline BASSA-MAZZONI	First Counsellor
Miss Anne DABIN	International Volunteer
Mr François MANNEVILLE	Cultural and Scientific Councillor
Mr Daniel LANES	Economic mission, Head of the capital good sector
AFSR	
Mrs Cristina BRATT	
Mr Tim FRANCOIS	
Mrs Françoise RUGEL	Secretary General
OKG Aktiebolag	
Ms Anna-Lena NARAGHI	Public Relations Director

SKB

Mr Claes THEGERSTRÖM	President
Mrs Saida ENGSTRÖM	Director - EIA & Public Information Departement

SKB-Aspö Hard Rock Laboratory

Mr Kaj NILSSON	Project Director
Mr Christer SVEMAR	Director of the Aspö Laboratory

SKI

Mr Christer VIKTORSSON	Deputy Director General
Mr Anders JÖRLE	Director - Department of Communication and PR
Mr Gustav LÖWENHIELM	Director - Department of Research
Ms Josefin PÄIVIÖ	Investigator
Mr Övind TOVERUD	Senior Geologist

SWITERLAND

Economic mission of the French embassy

Mr Philippe ABELIN	Trade Counsellor
Mrs Monique ARRIBET	Sectoral Attachée

Geotechnical Institute

Mr Heinz STEIGER	Site Manager Mont Terri

HSK-DSN

Mr Erik FRANK	DSN Delegate at Mont Terri

NAGRA

Mr André LAMBERT	Dep. Div. Head Repository Proj.
Mr Piet ZUIDEMA	Division Head Sc. & Tech.
Mr Theo KUPFER	Site Manager Grimsel

Federal Office for Water and Geology

Mr Marc THURY	Director, Mont Terri project

Paul Scherrer Institute

Mr Walter FISCHER	Head of Research-Dpt
Mr Jörg HADERMANN	Head of the Waste Mgt Lab.
Mr J. Friso VAN DEN VEEN	Dpt Head Synchrotron Radiation

ZWILAG

Mr Donat GUBLER	Chemiker HTL
Mrs PFISTER	Public Relations

France

Ministry delegate for Industry

Mr Patrick DEVEDJIAN	Minister delegate for Industry
Mr Bruno BENSASSON	Technical Counsellor

Ministry delegate for Research

Mr François D'AUBERT	Minister delegate for Research

Haute-Marne parliamentarian

Mr Bruno SIDO	Senator

Meuse parliamentarians

Mr François DOSÉ	Member of Parliament
Mr Jean-Louis DUMONT	Member of Parliament
Mr Gérard LONGUET	Senator

General Council of the Haute-Marne

Mr Bruno SIDO	Senator of the Haute-Marne
Mr Antoine ALLEMEERSCH	Vice-President, General Councillor of the Canton of Poissons
Mr Michel BOZEK	Vice-President, General Councillor of

	the Canton of Chevillon
Mr Jean-Luc BOUZON	General Councillor of the Canton of Saint Dizier
Mr Thierry DELONG	Vice-President, General Councillor of the Canton of Doulaincourt
Mr Gérard HEISERT	General Councillor of the canton of Joinville
Mr Didier JANNAUD	General Councillor of the canton of Auberive
Mr Jean MASSON	Director of the Haute-Marne GIP
General Council of the Meuse	
Mr Christian NAMY	President
Mr Denis CORDONNIER	First Vice-President (Monfaucon)
Mr Jean-Louis CANOVA	General Councillor (Ancerville)
Mr Daniel LHUILLIER	General Councillor (Gondrecrout-le-Château)
Mrs Sylvie MALFAIT-BENNI	General Councillor (Montier-sur-Saulx)
Mr Pascal BABINET	Administrative Director
Mr Eric CHAGNEAU	Directeur of the GIP
Regional council of the Champagne Ardenne region	
Mr DAVERDON	Regional Councillor
Mrs COTILLOT	Regional Councillor
Mr DAMEREY	Regional Councillor
Mr LEGRAND	Cabinet of Mr Jean-Paul BACHY, President
Regional council of Lorraine	
Mr Daniel BÉGUIN	Vice-President with responsibility for the environment
Mr Thibaut VILLEMIN	Vice-President with responsibility for culture
Public interest group – GIP 52	
Mr Bruno SIDO	President of the General Council of the Haute-Marne, President of GIP 52
Mr Jean-Marcel LAMBINON,	President of the Chamber of Commerce and Industry of the Haute-Marne, Administrator of the GIP
Mr Antoine ALLEMEERSCH	Vice-President of the General Council, General Councillor of the canton of Poissons
Mr Gilles LAVOCAT	Mayor of Poissons, Administrator of the GIP
Mr Denis MAILLOT	General Councillor of the Canton of Vignory, Administrator of the GIP
Mr Jean-Bernard HERGOTT	Director of the Chamber of Commerce and Industry
Mr Jean MASSON	Director of the GIP
Prefecture of the Haute-Marne	
Mr Alain WAQUET	Prefect of the Haute-Marne
Mr Jacques LAUVERGNAT	Sub-Prefect of Saint Dizier
Mr Thierry DEVIMEUX	Secretary General
Prefecture of the Meuse	
Mr Richard SAMUEL	Prefect
Mr Bernard FERY	Coordinator, major work sites
Mr Hubert VERNET	Secretary General
Mr Benoît JACQUET	Chargé de mission
Mrs Sophie COUTOR	Sub-Prefect of Verdun
Mr Éric ETIENNE	Sub-Prefect of Commercy
Mr Jérôme STERPENICH	Scientific Secretary of the CLIS
GIP 55 - Objectif Meuse	
Mr Eric CHAGNEAU	Director

Mr Jérôme GOELLNER — Administrator, DRIRE[117]
Mr Michel JUBERT — President of the Chamber of Commerce and Industry
Mr François GODINOT — Director of the Chamber of Commerce and Industry
Mr Denis CORDONNIER — First Vice-President of the General Council, Administrator
Mr Claude MOUTAUX — Mayor of Montiers-sur-Saulx, Administrator
Mr Daniel LHUILLIER — General Councillor, Administrator
Mr Jean-Paul BAILLET — Secretary General of the ANDRA, Administrator
Mr Noël EYRIGNOUX — Paymaster General

CLIS Bureau at the Meuse/Haute-Marne laboratory

Mr Richard SAMUEL — Prefect of the Meuse
Mr Jean-Marcel LAMBINON, Chamber of Commerce and Industry of the Haute-Marne
Mr Jean-Paul LHERITIER — Chamber of Trade, Meuse
Mr François DOSÉ — Member of Parliament, Meuse
Mr Antoine ALLEMEERSCH — General Councillor of the Haute-Marne
Mrs Sylvie MALFAIT-BENNI — General Councillor of the Meuse
Mr Jacky BOUSSEL — Mayor of Echenay
Mr Robert FERNBACH — Mayor of Houdelaincourt
Mr Gérard ANTOINE — Mayor of Bure
Mr Gilles LAVOCAT — Mayor of Poissons
Mr Jean-Marc FLEURY — Association of Meuse elected representatives opposed to the laboratory, Vice-President of the CLIS
Mr André MOUROT — CEDRA 52[118]
Mr Michel MARIE — CDR 55[119]
Mr Pascal WOJCIK — CFDT Meuse[120]
Mr Jean COUDRY — CGC Haute-Marne and Meuse[121]

ANDRA

Mr François JACQ — Director General
Mr Jacques-Pierre PIGUET — Director of the Bure laboratory
Mr Philippe STOHR — Deputy Director General
Mr Jack-Pierre PIGUET — Director of the Meuse/Haute-Marne laboratory
Mr Grégoire ANDRE
Mr Gilles ARMAND
Mr Martin CRUCHAUDET
Mr Jean-Marie KRIEGUER
Mr Jacques MOREL
Mr Yannick WILEVEAU

AREVA

Mrs Anne LAUVERGEON — President of the Executive Board
Mr Philippe GARDERET — Director of Research and Innovation
Mrs Christine GALLOT — Directorate for Institutional Relations

CEA

Mr Alain BUGAT — Administrator General

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[117] DRIRE : Direction Régionale de l'Industrie et de l'Environnement (Regional Directorate for Industry and the Environment)
[118] Collectif contre l'Enfouissement des Déchets Radioactifs de la Haute Marne (Collective against the burial of radioactive wastes of the Haute Marne department)
[119] Collective against the burial of radioactive wastes of the Meuse department
[120] Confédération française démocratique du travail (trade union)
[121] Confédération générale des cadres (trade union)

Mr Jacques BOUCHARD	Nuclear Energy Director
Mrs Pascale AMENC-ANTONI	Director of CEA/Cadarache
Mr Loïc MARTIN-DEIDIER	Director of CEA/ Marcoule
Mr Patrice BERNARD	Director of nuclear development and innovation
Mr Michel BOIDRON	Head of the fuel cycle technology department
Mr Gilles BORDIER	Head of the studies department on the processing and conditioning of wastes
Mr Bernard BOULLIS	Head of the radiochemistry and processes department
Mr Guy BRUNEL	Deputy Director of the CECER[122]
Mr Jean-Louis CARBONNIER	Head of the reactor studies department
Mr Franck CARRE	Directorate for nuclear development and innovation
Mr Charles COURTOIS	Directorate for the 'research on wastes management' programme
Mr Jean-Pierre MONCOUYOUX	Deputy director, Marcoule
Mrs Sylvie PILLON	Researcher engineer
Mrs Michèle TALLEC	DDIN[123]
Mrs Catherine SANTUCCI for the	Head of the laboratory modelisation of transfers in the environment
CNRS	
Mr Michel SPIRO	Director of the Nuclear and Corpuscular Physics Department
Mr Hubert DOUBRE	PACE programme officer
Mr Christian LEBRUN	PACE programme
Mr Sylvain DAVID	PACE programme
Commission nationale d'évaluation	
Mr Bernard TISSOT	President
Mr Pierre BEREST	Councillor
Mr Ghislain DE MARSILLY	Councillor
Mr Jean-Claude DUPLESSY	Councillor
Mr Robert GUILLAUMONT	Councillor
Mr Juan-Manuel KINDELAN	Councillor
Mr Jacques LAFUMA	Councillor
Mr Jean LEFEVRE	Councillor
Mr Olivier PIRONNEAU	Councillor
Mr Jean-Paul SCHAPIRA	Councillor
DGEMP[124]	
Mr Dominique MAILLARD,	Director General for Energy and Raw Materials
Mrs Sophie GALEY-LERUSTE	Director for energy and mineral resources
Mrs Florence FOUQUET	Officer responsible for the nuclear industry sub-directorate
DGSNR	
Mr André-Claude LACOSTE	Director General for Nuclear Safety and Radioprotection
Mr Romain CAILLETON	Sub-Director for Nuclear Facilities
Mr Philippe BODENEZ	Deputy Sub-Director for Nuclear Facilities
Technology Directorate, Ministry delegate for Research	
Mr Jean-Jacques GAGNEPAIN	Director of Technology
Mr Bernard FROIS	Director of the Energy Department

[122] Centre d'Expertise sur le Conditionnement et l'Entreposage des matières Radioactives (Expertise Centre on the Conditioning and Storage of Radioactive Materials)
[123] Nuclear Development and Innovation Division
[124] Direction générale de l'énergie et des matières premières (Directorate General for Energy and Raw Materials)

ECRIN[125]	
Mr Christian NGÔ	General Delegate
EDF	
Mr Pierre GADONNEIX	Président
Mr Bernard DUPRAZ	Deputy Director General - Production, engineering
Mr Bruno LESCOEUR	Deputy Director General - International
Mrs Anne LE LORIER	Deputy Director – Financial Directorate
Mr Gérard TROUVÉ	Public Affairs Director
Mr Bertrand LE THIEC	Public Affairs Directorate
IRSN	
Mr Jacques REPUSSARD	Director General
Mr Helmut PITSCH	DPE-modelisation laboratory
Ministry for ecology and sustainable development	
Mr Thierry TROUVÉ	DPPR[126]
Mr JOINDROT	Head of the radioactive pollutions bureau - DPPR
Mr Dominique BERGAUD	Chargé de mission – DPPR
Ministry of the Interior, Internal Security and Local Rights	
Mr Henri-Michel COMET	Prefect, Cabinet Deputy Director
Mr GAILLARD DE LAVERNEE	Director, Directorate for Defence and Civil Security
Mrs Florence BERTHOUT	Parliamentary adviser

[125] An association bringing companies and research laboratories together to optimise technology transfers and develop transversal innovation.

[126] Direction de la prévention des pollutions et des risques (Directorate for the prevention of pollutions and risks)

ANNEX 6 : LIST OF AUTHORS OF PRESENTATIONS DURING THE PUBLIC HEARINGS ON 20 AND 27 JANUARY AND 3 FEBRUARY 2005

NB: The verbatim report of the three days of public hearings can be consulted on the National Assembly (www.assemblee-nationale.fr) and Senate (www.senat.fr) websites.

PUBLIC HEARING OPEN TO THE PRESS
Thursday 20 January 2005
Strand 1 : Separation and Transmutation

AGENDA

9:00 : Introduction by **Mr Henri REVOL**, Senator, President of the Parliamentary Office for Scientific and Technological Assessment and by **Mr Christian BATAILLE** and Mr **Claude BIRRAUX**, Members of Parliament, Rapporteurs

9:15 : **M. Alain BUGAT**, Administrator general, CEA

9:30 : **Dr Hermann GRUNDER**, Director, Argonne National Laboratory, DOE, United States

9:50: **Mr Philippe PRADEL**, Nuclear Energy Director, CEA

10:00: **Mr Bernard BOULLIS**, Head of the radiochemistry and processes department

10:15 : **Dr. Kemal PASAMEHMETOGLU**, AFCI/GIV Technical Director for fuels, Idaho National Engineering and Environmental Laboratory (INEEL), United States

10h30 – 11h00 : Debate with stakeholders and other participants

<u>11h-11h15 : Break</u>

11h15 : **Mr Jean-Louis CARBONNIER et Ms Sylvie PILLON**, Reactor Studies Department, CEA

11h35 : **Professor Carlo RUBBIA**, Nobel Prize

11h55 : **Dr. Hamid Aït ABDERRAHIM**, SCK-CEN, Belgium

12h10 : **Professor Waclaw GUDOWSKI**, KTH, (Sweden)

<u>12h30 - 14h30 : Break</u>

14h30 : **Mr Michel SPIRO**, Director of the Nuclear and Corpuscular Physics Department, CNRS

14h45 – 15h15 : Debate with stakeholders and other participants

15h15 : **Mr André-Claude LACOSTE**, Director general for Nuclear Safety and Radioprotection

15h35 : **Ms Michèle VIALA**, Director of the waste management programme, IRSN

15h45 : **Mr Bernard DUPRAZ**, Deputy Director general-production and engineering, EDF

16h00 : **Mme Florence FOUQUET,** Nuclear Industry Department Head, DGEMP, Ministry delegate for Industry

16h15 : **Mr Bernard TISSOT**, President, et **Mr Jean-Paul SCHAPIRA**, Member, National Assessment Board

16h30 : **Ms Anne LAUVERGEON**, Chairman of the Executive Board, AREVA

16h45 : **Mr Bernard FROIS**, Director of the Energy Department, Technology Directorate, Ministry delegate for Research

17h-17h30 : Debate with stakeholders and other participants

17h30 : **Mr François d'AUBERT**, Minister delegate for Research

17h45 : Concluding Remarks by **Mr Christian BATAILLE et Mr Claude BIRRAUX**, Members of Parliament, Rapporteurs

PUBLIC HEARING OPEN TO THE PRESS
Thursday 27 January 2005
Strand 2 : Reversible or irreversible disposal in geological formations

Agenda

9:00 : Introduction by **Mr Henri REVOL**, Senator, President of the Parliamentary Office for Scientific and Technological Assessment and by **Mr Christian BATAILLE** and Mr **Claude BIRRAUX**, Members of Parliament, Rapporteurs

9:15 : **Mr Édouard BRÉZIN**, President, National Academy of science

9:30 : **Mr Didier LOUVAT**, Waste Safety Section Head, IAEA

9:45 : **Mr Jean-Paul MINON**, Director general, ONDRAF (Belgium)

10:00 : **Mr François JACQ**, Director general, ANDRA

10:15 : **Mr John ARTHUR**, OCRWM, DOE, United States

10:30 – 11:00 : Debate with stakeholders and other participants

11:00-11:15 : Break

11:15 : **Ms Sylvie JOUSSAUME**, Director, INSU, CNRS

11:30 : **Mr Christian FOUILLAC**, Director of research, BRGM

11:40 : **Mr Philippe LALIEUX,** Underground Repository Project Manager, and **Mr Guy COLLARD**, Radioactive Waste and Remediation Director, SCK-CEN (Belgium)

11:55 : **Dr Jürg SCHNEIDER**, NAGRA, Switzerland

12:10 : **Dr Siegfried KÖSTER**, Ministry for Economy and Labor, Germany

12:25 : **Ms Michèle TALLEC**, Projet Manager – Conditioning, Storage and Disposal of Intermediate-level Long-lived Wastes, CEA

12:35 – 13:00 : ***Debate with stakeholders and other participants***

13:00-14:30 : Break

14:30 : **Mr Jack-Pierre PIGUET**, Director, Meuse/Haute-Marne Laboratory, ANDRA

14:45 : **Mr Patrick LANDAIS**, Director of Research, ANDRA

15:00 : **Mr Bernard FROIS**, Director, Department of Energy, Ministry delegate for Research

15:15 : **Ms Saida LAÂROUCHI ENGSTRÖM**, SKB, Suède

15:30 : **Ms Anna VÄÄTÄINEN**, Energy Department, Ministry for Trade and Industry, Finland

15:45 : **Mr Philippe STOHR**, Deputy Director general, ANDRA

16:00 – 16:30 : ***Debate with stakeholders and other participants***

16:30-16:45 : Break

16:45 : **Mr Christophe DELLIS**, Project Manager, Simulation and Experimental Device Direction, CEA

17:00 : **Mr Jacques REPUSSARD**, Director general, IRSN

17:15 : **Mr Bernard TISSOT**, President et **Mr Jean-Claude DUPLESSY**, Member, National Assessment Board

17:30 : **Mr André-Claude LACOSTE**, Director general for Nuclear Safety and Radioprotection

17:45 : **Ms Sophie GALEY-LERUSTE,** Director, Energy and Mineral Resource, DGEMP, Ministry delegate for Industry

18:00 : Concluding remarks by **Mr Patrick DEVEDJIAN**, Minister delegate for Industry

PUBLIC HEARING OPEN TO THE PRESS
Thursday 3 February 2005
Strand 3 : Long term Conditioning and storage

Agenda

9:00 : IIntroduction by **Mr Henri REVOL**, Senator, President of the Parliamentary Office for Scientific and Technological Assessment and by **Mr Christian BATAILLE** and Mr **Claude BIRRAUX**, Members of Parliament, Rapporteurs

9:15 : **Mr André-Claude LACOSTE**, Director general for Nuclear Safety and Radioprotection

9:30 : **Mr Andris PIEBALGS,** European Commissioner for Energy, European Union

9:45 : **Professor Burton RICHTER,** Nobel Prize for Physics, United States

10:05 : **Mr Philippe PRADEL,** Nuclear Energy Director, CEA

10:15 : **Mr Claes THEGERSTRÖM,** President, SKB, Sweden

10:30 – 11:00 : Debate with stakeholders and other participants

11:00-11:15 : Break

11:15 : **Dr Jukka LAAKSONEN,** Director general, STUK, Finland

11:30 : **Mr Gilles BORDIER,** Head, Waste Characterization and Long term Packaging Department, CEA

11:45 : **Mr Jean-Pierre MONCOUYOUX et Mr Guy BRUNEL,** Department of Conditioning and Storage of Radioactive Wastes, CEA

12:00 : **Mr Jacques BESNAINOU,** Director, Processing and Recycling Business Unit, AREVA

12:15 : **Mr Jean-Christophe NIEL,** Director for Strategy, IRSN

12:25 – 13:00 : Debate with stakeholders and other participants

13:00-14:30 : Break

14:30 : **Mr François JACQ,** Director general, ANDRA

14:45 : **Mr Bernard TISSOT, President et Mr Robert GUILLAUMONT, Member,** National Assessment Board (CNE)

15:00 : **Mr Bernard FROIS**, Director, Department of Energy, Ministry delegate for Research

15:15 – 16:30 : ***Debate with stakeholders and other participants***

16:30 – 16:45 : Break

16:45 : **Mr Alain BUGAT,** Administrator general, CEA

17:00 : **Mr Pierre GADONNEIX,** Chairman, Électricité de France

17:15 : **Mr Dominique MAILLARD,** Director general for Energy and Natural Resource, DGEMP, Ministry delegate for industry

17:30 : ***Concluding Remarks by Mr Christian BATAILLE et Mr Claude BIRRAUX, Members of Parliament, Rapporteurs***

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