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Radioactive Waste Management

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Abstract

A common property of radioactive waste is that it presents a hazard to human health and the environment. Then, it must be managed in order to reduce risks to acceptable levels. The preferred strategy for the management of all radioactive waste is to contain it and isolate it from the accessible biosphere during its decay. However, the controlled discharge of effluents from waste management activities containing residual radionuclides is possible in some conditions. For solid radioactive waste, only disposal in appropriate safety conditions adapted to the type of waste should be considered as a definitive management option. The types of disposals can go from near surface landfill-type facilities, with limited regulatory control, to underground repositories in stable geological formations, at a depth of several hundreds of meters. As management of radioactive waste is a great concern for public and influences its perception of the nuclear industry, much concern should be given to stakeholder involvement in the field of radioactive waste. In particular, the public should not only be informed but also should be involved in the process of decision making.

Radioactive waste comes from the generation of electricity in nuclear power plants, from nuclear fuel cycle operations and from other activities in which radioactive materials are used, like hospitals or research facilities. Radioactive waste also arises from processes where naturally occurring radionuclides are concentrated in waste material. It is for example the case of mining and minerals processing facilities. The properties of radioactive waste are very different, not only in terms of radioactive content but also in terms of physical and chemical properties.

A common property of radioactive waste is that it presents a hazard to human health and the environment. Then, it must be managed in order to reduce risks to acceptable levels. The potential hazard being variable, the management and disposal options for various types of waste are also very different.

The preferred strategy for the management of all radioactive waste is to contain it and isolate it from the accessible biosphere during its decay. However, the controlled discharge of effluents from waste management activities containing residual radionuclides is possible in some conditions.

The first part of this paper deals with liquid and gaseous discharges treatment; the second part with solid waste management and disposal. Finally, the third part of this paper gives some considerations about stakeholder involvement in the field of waste management.

1. Liquid and gaseous discharges treatment

To satisfy the ALARA principle, the issue of liquid or gaseous discharge treatment cannot be examined in isolation.

Indeed, the production and treatment of liquid or gaseous discharges is the result of a compromise between various requirements associated with the operation of installations and the protection of different interests: safety, production and management of radioactive waste from a wide variety of activities and periods, protection of employees, public health, the environment, etc.

The decision whether to produce effluent or waste is regularly debated, both by nuclear installation operators and environmental protection associations with approaches which may appear contradictory.

The former argue that the implementation of treatment designed to avoid discharges will lead to waste being produced. They also underline the fact that procedures for containment of waste become proportionally all the more heavy and expensive that the radionuclide concentration is low. Below a certain level, they consider that the radionuclides cannot reasonably be recovered, particularly as containment operations become such that they have a radiological impact on employees which is disproportionate to the potential benefit for the public.

The latter usually call for radionuclide concentrations in the environment close to zero. They rely, in particular, on international agreements that are in place. This is the case, for example, of the convention on the protection of the marine environment of the North-East Atlantic, known as the OSPAR Convention, signed in 1992, ratified by 15 European countries and approved by the European Community. The aim of this convention is for concentrations in the marine environment to become close to zero for artificial substances and near background values for naturally occurring substances by 2020.

These approaches show the need:
- to have an integrated approach giving equal priority to safety, radiological protection and environmental protection through management of waste and liquid and gaseous discharges;
- to consider the impact each installation has on its own environment.

It is also vital that the choices put forward by nuclear installation operators are explicit. Thus, the trade-offs between the containment of substances or their dispersal and the abandonment, for safety and radioprotection reasons, of certain reduction at source or treatment options must be made clear. This approach is essential, on the one hand, to enable the authorities to validate the choices put forward by the operators and, on the other hand, to provide the public with all the assessment factors enabling them to form their own opinion.

What methodology should be used to validate these choices?

In this respect, the concept of Best Available Techniques (BAT) may be a vital methodological tool in analysing the situations.

This concept has been widely developed in the field of non-radioactive discharges. The European Union has thus defined it as a discharge optimisation process in the 1996 IPCC (Integrated Pollution Prevention and Control) Directive.

The IPPC directive defines in article 2, the concept of best available technique:
'best available techniques` shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

- 'techniques` shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,
- 'available` techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator,
- 'best' shall mean most effective in achieving a high general level of protection of the environment as a whole.'

The main considerations to be borne in mind, generally speaking or in a specific situation, for determining the best available techniques in economically and technically viable conditions, taking into account the costs and potential benefits of an action are as follows:

- use of techniques that produce low amounts of waste;
- use of less hazardous substances;
- development of recovery and recycling techniques for substances emitted and used in the procedure and waste, if any;
- comparable procedures, equipment or operating methods which have been successfully used on an industrial scale;
- technical progress and development of scientific knowledge;
- nature, effects and volume of the emissions in question;
- consumption and nature of raw materials (including water) used in the procedure and the energy efficiency;
- need to prevent or reduce to a minimum the overall impact of emissions and risks to the environment.

The work carried out in 2003 by the OECD Nuclear Energy Agency suggests, in the report "Effluent Release Options from Nuclear Installations" [1], transcribing these principles in nuclear installations.

These principals are detailed in the following figure:

Figure 4a. **Nuclear BAT management factors for optimisation of releases from nuclear installations**

Use of low waste technology	Efficient use of resources	Reduced emissions	Use of less hazardous substances
• Minimise the generation of radioactive wastes from the nuclear facility	• Improve the eco-efficiency of the nuclear facility (e.g. emissions / Gwa)	• Concentrate and contain environmentally persistent or bioaccumulative emissions	• Radioactive wastes should be created in a passively safe waste form
• Radioactive wastes should be created in a manageable waste form	• Optimise both radioactive and non-radioactive impacts to reduce the environmental footprint of the facility	• Reduce transboundary geographic displacement of environmental impacts	• Condition and immobilise unstable waste forms into a passively safe state
• Minimise treatment and conditioning necessary to safely store wastes	• Prioritise environmental expenditure to maximise the amount of radioactive pollution avoided for each € invested	• Minimise potential radioactive releases from credible accident conditions and their consequences for the environment	• Wastes should be capable of interim safe storage prior to final disposal in a repository
	• Progressively reduce worker doses from waste treatment and conditioning processes	• Progressively reduce emissions	• Wastes should be capable of being stored in a monitorable and retrievable waste form

This process is an iterative process which should be reviewed periodically, in particular to take into account advances in technology, scientific and regulatory knowledge and the state of the environment.

Examples of this approach being used are starting to be identified and demonstrate its relevance. However, general data allowing the introduction of the best available techniques in a given installation to be assessed is fragmented. More in-depth work on the subject could be carried out internationally.

Moreover, pre-discharge effluent management policies must not simply relate to the actual effectiveness of treatment but also integrate the radioactive reduction of radioelements and consideration of the environmental discharge conditions themselves. France has therefore integrated regulatory obligations aimed at storing radioactive gaseous elements for at least 30 days before discharge and the obligation to carry out such discharge in meteorological conditions that will allow the best possible dispersal into the environment. Similarly, for liquid discharges, operators have a legal duty to store radioactive liquid effluents for as long as is necessary to obtain a level of radioactivity compatible with the discharge parameters (flow rate, duration, quantity) required for the receiving environment.

2. Solid waste management and disposal

2.1. General principles

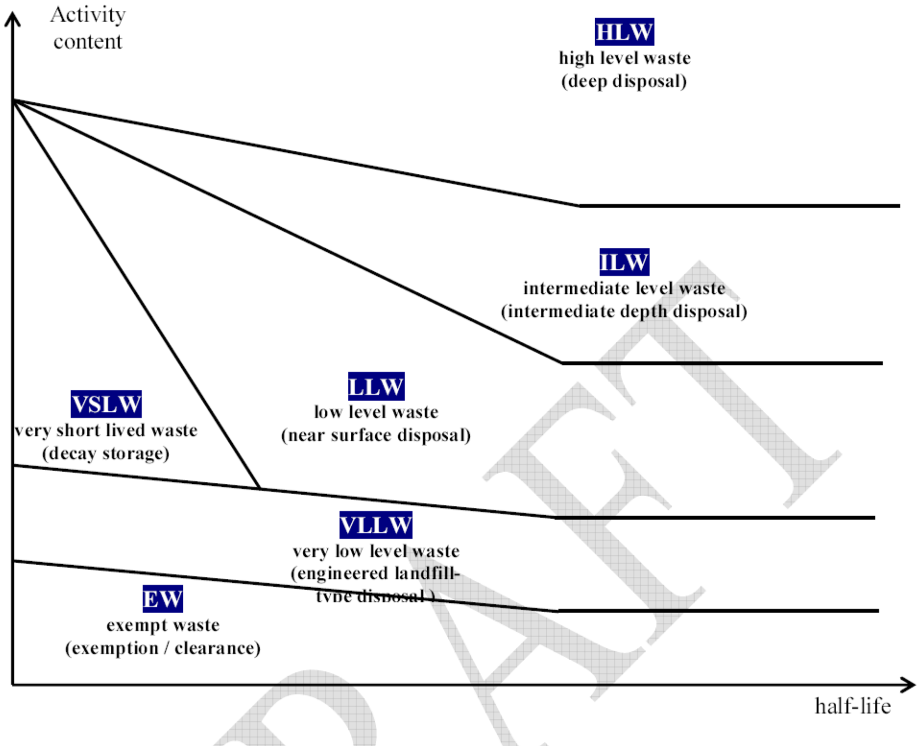
In « The Principles of Radioactive Waste Management » [2], approved by the IAEA's Board of Governors in 1995, the objective of radioactive waste management is defined as "to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations".

Nine major principles that should be applied to radioactive waste management are defined in this document:

- "Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
- Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
- Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
- Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
- Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
- Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
- Generation of radioactive waste shall be kept to the minimum practicable.
- Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
- The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime."

Those general principles should be declined in the ways chosen to manage different types of waste. In all cases, storage should be considered as a non-definitive solution and only disposal in appropriate safety conditions considering the type of waste should be considered as a definitive management option.

The IAEA draft safety standard 390 [3] proposes a classification of radioactive waste considering their activity content and their half-life. This classification is based on the management option available for each type of waste. The corresponding chart is the following.



Classification of radioactive waste in draft safety standard DS390 [4]

In the following paragraphs, this article will develop, for each waste described in this chart, the possible management options and the adapted types of disposal.

2.2. Exempt waste / Very Low Level Waste

Some wastes contain such small concentrations of radionucleides that they do not require specific radiation protection measures. A management solution for those wastes can be to clear, exempt or exclude them from regulatory control. The IAEA Safety Guide RS-G-1.7 [4] provides guidance on the concepts of exemption and clearance from regulatory control. The Safety Guide gives values of activity concentration for radionuclides of both natural and artificial origin. Those values can be used by regulatory bodies for determining when controls over wastes are not required or are no longer necessary.

Those levels are based on generic scenarios for the recycling and disposal of waste. The radiological safety basis for establishing values of activity concentration for the clearance of waste is that the effective doses to individuals arising from this clearance should be of the order of 10 microSv or less in a year. To take account of the occurrence of low probability events leading to higher radiation exposures, an additional criterion was used which is that the effective doses due to such low probability events should not exceed 1 mSv in a year. Doses to the skin were also taken into account with an equivalent dose criterion of 50 mSv in a year to the skin. This approach is consistent with that used in establishing the values for exemption provided in the BSS [5]. For radionuclides of natural origin a different approach was adopted. The values have been determined on the basis of consideration of the worldwide distribution of activity concentrations for these radionuclides.

The levels of activity concentration for clearance are highly dependent on the conditions under which clearance is granted. Then, levels of activity concentration different from those suggested in the IAEA

Safety Guide may be established by the national authority on a case by case basis if specific national circumstances which significantly influence exposure scenarios are considered.

However, some countries like France chose to have a different approach for management of very low level wastes. In the 90s, the topic of clearance levels was discussed in France. As it was difficult to answer the question of these levels and to define who should be responsible to establish them, the authorities decided to implement an approach which would not justify the clearance of non radioactive material on the sole argument of clearance levels. The approach that was chosen is based on the zoning of nuclear installations in “nuclear waste zones” and “conventional waste zones”. A “nuclear waste zone” is a zone where there is a risk that wastes produced in this zone may be contaminated because of the nuclear activity and each waste produced in a “nuclear waste zone” has to be managed as a “radioactive waste”. This approach has been implemented by French nuclear operators that documented it in “wastes studies” that are submitted to nuclear safety authority approval. After the approval of the first studies, ANDRA opened a VLLW disposal that is designed so that, after a period of survey of 30 years, the impact for a person who would live not far from this disposal should not exceed 0,25mSv/year.

The two approaches may seem to be very different: in the case of disposal of VLLW in a repository, the idea is to apply the “concentrate and contain” principle, developed by the International Commission for Radiation protection, especially in its publication n°81 [6] whereas in the approach based on clearance levels, the principle “dilute and disperse” applies. However, after a few years of practice, it seems that the approaches have, on a practical view, many similarities. It appears that, rather than to harmonize clearance levels between different countries, it would be more efficient to harmonize the levels of protection of the public and the conditions according to which materials coming from nuclear industry can be cleared. This harmonization is very important if one considers the materials and waste which may be transferred from one country to another without being subject to regulatory control for the purposes of radiation protection. This harmonization would contribute to an increased level of confidence the public may have in the safety of such practices.

For VLLW that are not cleared, whatever the criteria for that are, the reference management option is disposal in near surface landfill-type facilities, with limited regulatory control. Those disposals are designed in order so that, after a period of survey of about some dozens years, the impact for a person who would live not far from this disposal should not exceed a fraction of 1mSv/year.

2.3. Very Short Lived Waste

This type of waste which involve very short-lived radioelements (their radioactivity is halved in less than a few days) is mainly generated by medical uses of radioactivity, whether for diagnostic or therapeutic purposes, and by research facilities. The waste generated is collected and stored for a time allowing the radioactivity to decay by a factor of 1000 after waiting for about ten half-lives. This waste is then disposed of in the conventional waste disposal channels.

2.4. Low Level Waste

This type of waste is in most countries disposed of, either directly or after incineration or fusion, to near surface repositories. Low level waste repositories are used in many countries, where they have been accepted both politically and by the public. They use a combination of restrictions on the levels of long lived radionuclides, engineering, monitoring and institutional control to keep the risk associated with both radionuclide migration and human intrusion scenarios low. In this case, institutional control can reasonably be expected to prevent intrusion for the limited time until most of the activity in the waste has decayed. The period of containment is about a few hundred years, during which the monitoring of the near surface disposal has to be maintained. In most countries, a duration of 300 years is taken for this monitoring period.

Safety implementation of a LLW disposal is a complex process, which requires:
- good characterization the waste,
- site and engineered barriers,
- adequate waste conditioning process and verification of compliance with the waste acceptance criteria,
- appropriate execution of operational and closure activities from a safety and radiation protection point of view,
- adequate institutional control and surveillance programme after closure.

Institutional control is important for the long term radiological safety of a near surface facility. The scope, duration and magnitude of such control should be adapted to the radiological risk posed by the waste and should be considered in the disposal development stage, as well as in the safety assessment.

The limits between LLW and intermediate level waste and high level waste have to be defined radionuclide by radionuclide. LLW can contain high quantities of short lived radionuclides as their radioactivity will decline quickly whereas limits for long lived radionuclides have to be relatively low. In most country those limits for long lived radionuclides have been fixed to about 4000 Bq/g for each waste package with a limit of 400 Bq/g in average for the whole disposal.

However, some waste, mainly milling and mining waste and other materials containing significant amount of naturally occurring radionuclides are disposed of in near surface facilities whereas their concentrations in long lived radionuclides are higher than the values usually admitted. For those particular wastes, near surface disposal is the only economically feasible disposal option because of the very large volumes they represent. Although the activity concentrations are not high, the radionuclides in mining and milling waste are extremely long lived, and therefore near surface disposal facilities for such waste would require institutional perpetual control to prevent human intrusion. However, experience suggests that such control cannot be guaranteed for more than a few generations into the future. A possible way would be to implement a system comprising periodical assessments of the situation and presentation of the conclusions to designated authorities which can reconsider, if necessary, the future of the repository and take the appropriate decisions to adapt the institutional control.

Although near surface disposal is used in many countries, other approaches exist or are being considered to dispose low level waste, for example surface storage pending the construction of a geological repository for several types of waste. Such variations are very dependant on national circumstances, and we can observe that public acceptance played a larger role than cost in such decisions.

2.5. Intermediate level waste

Intermediate level waste contains long lived radionuclides in quantities that need a higher degree of containment and isolation from the biosphere than provided by near surface disposal. Because of its long life, it is impossible to take advantage of the radioactive decay of this waste within a time-frame compatible with permanent institutional surveillance. However, the activity of this waste is such as it could lead to subsurface disposal being envisaged at a depth of at least fifteen metres.

This waste usually comes from industrial activities leading to concentration of Naturally Occurring Radioactive Materials (NORM) (the former radium industry for example), or from the nuclear industry (such as the irradiated graphite contained in the structures of the old Gas Cooled Reactors (GCRs)). The activity level of graphite waste is between ten thousand and one hundred thousand Bq per gram, primarily long-lived beta-emitter radionuclides. Radium-containing waste mainly consists of long-lived alpha-emitter radionuclides with an activity of from a few tens of Bq per gram to several thousand Bq per gram.

The main function of a disposal for ILW is to confine the waste for a decay period that is about some 10^4 years. After this period, the remaining activity of the waste should be low enough to be acceptable for the human and environment exposures even if the installation loose its properties of confinement. A disposal for ILW will have to follow the main principles applicable to geological disposal, even if the requirements associated for example to the depth of the disposal or the packaging performances will be lower.

2.6. High Level Waste

This waste contains long half-life radionuclides, notably alpha emitters. The vast bulk of it comes from the nuclear industry. It includes spent power reactor fuel which has been declared as waste and waste originated from the processing of power reactor fuel. This waste is characterised by significant release of heat (up to 4 kW per 150-litre container), making the use of cooling systems necessary. The activity level of this waste is of several thousand Bq per gram.

The long timescales over which this waste remains radioactive led to the idea of deep geological disposal in underground repositories in stable geological formations, at a depth of several hundreds of meters. Internationally, this is the most accepted approach to manage this waste. Isolation is provided by a combination of engineered and natural barriers and there is no obligation for future generations to actively monitor the facility. This is often called a multi-barrier concept, where the waste packaging, the engineered repository and the geology are all providing barriers to prevent the radionuclides from reaching humans and the environment. This concept is based on the assumption that any releases are small and that these relatively small releases move very slowly, resulting in negligible impacts on public health and safety. The Safety Requirements N° WS-R-4 [7] of the IAEA dedicated to geological disposal of radioactive waste mentions that “the aim of geological disposal is not to provide a guarantee of absolute and complete containment and isolation of the waste over all time but to ensure that any levels of radionuclides eventually reaching the biosphere are such that possible radiological impacts in the future are acceptably low.”

The level and duration of protection that is required of a geological disposal is much longer than durations and levels usually required to waste disposals, including those for non-radioactive wastes. Then, implementation of a geological disposal requires to develop a sufficient level of confidence in the level of long-term protection finally achieved. A number of countries have already established regulatory criteria for judging the safety of long-term disposal, and others are still discussing to define what those criteria should be.

In WS-R-4, it is established that “The dose limit for members of the public from all practices is an effective dose of 1 mSv in a year… To comply with this dose limit, a geological disposal facility is designed so that the estimated average dose or average risk to members of the public who may be exposed in the future as a result of activities involving the disposal facility does not exceed a dose constraint of more than 0,3 mSv in a year or a risk constraint of the order of 10^{-5} per year. It is recognized that radiation doses to individuals in the future can only be estimated and that the uncertainties associated with these estimates will increase for times farther into the future. Care need to be exercised in using the criteria beyond the time where the uncertainties become so large that the criteria may no longer serve as a reasonable basis for decision making.”

In his report about “regulating the long-term safety of geological disposal” [8], AEN draw three main conclusions about the question of long-term criteria:
“- There exists important variation in numerical criteria for long-term disposal safety in NEA countries. The quantitative differences, however, have no significant consequences in terms of radiological impact. Besides, it should be borne in mind that the calculated doses and risks that are measured against these criteria are only indicators of performance and protection requirements related to complementary measures such as optimisation and the application of “best available techniques not entailing excessive costs” are equally important.
- There is important variation in the bases for criteria and the ways they are used in order to demonstrate the achievement of fundamental safety goals. This variation is grounded in societal differences and makes it difficult to compare different national approaches.

- Developing a common understanding of obligations to future generations and of how to implement these obligations in regulatory criteria for long-lived radioactive waste would make comparisons of regulatory approaches within national and international contexts, including at IAEA Joint Convention review meetings, more meaningful and useful."

The International Commission on Radiation Protection may also complete these considering with explanation on how to apply the new recommendations from IRCP 103 [9] to the disposal of long-lived solid radioactive waste. Indeed the ICRP Publication 103 recommends a new approach and new criteria but does not specifically addresses the issue of waste disposal which is so far considered in the ICRP Publication 81 [6], dedicated to radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste, and recommends other criteria.

Another way to manage HLW is based on the separation/transmutation processes. Those processes are aimed at isolating and transforming long-lived radionuclides in nuclear waste into short-lived radionuclides and stable elements. Separation covers a number of processes, the purpose of which is to separately recover certain long lived transuranians or fission products. These radionuclides, after repackaging, will be incinerated (by fission) to give short-lived nuclides, or transmuted (by capture) into stable atoms. Laboratory results have been obtained with separation of actinides (americium, neptunium, curium) and long-lived fission products (iodine 129, technetium 99, caesium 135). With regard to transmutation, simulations of various reactor populations were conducted, for transmutation of minor actinides: PWR, fast neutron reactors, 4th generation reactors which would be capable of producing energy by incinerating their own waste and that of the previous generation of reactors. The industrial feasibility of these projects still however has to be explored, in particular in the field of transmutation, which implies further extensive research. Given the scale of the research still to be carried out, it can be assumed that no industrial application of these processes could be possible before about 2040.

3. Stakeholder involvment

Management of radioactive waste is a great concern for public and is considered as a major issue of the nuclear industry. Governments frequently encounter difficulties when making decisions on radioactive waste management, especially when they are looking for a site for a disposal of radioactive waste. The way the public perceives the hazards and the impacts of radioactive waste often does not correspond to that of the specialists. So, it is highly important that those involved in these matters and the decisions makers take into account the concerns of the public in their decisions on this subject. However the ways to achieve this aim are not so clear and various means have been experienced in different countries, with more or less success.

Even if each case and each site are specific and if there is no completely generic approaches to the issue, some principles can be kept from those various experiences and can guide the future decisions in the field of radioactive waste management:

- The public should not only be informed but also should be involved in the process of decision making.
- The information about radioactive waste should be given in order to be understood by the public; moreover various information vectors should be used.
- The stakeholder involvement should not aim at achieving a concensus but rather at providing ways for interested people to participate in and to influence the decision.
- A balance has to be found between the different stakeholders (local, national and regional) interests.

The French example chosen in order to involve stakeholder on the subject of radioactive waste management can be developed.

First, after many years of discussions, the “Bataille act” in 1991 has given 15 years to take a decision for the management of high level waste. The act defined the objectives of the scientific research that should be achieved during those 15 years, in the three chosen topics (separation / transmutation, geological disposal, long term storage). After this period, a new act, the 2006 act on “sustainable management of radioactive materials and waste”, was adopted by the Parliament. The 2006 act was adopted after a national debate on the management of radioactive waste that involved many stakeholders at the end of 2005. The 2006 act decides the principle of creating a geological disposal and precises the future site of this disposal. The act organizes the different stages so that this disposal is operational and the term at which this should be achieved. It mentions in particular the stages at which the Parliament will have to intervene: before the disposal’s administrative authorization in order to fix the conditions of reversibility and before the definitive closure of the disposal.

But the 2006 act also deals with the management of all types of radioactive wastes. The act foresees the elaboration of a national plan for the management of radioactive materials and wastes, which is called “PNGMDR”. This plan should appraise the existing management modes of radioactive materials and wastes, identify the foreseeable needs for storage or disposal installations, state the necessary capacities for these installations and the storage timeframes and, for radioactive wastes which are not yet subject of a definitive management mode, determine the aims to be reached. The first “PNGMDR” was drawn up at the end of 2006 and was established within a working group where all the stakeholders where invited.

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