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The Roles of Storage in the Management of Long-lived Radioactive Waste

Practices and Potentialities in OECD Countries

NEA No. 6043

NUCLEAR ENERGY AGENCY
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FOREWORD

The NEA Radioactive Waste Management Committee (RWMC) is a forum of senior representatives of operator, regulator, policy-making and R&D organisations in the field of radioactive waste management. The Committee assists member countries by providing guidance on solutions to radioactive waste problems, and promotes safety in the management of radioactive waste.

The RWMC has defined strategic areas* in which progress would be beneficial to the further development of long-term radioactive waste management and geological disposal programmes in member countries. Area I concerns "Overall waste management approaches" and identifies the importance of gaining a better understanding of long-term waste management approaches. Such understanding is important from the point of view of sustainable development and may allow waste management to be better understood within the broader debate on environmental and ethical issues. In particular, it is important to examine the roles of long-term storage within an overall waste management strategy.

Storage has long been incorporated as a step in the management of many types of radioactive waste and materials, especially in the management of the most highly active and long-lived materials, such as spent nuclear fuel and the wastes arising from the reprocessing of spent nuclear fuel. Conventionally, storage has been seen as an interim step, only needed until disposal of the waste or re-use of the materials became possible. More recently, however, the question is being asked in several countries whether longer-term storage might have some expanded role to play in radioactive waste management.

This report examines the roles that storage plays, or might play, in radioactive waste management in OECD member countries, and draws conclusions on the roles of storage. It focuses on spent nuclear fuel, high-level waste from reprocessing and other long-lived, solid radioactive wastes.

The report was produced by a working group set up under the RWMC, with NEA Nuclear Development Committee (NDC) representation. The group also worked in correspondence with other RWMC members.

The RWMC would like to acknowledge the contributions the following individuals made to this report: Alex Nies, Chairperson of the Working Group; Members of the Working Group, as follows: Steven Baggett (US NRC), Bruno Baltes (GRS), Peter Brennecke (BfS), Peter Brown (NRCan), Wolfgang Hilden (European Commission), Pál Kovács (OECD/NEA – NDC Secretariat), Carmel Létourneau (NRCan), Thierry Lièven (CEA/Saclay), Doug Metcalfe (NRCan), Kai Möller (BfS), Claudio Pescatore (OECD/NEA – RWMC Secretariat), Christopher Regan (US NRC), Hans Riotte (OECD/NEA – RWM Division), Klaus-Jürgen Röhlig (GRS), Timo Seppälä (Posiva), Trevor Sumerling (SAM), Mitsuo Takeuchi (NUMO), Derek Taylor (European Commission), Abraham van Luik (US DOE), Magnus Westerlind (SKI) and David Bennett (UK EA), as well as Hendrik Selling (Ministry of the Environment, Netherlands), who provided input to the Working Group.

* S*trategic Areas in Radioactive Waste Management: The Viewpoint and Work Orientations of the Radioactive Waste Management Committee*, OECD, Paris 1999.

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EXECUTIVE SUMMARY

In March 2004, the RWMC initiated a Working Group on the Roles of Storage (RoSt). The work of the group is documented in this report, which examines the roles that storage plays, or might play, in the management of long-lived solid radioactive waste and spent nuclear fuel in OECD member countries.

Storage has long been incorporated as a step in the management of long-lived solid radioactive waste and spent nuclear fuel. Conventionally, storage is seen as an interim step within a management strategy in which the ultimate goal is disposal, or re-use of fissile material and disposal of the residue.[1] Within such a strategy, storage may be needed (a) to allow the levels of radioactivity and heat output to decline before the next step or process of the waste management strategy can be enacted (*decay storage*); (b) to provide stock for an ongoing process, transport step or immediate disposal (*buffer storage*); (c) awaiting a step for which the required facility or transportation capability are not yet available, or awaiting a decision to be made on the next step for a particular waste or material (*interim storage*); (d) for materials that, while not immediately required, have some potential future use or value and, therefore, have not been declared as a waste (*strategic storage*).

In recent years, there have been developments that have led some countries to consider whether the roles of storage might be expanded to provide longer-term care of long-lived solid radioactive waste and spent nuclear fuel. The consideration of such "expanded roles" is linked to discussion of alternative strategies for the long-term management of long-lived solid radioactive waste and spent nuclear fuel, i.e. that final disposal is not necessarily the endpoint or that it might only be implemented after an extended period of storage. The latter is the case in the Netherlands where a policy decision has been taken to store radioactive waste for at least 100 years before final disposal is decided, and a facility has been commissioned for this purpose. Similarly, long-term storage, of the order of 100 years or more, is being discussed in other countries, and various motivations are cited. Some stakeholders consider that long-term storage, itself, is a valid endpoint. The latter is in contradiction to the definition of storage as used in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management but presumes different notions. The ambiguity in terminology seems to indicate a consideration of a continuum of concepts for which a dividing line between "storage" and "disposal" is sometimes hard to identify. This is further illustrated by the development of deep geological repository concepts in several OECD member countries that include a phase or several phases with different degrees of reversibility. The duration of each phase is technically determined and society would decide whether the full technical limit should be reached. It may be claimed that, at the very beginning, the initial phase provides the same reversibility as an underground "storage". A phase of relatively straightforward retrievability in repository development is still a step towards geological disposal, and is not "storage" in the usual sense. A monitored, retrievable phase has, however, many characteristics of storage, and the safety and security

1. All countries that have so far made a policy decision on a final step for the management of long-lived radioactive waste (and spent fuel if it is declared a waste) have selected geological disposal as the endpoint. Geological disposal is also considered the reference solution in NEA collective opinions.

requirements are similar. In addition, provisions for such a phase must not jeopardise long-term safety of the facility.

Various motives have been put forward for considering long-term storage, i.e. a storage period of the order of 100 years or more. The reasons more frequently cited include (a) immediate and practical reasons, e.g. related to the need to gain greater public acceptance for disposal strategies and (in countries with smaller amounts of radioactive waste) that disposal would be more economical if a larger volume of waste is accumulated, and (b) future strategic reasons, e.g. related to the possible development of regional or multi-national final solutions or developments in technology.

With respect to public acceptance, it is not clear that long-term storage facilities are, in general, more acceptable than disposal facilities. Rather, the siting of any new radioactive waste management facility is a sensitive matter, in which the concerns and views of the potentially impacted communities should be considered. Although in some countries economies of scale might be gained by waiting, this must be weighed against the costs, and the safety and security implications, of longer storage. If a policy of long-term storage is adopted in view of possible future developments, e.g. of technology or multi-national solutions, then the country adopting that policy should work actively to investigate and develop these possible solutions. Waiting, on its own, is not enough.

Questions arise about the viability of expanding the roles of waste storage, including:

- for how long can radioactive wastes and materials be safely stored?
- for how long is it prudent to store such wastes and materials?
- and, more broadly, can long-term storage be considered a sustainable option?

Long-lived solid radioactive waste and spent nuclear fuel have been safely and securely stored in OECD member countries now for several decades. Such storage could continue for many more decades, given proper controls and supervision as well as repackaging of some wastes and periodic refurbishment of stores. Today, stores of modern design have typically been licensed for periods of decades, in one case (the HABOG in the Netherlands) for a century. Some countries are undertaking research on the feasibility of long-term storage concepts. Especially in France, innovative storage concepts with lifetimes of a few centuries are being investigated. The maximum period for which institutional control for waste management facilities can be assumed is in the same order of magnitude. In any case, these periods are considerably shorter than the period for which long-lived waste presents a hazard and needs to be managed. It should also be noted that storage facilities – especially if they are at the surface – as any other industrial facilities, are vulnerable to acts of terrorism with increasingly destructive weapons. Maintaining good quality storage is a technical activity that presents ongoing challenges, and the continued safety and security of storage rely on a suite of technical and organisational requirements. These, in turn, must be underpinned by secure financial resources and an ongoing political and societal commitment to take care of the waste.

If long-term storage (of the order of 100 years or more) is being considered, then:

- The technical challenges of extended storage periods must be taken into account. These challenges will continue throughout the storage period.
- The time period for which storage is planned must be defined. This is necessary to enable design, to allow estimation of costs, for licensing, and to indicate the organisational commitment entailed.
- To maintain the technical assurances of safety and security, it is essential to provide secure financial resources and stability for the organisations and agencies that are charged with

carrying out and supervising the storage as well as with subsequent waste management steps. This will require continued political and societal commitment and, also, national economical stability to maintain these organisations and resources and their know-how (loss of know-how is especially conceivable if the use of nuclear energy is phased out). Such factors become more uncertain and harder to guarantee as the planned time period for storage extends further into the future.

Planning for extended periods of storage (involving multiple renewals of storage facilities), introduces significant uncertainties over which the present generation can have relatively little influence. One of these uncertainties is the possibility that such storage might become the endpoint by default (instead of by design), which is considered by many to be unsatisfactory and, inherently, unsafe.

As “indefinite” storage relies on active controls, maintenance and periodic renewal of facilities, this form of storage can only be an interim measure. An “open” solution, such as indefinite storage, is probably not sustainable, because it relies on speculations concerning future societal, scientific or technological developments and implies impacts and use of resources which cannot be quantified. To be sustainable, it is essential to define a “closed” waste management strategy that does not rely on such speculations and that incorporates a well-defined endpoint as well as the path (or alternative paths) to reach that endpoint. Consequently, indefinite storage cannot be seen as a viable strategy for long-term radioactive waste management.

1. INTRODUCTION

1.1 Storage is required – but for how long?

Most long-lived radioactive wastes are managed through a strategy of "concentrate and contain", and this is generally accepted as the preferred strategy[2] from environmental and ethical perspectives, e.g. see (IAEA, 1995; ICRP, 2000). This inevitably leads to the accumulation of radioactive wastes, which must be safely managed. Typically, this is done by conditioning the waste into stable, solid waste forms, which are then packaged, and stored, at least until a final disposal route is available.

Storage has long been incorporated as a step in the management of many types of radioactive wastes and materials, especially for those containing high levels of long-lived radionuclides, such as spent nuclear fuel and the wastes arising from the reprocessing of spent fuel. This is done mainly for operational safety and practical reasons (e.g. to allow the radioactivity and heat output to decline to levels that are acceptable for transport, reprocessing, conditioning or disposal of the waste). As such, storage is clearly an interim step within a waste management strategy in which the ultimate goal is final disposal, or re-use of fissile material and final disposal of the residue.

In recent years, the question has been asked whether the roles of storage might be expanded to provide longer-term care of the waste. This may be because of difficulties in gaining the necessary public acceptance for siting of geological disposal facilities in some countries. Indeed, some stakeholders consider that storage is preferable to immediate and final disposal as a long-term management option. Whatever the cause, a failure to enact disposal on the time scale originally expected, has led to increasing volumes of long-lived radioactive wastes and materials being stored over longer time periods than originally envisaged. This has led some governments to review their radioactive waste management policies. In this light, questions arise about the viability of expanding the roles of waste storage, including:

- for how long can such wastes and materials be safely stored?
- for how long is it prudent to store such wastes and materials?
- and, more broadly, can long-term storage be considered a sustainable option?

This report provides a basis for discussion of these questions.

2. The alternative is to "dilute and disperse" the radioactivity into the environment. This is practiced only for certain liquid and gaseous effluents containing very low concentrations of radionuclides.

1.2 The objectives and scope of this report

The objectives of this report are:

- to examine the roles that storage plays in the management of long-lived solid radioactive waste and spent nuclear fuel, as conventionally practiced or envisaged in OECD member countries (Chapter 2);
- to consider the expanded and longer-term roles that storage might play in some OECD member countries, and to consider the motives for, and implications of, longer-term storage of these wastes and materials (Chapter 3);
- to summarise the key points that should be considered concerning the storage of these wastes and materials (Chapter 4).

The emphasis in this report is on the management of spent nuclear fuel, high-level waste from reprocessing and other long-lived radioactive wastes, but lessons may also be learned from the management of other radioactive wastes. The report does not consider uranium mill tailings and other, large volume, waste and materials with lower concentrations of long-lived radionuclides. Nor does the report consider the additional issues associated with the storage of stocks of plutonium and uranium that may be surplus to national requirements.

The RoSt group acknowledges the Position Paper of international experts on "The Long Term Storage of Radioactive Waste: Safety and Sustainability", published by the International Atomic Energy Agency (IAEA, 2003b), and the European Commission study on the Comparison of Alternative Waste Management Strategies for Long-lived Radioactive Wastes (COMPAS) (EC, 2004), as important starting points for considerations in this report. Key statements from the conclusions of the Position Paper are reproduced in Appendix 2. To some extent, the IAEA Position Paper considers or compares storage against other waste management options. It is not intended to explore this issue further in this report but, instead, to focus on established as well as potential expanded roles of storage and to discuss implications of the latter.

1.3 Policies and positions in OECD member countries

Policies and positions for the long-term management of radioactive waste in OECD member countries that have significant inventories of long-lived solid radioactive waste and/or spent nuclear fuel to manage are summarised in Table 1. Three questions are addressed:

- Has the Government taken a decision on the final management of long-lived radioactive waste and spent nuclear fuel?
- Has the Government a policy, a stated preference or an assumption towards a given management endpoint, e.g. geological disposal?
- Is the country implementing, researching or seriously considering long-term (ca. 100 years or more) storage as part of the national radioactive waste management strategy?

The following can be observed:

- In several countries, decisions are still to be made on the treatment of spent nuclear fuel, i.e. whether it should be declared as a waste, reprocessed or stored as a potential resource.
- All countries that have made a policy decision on a final step for the management of long-lived radioactive waste (and spent fuel if it is declared as a waste) have selected geological

disposal as the endpoint. (This statement applies worldwide, not only to OECD member countries, see IAEA, 2003).

- Several other countries have a preference or assumption towards geological disposal, although this is not confirmed in policy. Some countries, with smaller amounts of radioactive wastes to manage, might prefer disposal in a regional or multi-national geological disposal facility.
- Some countries are undertaking research on the feasibility of long-term storage (up to 100 years or more). For example, in France, research on long-term storage is being undertaken in the context of a comprehensive research programme[3] to provide the basis for a decision on options to be made in 2006 (Journal Officiel Lois et Décrets, 1991). In order to pave the way for this decision, a draft law ("Projet de Loi") regarding the management of radioactive waste and materials has been established and is currently being debated by the French Parliament (the draft law was passed by the National Assembly, after its first reading, on 12 April 2006) (Assemblée nationale, 2006).
- In Canada and the United Kingdom, formal consultations are currently taking place with a view to defining policy within the next few years, and long-term storage is or was an option under consideration (NWMO, 2005; DEFRA, 2001).
- In the Netherlands, a policy decision has been taken to store radioactive waste for at least 100 years, and a facility (HABOG) has been commissioned for this purpose (Netherlands, 2003).

The roles that storage plays in radioactive waste management, as conventionally practiced in OECD member countries, are described in Chapter 2. The motives for the decision by the Netherlands, and the considerations of other countries relating to longer-term storage, are discussed in Chapter 3.

3. See Section 3.2 and also Annex 1.

Box 1 provides clarification of terms that are used in this report.

Box 1. Radioactive waste management – terminology used in this report

A **radioactive waste management strategy** consists of a plan for managing the radioactive wastes that may be produced nationally; this includes spent nuclear fuel if it is national policy to treat it as a waste. The strategy may involve a range of processes and facilities, and arrangements for the development, operation and control and regulation of those processes and facilities.

The plan for any single waste type may include a number of steps including chemical and physical treatments, containment/packaging and disposal. Storage may be needed at or between several of the steps. In this report, we use the following definitions provided in Article 2 of the Joint Convention (IAEA, 1997):

- **storage** means the holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval;
- **disposal** means the emplacement of spent fuel or of radioactive waste in an appropriate facility without the intention of retrieval.

According to these definitions storage is an interim step undertaken while awaiting some further step. In contrast, disposal is the final expected step within a waste management plan, although additional steps might be possible.

It must however be noted that there are also notions of the term "storage" deviating from the above (IAEA, 2002). For instance, some use not the *intention* but the *possibility* of retrieval as distinctive feature (NWMO, 2005) – by doing so, however, blurring the dissociation from (retrievable) disposal. Another distinction, sometimes made, is that storage implies continued supervision so that safety is provided by a combination of engineered features and *active controls*; whereas disposal implies a move towards reliance on *passive safety functions* of the disposal system's engineered and natural features, making active controls unnecessary.

By **endpoint** we mean a final step in the management of a given waste, beyond which no further transport, conditioning or active care of the waste is necessary. Thus, storage in the notion of the Joint Convention cannot be an endpoint by definition. Without an endpoint a radioactive waste management strategy is incomplete and, therefore, does not provide for a sustainable solution.[4]

The phrase **long-term storage** is used to mean storage for about 100 years or more.

4. According to the 1987 Brundtland Report (WCED, 1987), sustainable development is characterised by: "Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

Table 1. Policies and positions on the long-term management of long-lived, solid radioactive waste and spent nuclear fuel in selected OECD member countries

Country	Policy or position
Australia	Policy of eventual geological disposal. May be preceded by storage for 50 to 100 years.
Belgium	Geological disposal as reference option – no official policy yet.
Canada	Previously investigated option of deep geological disposal was expanded to include options for long-term storage of used nuclear fuel at reactor sites and at a central facility. A period of dialogue and engagement with Canadian citizens and analyses of various approaches for long-term management was completed in 2005. The study lead to a recommendation of "Adaptive Phased Management" which includes continued used fuel storage at reactor sites, an option for shallow underground storage at the central long-term management site, and placement of used fuel in a deep geological repository with monitoring, access and retrievability for an extended period of time. Government decision is expected in 2006.
Czech Republic	Policy of geological disposal.
Finland	Policy of geological disposal. Investigations begun at the Olkiluoto candidate site.
France	Policy of research on equal footing into geological disposal, long-term storage and partitioning and transmutation (P&T). Decision expected in 2006 (Draft law debated at the Parliament April-June 2006).
Germany	Policy of geological disposal. Official objective of operational repository by 2030.
Hungary	Preference for eventual geological disposal. Decision expected in 2006.
Italy	Preference for eventual geological disposal of HLW.
Japan	Policy of eventual geological disposal of HLW and a part of TRU waste.
Korea	Policy of eventual geological disposal.
Netherlands	Policy of storage for at least 100 years (in the HABOG facility) and then to decide, although geological disposal is the reference endpoint.
Norway	Preference towards eventual geological disposal.
Spain	Decision expected in 2010. Geological disposal is the reference long-term option. In December 2004, however, the government passed a new resolution in order to draw up a plan for the development of a centralised interim storage facility for spent fuel.
Sweden	Policy of geological disposal. A repository for L/ILW is in operations since 1988 and investigations for disposal of SNF is on-going at two sites.
Switzerland	Geological disposal required by law for all types of radioactive wastes.
United Kingdom	Previous position of deferring a decision on HLW and investigating geological disposal of ILW and some LLW. Now in formal consultation where decisions in principle will be made between a wide range of options, including storage, for a range of radioactive waste and materials. Decision expected in 2007.
United States	Defence waste (including TRU) to be disposed deep underground at the WIPP facility (operating since 1999). Currently, investigating geological disposal of civilian HLW and SNF, plus defence HLW at Yucca Mountain.

Information based on the national reports on the Joint Convention submitted by IAEA Member States to the first review meeting (IAEA, 2003c).

SNF = spent nuclear fuel; HLW = high-level waste; ILW = intermediate-level waste; LLW = low-level waste;

TRU = transuranic-bearing waste (long-lived ILW)

2. THE CONVENTIONAL ROLES OF STORAGE

2.1 Storage in the context of radioactive waste management strategy

Radioactive waste is a by-product of the generation of electricity by nuclear power and of other uses of radioactive materials. Radioactive waste has no benefit to man, rather it is a liability that has to be managed. Similarly, the storage of radioactive waste has no benefit, rather it is an action that is needed to protect man from the hazard that the waste presents. Even spent nuclear fuel, and other radioactive materials that may have some future use, must be managed until the time when they can be re-used.

Thus, storage should only be considered as an element of a radioactive waste management strategy designed to ensure the safety and security of the radioactive material, and the protection of man and the environment, while permitting re-use of materials if desired. Storage is carried out for reasons generated by the requirements of the strategy, never for its own sake. The conventional view on storage and its long-standing roles in a radioactive waste management strategy is presented in Box 2, which is quoted from (NEA, 1977).

The reasons for storage given almost 30 years ago (in Box 2) are still true today, except that the last bullet point could be amended to take account of more recent experience of the difficulty of implementing disposal solutions for long-lived solid radioactive waste and spent nuclear fuel. Thus, today, storage is necessary to provide safe management while methods for the conditioning, further storage and disposal are developed and evaluated, and to implement these methods, including gaining the necessary technical confidence and also public acceptance.

2.2 Storage according to its function in waste management

Figure 1 provides a basis to discuss different roles of storage for long-lived radioactive waste and spent nuclear fuel within management strategies leading to geological disposal. Geological disposal is assumed, because it is the endpoint that is conventionally considered, and because (as indicated in Chapter 1) it is the endpoint that has been selected in all OECD member countries that have so far made a policy decision on the endpoint of long-term management of long-lived solid radioactive waste and spent nuclear fuel.

The figure presents the main decision points and steps of strategies, both with and without reprocessing, together with an indication of the main storage steps for spent nuclear fuel, high level waste and recovered materials from reprocessing. The Figure does not include some other long-lived radioactive wastes produced in the nuclear fuel cycle, such as those from nuclear plant operations, from reprocessing, and from nuclear facility refurbishment and dismantling. However, much of the following text does apply to these other wastes, except where it specifically refers to spent nuclear fuel.

Box 2. The conventional view on storage and long-standing reasons for storage

Storage is defined as the emplacement of waste materials in such a manner that the later retrieval can be carried out and with the intention of doing so. Therefore, storage is a temporary measure by definition and cannot constitute a solution of the problem of long-lived radioactive waste. Nevertheless, waste storage plays an important part and integral part in the achievement of an optimised waste management strategy. Storage satisfies one or more of several waste management needs, the more important of which include:

- the development and maintenance of a materials backlog; this is important economically to ensure the continuity of process operations; for example, the accumulation of a backlog of irradiated fuel elements to maintain continuity in fuel reprocessing;
- the provision of hold-up capacity to allow radioactive decay, thus reducing radiation and heat generation levels in the waste; this may facilitate subsequent waste handling, treatment, storage and disposal;
- the accumulation of sufficient quantities of waste to enable economic treatment, transport, recovery etc.;
- the provision of hold-up capacity while optimum methods are evaluated for treatment, further storage and disposal.

Quoted from p.137 (NEA, 1977)

Storage is needed to allow the levels of radioactivity and heat output to decline before the next step or process of the waste management strategy can be enacted – **decay storage**. This is especially important in the case of fuel discharged from a nuclear reactor. Most short-lived radionuclides must be allowed to decay so that the heat output and radioactivity is reduced to a level at which the spent nuclear fuel can be safely transported and, if so decided, reprocessed. In most cases, this initial storage will be under water in cooling ponds at the reactor site, typically for periods of at least several months.

Beyond this time, storage may continue at reactor sites or the spent fuel may be transported to a reprocessing facility or central store to await disposal. Here storage may again be under water, as in the CLAB facility in Sweden (SKB, 2004), or in dry storage facilities.[5] In some dry storage concepts, the fuel assemblies are placed into sealed, shielded casks,[6] which ensure containment of the spent fuel.

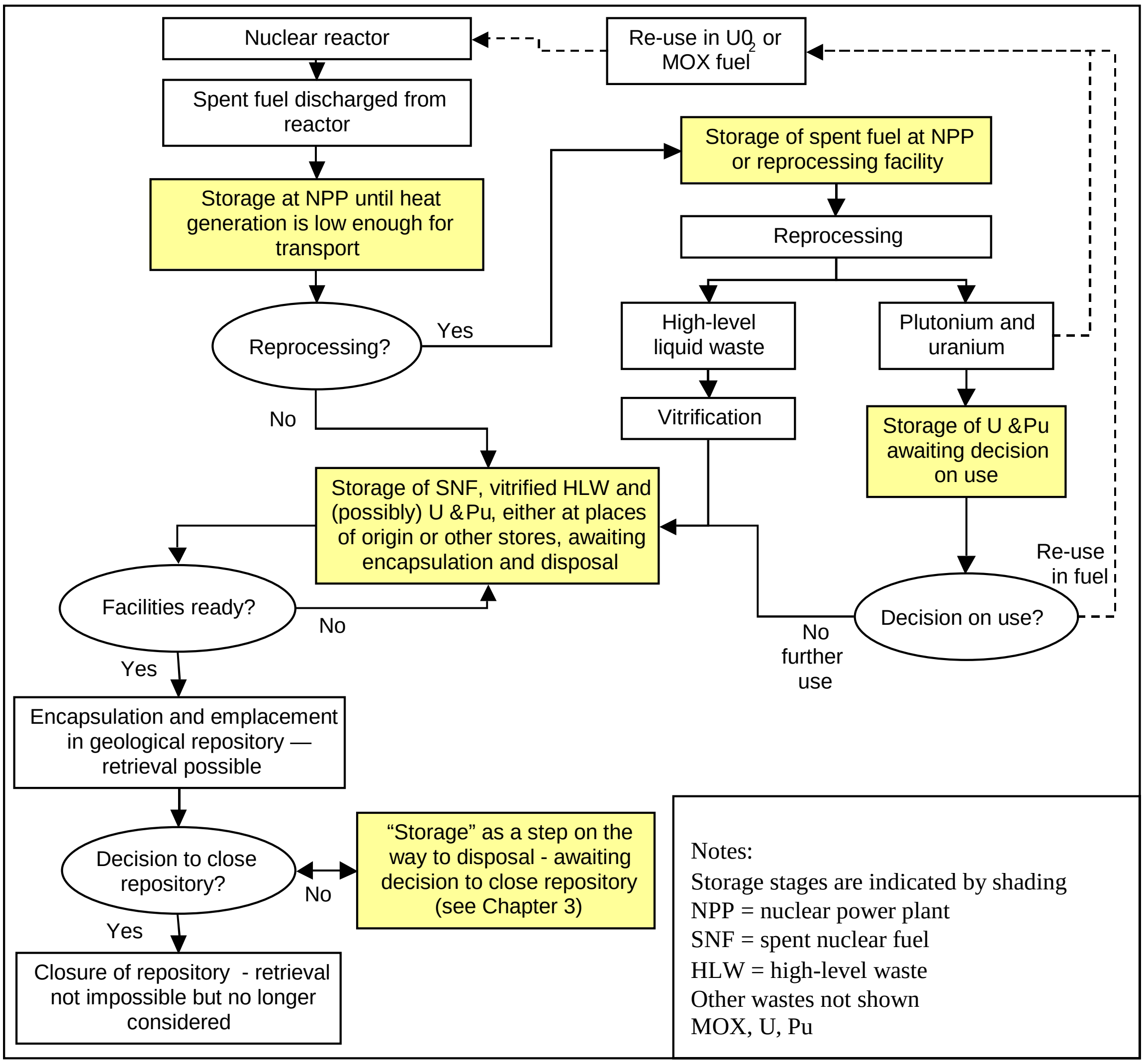
Storage may also be required to provide stock for an ongoing process, transport step or disposal – **buffer storage**. This may be a continuous or a batch process including, for example, a waste treatment

5. For example, as at Fort St Vrain, Colorado, USA and Torness, Scotland, in the United Kingdom.

6. Casks contain an array of storage sleeves to hold the spent fuel assemblies. Loaded casks are filled with an inert gas such as helium. Designs include the steel CASTOR design used in Germany (Dierkes *et al.*, 1980) and the steel and concrete TranStor system, developed by BNFL and used in the USA (Dickson, 1999). The designs allow heat dissipation to ensure the fuel remains within the designated spent fuel temperature envelope.

or conditioning step, or packaging for transport, further storage or disposal. Waste might be retained in a given store for a period of days to months.

Figure 1. General strategies leading to geological disposal (with and without reprocessing) for the management of spent nuclear fuel, high-level waste and recovered materials



Storage may be needed awaiting a waste management step for which the required facility or transport capability are not yet available, or awaiting a decision to be made on the next step for the particular waste or material – **interim storage**.[7] Similarly, if the process or step is not yet available or the output from the previous step exceeds the input capacity of the next step, then larger amounts of

7. The recent IAEA glossary (IAEA, 2003d), remarks that storage is always interim and, therefore, the term "interim storage" should not be used. We find this advice unhelpful because the term is used in several national programmes; the term also appears in the title of IAEA documents, e.g. (IAEA, 1998). This terminology problem is further discussed in (IAEA, 2002).

waste may be accumulated and stored for longer time periods. Interim storage implies waiting for something, whereas buffer implies storage to facilitate the efficient running of a process or next step.

Waste may remain in interim storage for several years to decades. In particular, in many countries, it is expected that spent nuclear fuel and high-level waste from reprocessing will remain in interim storage for periods of several decades awaiting the commissioning of suitable encapsulation and disposal facilities. This does not mean the waste will necessarily remain in the same store or conditions. For example, waste could be transferred from local stores to a centralised facility, or from older to newly constructed or refurbished stores. The waste could also be repackaged in some cases. To date, stores of modern design have typically been licensed for between 20 and 40 years,[8] e.g. (SKB, 2004), although in some cases applications to extend license periods are expected. For example, in the USA, regulation allows for periodic renewal of a storage license in 20 year increments (US NRC, 2003).

Interim storage periods may be extended beyond that expected at the time when storage commenced. This may occur because of a continuation of the conditions that made interim storage necessary in the first place, e.g. a suitable disposal facility is still not available, or because the decision to implement the next step is to be reviewed. If the extension is only for a few decades then storage may continue in the same facilities, but if much longer delays are expected then new storage facilities may be required. In any case, additional storage capacity is likely to be needed to accommodate the wastes that are still being produced.

Finally, storage is required for materials that, while not immediately required, have some potential future use or value and, therefore, have not been declared as a waste – **strategic storage**. This applies to spent nuclear fuel in several countries, the plutonium and uranium separated during the reprocessing of commercial fuels, and also stockpiles of weapons grade fissile materials.

Whereas nuclear power plants are operated in a large number of OECD member countries, industrial-scale reprocessing of spent nuclear fuel only occurs in France, Japan (pilot facility) and the United Kingdom. Several other countries, however, have had spent fuel reprocessed in France and the United Kingdom. Thus, some wastes and recovered materials are stored in the country in which the spent fuel was reprocessed, awaiting eventual return to the country from which the spent fuel originated.

Table 2 identifies representative examples of storage facilities for spent nuclear fuel and long-lived radioactive wastes in OECD member countries.

8. The HABOG facility in Netherlands is licensed for up to 100 years. This is an exceptional case and is discussed in Chapter 3.

Table 2. Representative examples of storage facilities for spent nuclear fuel and long-lived radioactive wastes in OECD member countries

Storage facility type or concept	Examples	Expected storage time
Immediate storage for cooling after unloading from reactor	All SNF is cooled under water after its unloading from reactor	Months to years
Interim storage of SNF in storages at reactor sites, in central stores or at reprocessing plants	Dry or wet storage facilities for SNF at reactor sites	Months to decades
	Above ground dry storage of LWR fuel assemblies at Gorleben (Germany)	Until after 2030
	Below ground wet storage of SNF at CLAB Oskarshamn (Sweden)	At least 30 years
	Above ground storage of SNF at ZWILAG (Zentrales Zwischenlager Würenlingen, Switzerland)	40 years or more
	Storage pools for baskets with spent fuel assemblies unloaded from transport casks (La Hague)	Minimum of 2 years
Storage of vitrified HLW at reprocessing facility or (after return) in country of origin of SNF	La Hague (EE-V-SE & R7T7) Dry storage of vitrified high level waste	Up to 100 years (on the basis of studies on durability)
	Dry storage of HLW canisters at Gorleben (Germany) JNFL Vitrified Waste Storage Center (Cooling and temporary storage awaiting disposal in a future repository) (Rokkasho, Japan) Dry storage of vitrified HLW at HABOG (The Netherlands) Above-ground storage of vitrified HLW at ZWILAG (Zentrales Zwischenlager Würenlingen, Switzerland)	Until after 2030 30-50 years Until 2130 (design basis ~100 years) 40 years or more
Geological disposal concepts that include phase(s) or step(s) of underground "storage" before closure	No existing facilities Discussed in Chapter 3	
ILW storage awaiting disposal	Storage of medium level waste (mainly cladding from reprocessing of fuels) at ECC La Hague	Up to 100 years (on the basis of studies on durability)
	Rock cavern (BFA) at Oskarshamn nuclear power plant: Storage for short-lived LILW awaiting disposal in SFR. Some long-lived LILW (e.g. core components) awaiting disposal in a future repository	License until 2010 but likely to be extended. Long-lived LILW likely to be stored for at least 30 years.
	above ground storage of LILW at ZWILAG (Zentrales Zwischenlager Würenlingen, Switzerland)	40 years or more

2.3 Preserving the safety and security of storage

It is frequently stated that spent nuclear fuel and long-lived radioactive wastes have been stored safely and securely in many countries now for several decades, e.g. (IAEA, 2003). It is also stated that such storage could be continued for many more decades, given repackaging of some wastes and periodic refurbishment of stores.

Both statements are true, but this does not mean safety and security are automatic characteristics of storage. Rather the continued safety and security relies on a suite of technical and organisational requirements. A non-exhaustive list of factors needed to preserve the safety and security of storage of radioactive waste is given in Box 3.

Box 3. Some factors needed to preserve the safety and security of storage of radioactive waste

- initial conditions of stable waste form, adequate packaging or containment and good facility design;
- good record keeping on waste origin, characteristics and location in store;
- maintenance of store structure and all infrastructure for handling and inspecting packages and waste;
- adequate control of store environment, e.g. temperature and humidity in dry stores and water chemistry in wet storage of spent fuel;
- monitoring of environmental and radiological conditions and degradation, if any, of packages or waste;
- security of the site and facility from malicious interference and inadvertent human events, including terrorist attacks and accidents;
- protection of the site and facility from natural events, e.g. flooding, hurricane and major seismic events;
- capability to assess risks from routine operation, normal degradation and design basis accidents, including events such as above, and apply appropriate mitigation strategies;
- capability to recognise when repackaging, store refurbishment or replacement of equipment is required and to perform such operations;
- capability to remediate in the event of any potential failure of safety or security;
- organisational capability to continue all of the above, including staff training and maintenance of safety culture, technical knowledge and records;
- appropriate regulations and independent inspections to ensure compliance with national regulations and safety requirements;
- compliance with international nuclear safeguards requirements;
- secure financial resources to ensure all of the above;
- political and societal commitment to continue all of the above;
- preparedness for the eventual implementation of an endpoint solution.

Extensive experience and technical knowledge related to storage exists in OECD member countries. Activities are firmly regulated and the principles for regulation are developed at international level, e.g. (IAEA, 1994). In addition, the IAEA has developed an indicator for radioactive waste management which countries can use as self-assessment for the sustainability of their radioactive waste management programmes (IAEA, 2001). Therefore, in simple terms, it could be stated that if the final two points of Box 3 are present then all the other points could be met. The list of points, however, indicates that maintaining good quality storage is a complex technical activity that does present ongoing challenges; and “could be met” is not the same as “will be met”.

One concern is whether older stores will preserve waste in an acceptable condition for safe onward handling. Originally, most stores were given a design life commensurate with expected duration of the processes that they supported, typically a few tens of years up to about 50 years. In some cases, however, packaging and environmental controls were designed to preserve the waste only for the time for which a given waste consignment might have been expected to remain in the store – possibly a shorter period. As a result, the condition of waste in older stores may be unsatisfactory, and must be checked. In some cases, where waste has been preserved in poor conditions, safe recovery and re-packaging may be required. While this is a legacy problem, it is possible that similar problems could affect even the most modern stores, if storage continues beyond the design life of the store and its environmental control systems.

In addition, cases can be cited (not from OECD member countries) in which a failure of supervision of radioactive waste storage has led to loss of material and radiation exposures, and to at least one radiation exposure fatality, see (IAEA, 1998b; IAEA, 2000).

Finally, risks from terrorist activities have to be given much more serious consideration than in the past. Several possibilities are of concern. These include terrorist attacks aimed at damaging a storage facility and consequent dispersal of radioactivity, theft of radioactive material to create so-called “dirty bombs”, and interruption of operations by activists in hostage-style incursions.

3. CONSIDERATIONS ON EXPANDED ROLES OF STORAGE

3.1 Discrimination between "conventional" and "expanded" roles of storage

The previous chapter has described the "conventional roles" of storage in OECD member countries, meaning:

> storage as needed in a management strategy for spent nuclear fuel and long-lived radioactive waste, expected to lead in a timely fashion to geological disposal, or re-use and disposal of the residues;

This is storage as it has been practiced over the last several decades in OECD member countries. It may include storage lasting for several decades, while a national geological disposal facility is implemented.

In recent years, there have been developments that have led some countries to consider using storage for roles that are beyond those considered as above. These are referred to as 'expanded roles' of storage.

The consideration of such "expanded roles" is linked to discussion of alternative strategies for the long-term management of long-lived solid radioactive waste and spent nuclear fuel, i.e. that geological disposal is not necessarily the endpoint or that it might be implemented only after an extended period. This may lead to long-term storage to provide time to investigate alternatives, to make a decision on endpoints, or even to wait for certain developments in science and technology. Some stakeholders consider that long-term storage is an acceptable endpoint, e.g. see (NWMO, 2004a; CoRWM, 2004). The latter is in contradiction to the definition of storage as used in the Joint Convention (cf. Box 1) but presumes different notions, e.g.: "For purposes of this report we have defined storage as a method of managing the waste in a manner that allows access under controlled conditions for retrieval or future activities while disposal is conclusive without any intention of retrieval or further use." (NWMO, 2005). The ambiguity in terminology seems to indicate the consideration of a continuum of concepts, for which a dividing line between "storage" and "disposal" is sometimes hard to identify. This is further illustrated by the development of geological disposal concepts that include a phase or step of underground "storage" before closure of the repository in order to provide a period during which confidence in the long-term safety of disposal can be enhanced, while the wastes can still be relatively easily retrieved if required.

These developments and the consequent storage concepts are described and discussed in the following sections.

3.2 Storage in view of unresolved choices in waste management strategy

As mentioned in Chapter 1, some countries are reviewing their strategies for the management of long-lived solid radioactive waste and/or spent nuclear fuel.

In **France**, the “Loi Bataille” requires research related to the management of long-lived HLW and other long-lived radioactive waste along three main axes in parallel (Journal Officiel Lois et Décrets, 1991):

- research on partitioning and transmutation (P&T) of long-lived radioactive elements in the waste;
- evaluation of options for retrievable or non-retrievable disposal in deep geological formations, particularly through the creation of underground laboratories; and
- study of immobilisation processes and long-term surface storage techniques for the waste.

The aim is to achieve a parliamentary decision on how to proceed in 2006. A draft law (“Projet de Loi”) about the management of radioactive waste and materials has been established and is currently being debated at the French Parliament (the draft law was passed by the National Assembly after its first reading on 12 April 2006) (Assemblée nationale, 2006). The draft law establishes a National Plan that estimates the future needs for storage and disposal facilities and set up objectives. It should comply with the following orientations:

- reduction of the quantity and toxicity of the waste;
- interim storage in dedicated facilities of waste to be processed or ultimate radioactive waste. At present, the technical requirements for interim storage for up to 300 years are being investigated;
- after interim storage disposal in deep geologic formations of all those wastes for which surface or shallow disposal is not feasible for reasons linked to nuclear safety or radiation protection.

According with the draft law, and as far as storage facilities are concerned, studies and research should be carried out about the creation of new storage facilities or about the modification of existing facilities in order to meet the objectives set up by the National Plan.

In **Canada**, the *Nuclear Fuel Waste Act* required the Nuclear Waste Management Organization (NWMO) to prepare a study comparing various approaches for long-term management options of Canada’s used nuclear fuel. The main options under consideration were geological disposal, storage at nuclear reactor sites and centralised storage, either above or below surface (NWMO, 2004a). After an extensive period of analysis, dialogue and engagement with Canadian citizens, the Nuclear Waste Management Organization has recommended “Adaptive Phased Management” (NWMO, 2005), an approach which includes continued storage at reactor sites, option for shallow underground storage at a central long-term management site, and placement in a deep geological repository at the central site with an extended period of monitoring, access and retrievability for an extended period of time. Dependent on the outcome of future decisions, used fuel could remain at reactor sites for the next 30 to 60 years prior to transport to the central facility for long-term management.

In the **United Kingdom**, the Government has commissioned an independent committee – the Committee on Radioactive Waste Management (CoRWM) – to review options for managing all solid radioactive wastes in the United Kingdom and to recommend the option, or combination of options, that can provide a long-term solution. This committee is unconstrained in the options it may consider and evaluated several variants on long-term storage above and below ground (CoRWM, 2004). In April 2006, the committee announced an integrated package of draft recommendations for the long-term management of the UK's radioactive waste. The package envisages that, in the long term, radioactive waste will be disposed of deep underground. It recognises, however, that the process leading to the creation of suitable facilities for disposal may take several decades and should therefore be underpinned by robust interim storage (CoRWM, 2006).

In each of the above mentioned countries, there is the possibility that the Government may decide to adopt a policy of long-term storage (i.e. storage for about 100 years or more) for some or all long-lived radioactive wastes and/or spent nuclear fuel.

The **Netherlands** have already made such a decision to store radioactive waste for at least 100 years, and a facility (HABOG) has been commissioned for this purpose (Netherlands, 2003). The HABOG is, so far, the only existing example of a facility specifically designed to provide storage for a century or more. The stated reason for adopting this solution is that:

> "The waste volume that is actually accumulated now is only a few thousand m^3 and it is not economically feasible to construct a deep geological disposal facility for such a small volume, whereas, the waste volume collected in a period of 100 years is judged as large enough to make a disposal facility viable." (Netherlands, 2003)

The Netherlands' solution, therefore, is to store the waste for a period of at least 100 years and to prepare financially, technically and socially for deep disposal during this period so that it can be implemented after the storage period. Of course, at that time, society will have the freedom of choice between a continuation of the storage for another 100 years (or more) or to realise the final disposal. Figure 2 illustrates storage variants that have been considered, where variant B corresponds to the current expectation.

Further information on the position in each of the above countries is given in Appendix 1.

Box 4. "Positive benefits" for the strategy of storage for at least 100 years in the Netherlands

1. Public acceptance is quite high for long-term storage. The general public has more confidence in physical control by today's society than in long-term risk calculations for repositories even when the outcome of the latter is a negligible risk.
2. There is a period of 100 years available to allow the money in the capital growth fund to grow to the desired level. This brings the financial burden for today's waste to an acceptable level.
3. During the next 100 years an international or regional solution may become available. For most countries the total volume of radioactive waste is small. Co-operation creates financial benefits, could result in a higher safety standard and a more reliable control.
4. In the period of 100 years the heat generating waste will cool down to a situation where cooling is no longer required.
5. A substantial volume of the waste will decay to a non-radioactive level in 100 years.
6. A little bit more than 100 years ago, mankind was not even aware of the existence of radioactivity. In 100 years from now new techniques or management options can become available.

from National Report of the Netherlands under the Joint Convention (Netherlands, 2003).

3.3 Motivations for long-term storage

In this section, the arguments presented by the Netherlands are taken as a starting point to discuss the motivations for long-term storage more generally.

The main motivation for the adoption of long-term storage by the Netherlands is practical (as described earlier in Section 3.2). The Netherlands considers, however, that its strategy creates at least six “positive effects”, as set out in Box 4, which might be termed motivations. These are not necessarily accepted as valid motivations in other countries.

In respect of public acceptance, although the HABOG storage facility has gained acceptance in the Netherlands, it is not clear that storage facilities are necessarily more acceptable than disposal facilities in general. Rather, in many countries, there is difficulty in gaining acceptance of any new facility related to radioactive waste. This is especially true of attempts to site facilities in locations away from existing nuclear sites (EC, 2004). Box 5 gives some examples concerning public acceptance of radioactive waste management facilities.

Box 5. Public acceptance of waste management facilities: some examples

It is important to distinguish overall societal acceptance from acceptability to the local communities. The latter is the more important aspect because it is the local communities that must bear any actual or perceived negative aspects of the development.

- According to a representative opinion poll in Germany, more than 70% of the people interviewed regard the question of radioactive waste management as very urgent (51%) or urgent (22%). More than 60% of the people asked describe it as desirable to solve the problem of disposal within the next decade. However, 80% would not agree with a disposal facility for radioactive waste in their own region (EC, 2004).
- A successful example of how to achieve public acceptance for a long-term storage facility by means of a consensus approach is the development of the HABOG facility in the Netherlands (Borssele, Zeeland) (EC, 2004).
- The municipality of Kincardine (Bruce County, Canada), presently hosting the Western Waste Management Facility (WWMF) for LILW storage, agreed in 2004 after having studied a number of long-term management options (Golder Associates, 2004), to host a deep geological repository for the waste presently stored at WWMF (OPG, 2004).
- Other examples where municipalities hosting storage facilities tend to accept disposal solutions in their own area can be found in Sweden and Finland (EC, 2004). The COMPAS report (EC, 2004) suggests: “Nuclear host communities, where the waste is already stored or where waste is being produced, tend to be the communities that are most interested in the implementation of a permanent, safe solution.”
- In Spain, the nuclear municipalities oppose any further plant life-time extension as this will automatically mean more waste and for longer time on their commune. They have requested a centralised interim storage facility (AMAC, 1999).
- In the United Kingdom, Cumbria County Council have recently stated in a submission to CoRWM that above ground “indefinite” surface storage raises many concerns. The Council considers that underground storage (near to the surface) and phased deep disposal should be assessed in more detail; the Council would not favour immediate deep disposal (CCC, 2005).

Figure 2. Schematic of long-term storage variants considered in the Netherlands

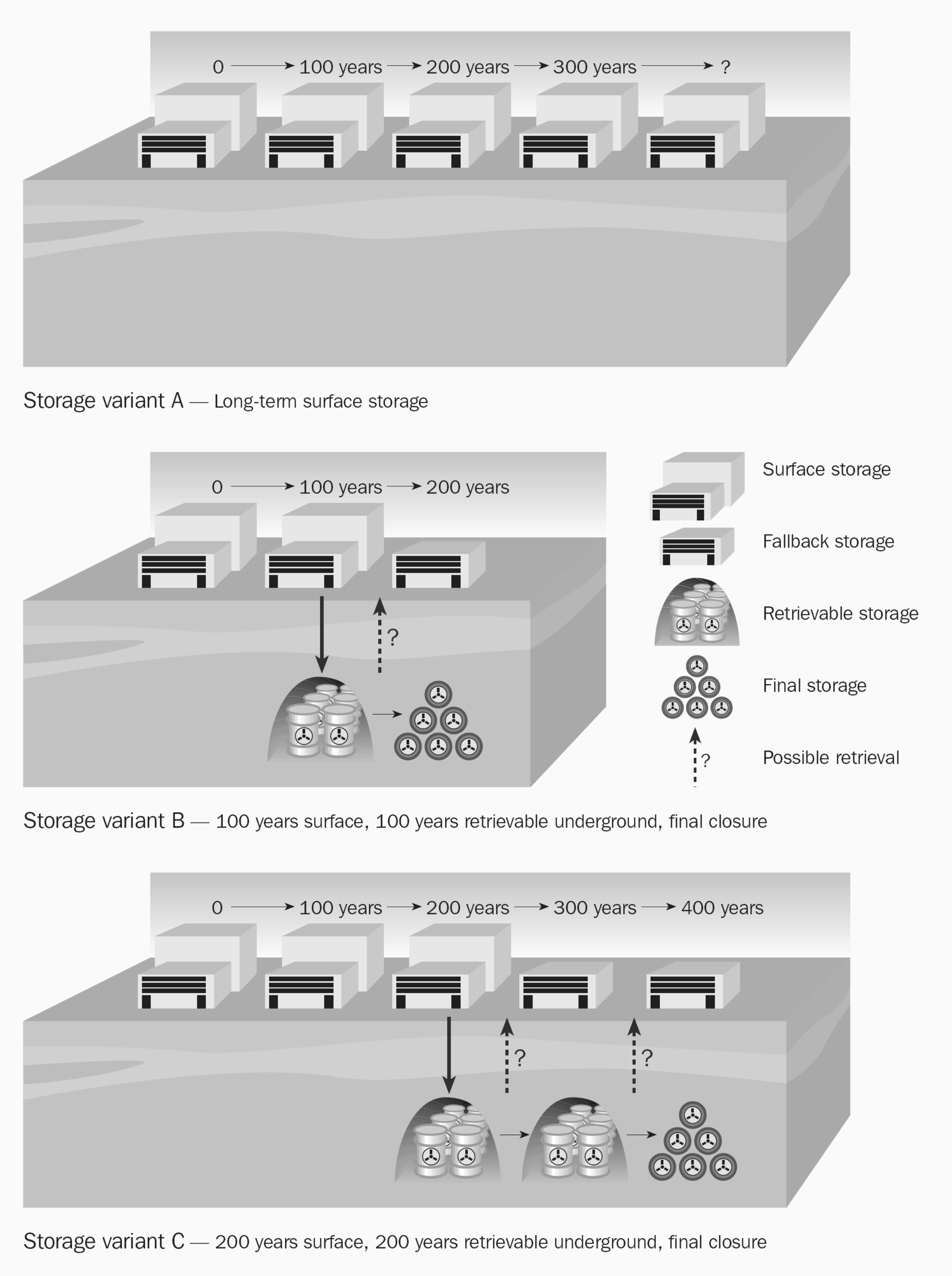


Figure from (CORA, 2001). Storage variant B is the currently expected case.

With regard to finance, in many OECD member countries, radioactive waste producers make contributions into a managed fund that is maintained for the purpose of financing disposal and related research and development costs. This is as an important requirement to ensure the sustainability of nuclear power and the associated waste management costs, i.e. all costs can be internalised (NEA, 2001). Thus, the situation in the Netherlands is not typical. It can also be observed that the growth of capital funds depends on growth of the investment and, loosely, continued growth in the World economy; these factors are not guaranteed.

The possible availability or development of a regional or a multi-national solution is of interest to countries that have relatively small amounts of wastes to manage. The possibility of such a repository is considered or not excluded, e.g. in the Czech Republic, Hungary, Slovenia and Switzerland, mainly because of economies of scale that it would deliver.[9] Member states of the IAEA are exploring this option, and a recent IAEA TECDOC concludes that it is reasonable to consider regional repositories based on sound environmental and ethical arguments, as long as international standards of health, safety and environment protection are followed (IAEA, 2004). The option is also mentioned in the proposed EC Directive on the Management of Spent Fuel and Radioactive Waste and is supported in a report adopted by the European Parliament of 13 January 2004 (European Parliament, 2004). The initial phase of the SAPIERR pilot study, which is being performed within the 6th EC Framework Programme, looks at the technical and legal requirements for a regional repository, but does not address the issue of identifying a country or countries that could host a shared repository (SAPIERR, 2004).

Most countries, however, are dealing with their radioactive wastes within their own borders as a reference case, even if a regional or a multinational solution might become available in the future. In Switzerland, for example, it is a legal requirement to demonstrate the feasibility of geological disposal of spent fuel and long-lived radioactive waste within Swiss borders, although disposal in a multi-national repository is not excluded. If the prospect of participating in a regional or a multi-national repository is the motivation, then it seems to be prudent and responsible for a country with this view to collaborate actively in seeking such a solution.

With regard to possibilities for new technology, it is true that 100 years ago nobody could have foreseen the technologies that are available today. Nevertheless, it cannot be assumed that new technologies will dramatically change the situation in respect of managing radioactive waste. In particular, technologies generally only change in response to a need and commitment to developing the technology. For instance, development in the waste management area seems to be tied to that in the nuclear energy field. P&T technology is dependent on the utilisation of novel reactor technologies and it is still unclear at which time it will be implemented at an industrial scale. Furthermore, there is no incentive to develop advanced treatment technologies for vitrified HLW and TRU-waste. Thus, it is necessary to work positively on developing new technologies if that is the motivation claimed; it is not sufficient to wait in the hope that a technology for a specific purpose will just happen or be developed by others.

Box 6 shows a more extensive collection of motivations that have been suggested as reasons for long-term storage of radioactive wastes and spent nuclear fuel. Some of these relate to practical matters and difficulties while others are based on ethical interpretations. Different stakeholders may favour, or not favour, long-term storage for various reasons. Whether some reasons are valid or not may be partly a subjective judgement, and certainly depends on opinions concerning the future and how this generation should best limit the liabilities that it will leave for future generations.

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9. However, present legislation in some of these countries would prohibit the import or export of radioactive waste.

Box 6. Some further motivations suggested for long term storage

In the following, some motivations are compiled that have been suggested for long-term storage and extension of storage periods. Some of the reasons given come primarily from outside the organisations with responsibilities for radioactive waste management or its regulation.

- For practical reasons (due to lack of available alternative). This applies especially to spent nuclear fuel not destined for reprocessing which is currently stored on power generating sites awaiting the construction of centralised spent fuel storage facilities or disposal facilities; it also applies to high-level waste and intermediate level waste from reprocessing stored at the reprocessing sites. Adequate safe storage facilities must be constructed at these sites until a centralised storage or disposal facility is ready to receive them – which in the case of a geologic disposal facility may be some decades away in many countries.
- For future technological reasons; because there is an expectation or hope that alternative technological solutions may be developed which may be usefully incorporated into waste management, e.g. P&T, although this would not avoid the need for disposal of wastes.
- For future resource reasons; because on a time scale of decades resource needs are likely change, and especially energy resources become more scarce, which raises a prospect that recovery and reprocessing of spent fuel may become desirable.
- For ethical and societal reasons; that disposal is not necessarily regarded as the most ethical path if it forecloses options to future generations; that there is a general social or political preference against taking irrevocable decisions; or that there is lack of public acceptance of a disposal solution.
- For economic and related technical reasons; since delay of implementation leads to a delay in expenditure, which under typical government and business accounting practice implies an apparent cost saving; because it may be cheaper to build and load the repository in a short time span and it is convenient if more waste is accumulated before construction begins. For the disposal of spent fuel, especially MOX fuel, it may be desirable if there was greater decay in the thermal output of the fuel so that waste could be emplaced at higher density.
- For technical and confidence reasons; because greater technical assurance is required of the long-term safety of geological disposal systems, or demonstration of disposal technology, so that periods of investigation and development may be longer, or extended confirmatory periods of monitoring and review are required, or the closure of disposal facilities may be delayed after waste emplacement and the facility operated for a period as a monitored underground store.
- For political reasons; because there may be delay in formulating and adopting an effective national policy for radioactive waste management, or local political or public opposition may delay or prevent implementation of national policy.
- For ideological reasons; because favouring of indefinite storage can be regarded as an argument for those who oppose nuclear power. (If the nuclear waste problem is not resolved then new-build of nuclear power plants should not be allowed.)
- Awaiting a possible international or multinational solution; especially for countries with relatively small quantities of waste there would be economic advantages in pooling resources with one or more other countries to collaborate on development of a disposal facility.

3.4 Challenges to be met when expanding the roles of storage

If, *for whatever reasons*, long-term storage is being considered then the challenges that this imposes must be taken into account.

In Box 3, some of the factors needed to ensure the safety and security of storage facilities were summarised. It is necessary to address these factors within environmental impact assessments and safety cases and associated long-term safety assessments for the facilities under question. At present, such safety cases seem to be not very well developed. Indefinite storage would even, at least in the European Union, invoke the execution of strategic environmental assessments (SEA) within the current European legislative environmental framework (European Parliament, 2001). So far, the only long-term storage facility for which an environmental impact assessment and a safety assessment has been carried out is the HABOG facility in the Netherlands, cf. (EC, 2004).

There are, however, a number of investigations[10] for a variety of storage and disposal facilities and concepts considering the durability of materials, structures and installations which is an important pre-requisite for such assessments. Amongst other issues, corrosion and degradation mechanisms, chemical changes of materials over time, dilution and/or evacuation of gases and long-term stability of underground vaults have been considered. For longer storage times (in the order of centuries), these investigations indicate that the requirement to maintain the factors listed in Box 3 over prolonged times imposes challenges going beyond a simple extrapolation. Although the concepts considered vary with regard to many aspects (waste types to be stored, emplacement depth, building type, wet versus dry storage etc.), they have much in common with regard to timescales of active measures necessary to provide safety, environmental protection, and security. While activities like record keeping, monitoring, safeguarding have to be carried out continuously, longer storage times may also require periodic refurbishment, repackaging and even renewal or erection of new storage buildings. The cost, dose and environmental implications of such activities need to be considered in long-term safety and environmental impact assessments. At present such assessments are not well developed. The time interval for such activities lies in the range of several decades to a century. So far, only CEA seriously explores possibilities for innovative storage concepts with lifetimes of a few centuries (Lieven and Sylvie, 2005; CEA, 2005; cf. also Annex 1). Maintenance may become even more challenging in older facilities.

It is important to define the time period for which storage is expected under the national waste management strategy. This is needed in order:

- to set waste package requirements and to design facilities that offer an appropriate level of durability;
- to set licensing requirements;
- to calculate costs and to ensure that sufficient resources are provided;
- to indicate the organisational commitments entailed.

If long-term storage is associated with any uncertainty about the endpoint, this has the potential to create considerable uncertainty in relation to the operational management of wastes. These

10. For example, the Swedish CLAB (Söderman, 1997; SKB 2004), above-surface and near-surface long-term storage concepts considered in France (Leconte, 2002; Marvy and Ochem, 2003; Lieven & Sylvie, 2005; CEA, 2005) and in Canada (NWMO, 2004b; NWMO, 2004c) or repository concepts allowing retrievability/reversibility for long times in the Netherlands (CORA, 2001) or in France (Andra, 2005).

uncertainties can result in considerable risks and associated costs, which should not be underestimated. In any case, it should be kept in mind that the most optimistic assumptions and regulatory requirements about the duration of institutional control periods for waste management facilities do not go beyond the order of centuries.

If the technical assurances of safety and security listed in Box 3 are to be maintained over the decided time period, it is essential to provide correspondingly secure financial resources and stability for the organisations and agencies that are charged with carrying out and supervising the storage.

In addition, safe and secure storage will depend on continued political and societal commitment and also national economic stability to maintain the responsible organisations and resources. Such factors become harder to guarantee the further into the future that is considered. Therefore, regardless of the reasons why long-term storage is initiated, assessments of its future safety are based on assumptions concerning future economic, political and societal continuity and stability – which introduce large and unknowable uncertainties into the prospects of future safety and security.

Maintaining flexibility has been cited as one of the possible reasons for continuing storage, see Appendix 2. However, flexibility accompanied by a lack of clarity in the strategy, and future decisions needed, generates uncertainty in both costs and safety, which is undesirable. Ultimately, flexibility, without clear plans on how this flexibility will be used, encourages no decision at all and therefore continued storage by default. It has been observed by the chairman of the European Radioactive Waste Regulators' Forum that "open-ended storing of the waste due to delaying the decisions necessary to obtain the far-reaching solution is, from the safety perspective, the worst option containing most uncertainties" (Varjoranta, 1999, quoted in NRC, 2001).

Finally, if a policy of long-term storage is adopted in view of possible future developments, e.g. of technology or multinational solutions, then the country must work actively to investigate and develop these possible solutions. Thus, the continuation of storage must be focused on a goal towards which the country is working. Just waiting, on its own, would be irresponsible and not in accordance with the principle of sustainability and, therefore, not sufficient.

3.5 Can storage become an endpoint?

As stated earlier, storage in the notion of the Joint Convention (Box 1) cannot be an endpoint by definition. The Joint Convention also requires that "at the design stage, conceptual plans and, as necessary, technical provisions for the decommissioning of a radioactive waste management facility other than a disposal facility are taken into account" (IAEA, 1997). However, as indicated in Figure 2 (Variant A) the Netherlands and several other countries, e.g. France, Canada and the United Kingdom, have considered, or are considering, the possibility of periodic renewal of storage facilities which might, in theory, result in an indefinite continuation of storage.

Can, then, such a continuation ever be considered as an endpoint?

With regard to "indefinite" storage, it can be observed that because storage relies on active controls, maintenance and periodic renewal of storage facilities, then storage can only ever be interim. Storage can be planned for the period over which a store can be designed to operate and waste packages remain intact. Beyond this time a further decision will need to be made and additional resources committed. Although possible options can be suggested now, the decision will not be taken by this generation. Rather, each generation will make its own decisions on whether to continue storage or enact some other solution. Planning for indefinite storage is, therefore, failing to define an endpoint and passing that responsibility to future generations.

Concepts of perpetual storage and guardianship, e.g. utilising mausoleum type facilities, have been proposed since the late 1940s (Buser, 2003). However, if no further step or action is planned in a waste management strategy then either the waste management strategy is incomplete or the last step is, in fact, disposal. Thus, logically, if a mausoleum type facility was proposed, it would have to be assessed against the same criteria and safety standards as geological disposal. Guardianship of the facility could not be assumed to be effective beyond a certain time.

Therefore, storage can never become an endpoint for radioactive waste management. Further, it can be observed that planning for very long periods of storage, involving multiple renewals of storage facilities poses significant technical challenges and introduces very significant economical, managerial and societal uncertainties over which the present generation can have no control, as discussed in Section 3.4. It can also be considered as a failure to meet the responsibilities of the waste producers, since the decision to renew storage can only be made by future generations.

3.6 Underground "storage" as a step towards geological disposal

In some countries, it is considered that closure of the repository should not be delayed unless it is technically necessary. In other countries, for example in Belgium, Canada, France, Switzerland, the United Kingdom and the United States, modifications of the geological disposal concept have been adopted or considered that deliberately extend the period during which access to the repository might be held open beyond completion of waste emplacement. In such cases, a longer period of time or several phases with different degrees of reversibility are created during which the waste, or a representative part of it, would be monitored and, if needed, the waste could be retrieved by reversal of the emplacement process (NWMO, 2005; Andra, 2005; EKRA, 2000; Nirex, 2003; U.S. Department of Energy, 2001).[11]

According to the definitions in Box 1, such repository concepts belong clearly to the category "disposal". Nevertheless, they are briefly addressed here since the period after waste emplacement and before closure is a period of retrievability, monitoring and active care and, therefore, might by some be regarded as storage.

There are some difficulties with the storage within the repository concept from a design and also regulatory perspective. This is because it must be clear at the time at which a facility is planned whether it is ultimately a storage or disposal facility. Planned delay of closure could have an impact on the safety case for the deep repository and on the license requirements and would need to be clearly addressed in licensing of the facility. Authorisation to place waste in a disposal facility is unlikely to be given unless a safety case had been made for ultimate endpoint.

Thus, any underground monitored, retrievable phase in repository development is a step towards geological disposal, and is not storage in the usual sense. This is reinforced by the definitions of

11. In the case of the United States, the primary motivation for extended underground storage stemmed from a desire to allow a future decision on the heat-loading of the repository. A period from 76 to 300 years after final emplacement was considered for the heat-loading flexibility offered by that range. The shorter period, 76 years after waste emplacement has ceased (which is 100 years after the start of waste emplacement), is the preferred timescale.

storage and disposal, see Box 1, wherein the distinction is whether there is an intention of retrieval or not. However, a monitored, retrievable phase has many characteristics of storage so that the safety and security requirements, see Box 3, are similar. In addition, provisions for such a phase must not jeopardise long-term safety of the facility.

3.7 Undue burden, responsibility and sustainability

In managing long-lived radioactive waste and spent nuclear fuel, all signatories of the Joint Convention (IAEA, 1997) are obliged to follow accepted safety standards including the IAEA Safety Fundamentals (IAEA, 1995). This latter publication includes a Principle that "Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations", see Box 7.

Box 7. The "undue burden" requirement

The objective of radioactive waste management, as given in the *IAEA Principles of Radioactive Waste Management* (IAEA, 1995), 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."

This is formalised in "Principle 5: Burdens on future generations.

Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations."

This is supported by comments, wherein the following key points are made:

- "The principle is based on an ethical consideration, that generations that receive the benefits of a practice should bear the responsibility to manage the resulting waste."
- "The responsibility of the present generation includes developing the technology, constructing and operating the facilities, and providing a funding system, sufficient controls and plans for the management of the radioactive waste."
- "The management of radioactive waste should, to the extent possible, not rely on long-term institutional arrangements or actions as a necessary safety feature, although future generations may decide to utilise such arrangements, … ".

The stipulation not to impose undue burdens on future generations is interpreted by the IAEA, and many others, to lead to a requirement for radioactive waste management solutions that do not require active care and provide, instead, passive safety. This is consistent with the selection of geological disposal, in accordance with the RWMC 1995 Collective Opinion, which considers that "geological disposal is currently the most favoured strategy" (NEA, 1995).

Critical in the IAEA's discussion, however, is the statement that the undue burden principle is based on an ethical consideration. In this case, the question remains open, because alternative interpretations of "undue burden" can be advanced. The technically-based interpretation above, for example, considers that placing an extended duty of care on future generations is an undue burden. Others can argue that disposing of a hazardous material in such a way that future generations cannot easily control the hazard is an undue burden. Adopting a solution such as geological disposal, a challenging enterprise that could take many decades to complete, is itself a significant burden on at least the immediate future generation – but is this "undue burden"?

What can be said is that each generation leaves a legacy to future generations and this consists of both benefits and burdens. Burden is, presumably, undue burden if the burden exceeds the benefits. It is difficult, however, to see how this can be judged when both benefits and burdens have multiple attributes that may be assigned different values by different stakeholders and at different times. It is particularly difficult for this generation to guess which parts of their legacy will be considered significant burdens, or undue burden, by future generations.

The concept of sustainability offers a more useful tool. One definition of sustainability is that all financial costs and technical burdens must be internalised. That is, if a responsibility is handed forwards, then so must the means to deal with the responsibility. This approach provides the resources, so that future generations can at some point discharge the responsibility.

This can be elaborated as follows:

- Responsibility (financial and intellectual) – the generation that has derived the primary benefit should provide the solutions and resources to deal safely with the associated waste. This is both a matter of financial and intellectual responsibility. It is our duty to understand the problem and provide solutions according to our understanding.
- Sustainability – an "open" solution is not sustainable, since it implies non-quantified impacts and use of resources.[12] Only if the total associated environmental burden and cost can be estimated can they be internalised within the process. Technical and financial provision must be made. The technical and financial provision for any waste management activities needed beyond those that can be guaranteed by the current waste management organisations must be guaranteed by the Government.

To be sustainable, it is essential to define a complete "closed" waste management strategy that does not rely on speculations concerning future societal, scientific or technological developments. To be complete, the strategy must have a well-defined endpoint, and the path (or alternative paths) to reach that endpoint must be specified. To be successful, both this and future generations need to continue working to ensure that storage of radioactive wastes can be ended at an appropriate time.

Of course, future generations may choose to follow the waste management strategy that is defined today, to amend it or to adopt some alternative strategy. In doing so they will take into account the increased knowledge that they may then have and their constraints and preferences. If flexibility is built into a radioactive waste management strategy, then future generations will be able to exercise more judgement for themselves. This, however, should not distract the present generation from the importance of our responsibility, to implement as much of the plan as can be done now.

12. The potential impacts and resources needed are probably unquantifiable, because there is no constraint on the time frame to be considered.

4. SUMMARY AND CONCLUSIONS

4.1 Policies in OECD member countries

Storage has long been incorporated as a step in the management of long-lived solid radioactive waste and spent nuclear fuel.

Article 2 of the Joint Convention (IAEA, 1997) provides the following definition: storage means the holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval.

According to this definition, and conventionally, storage is an interim step within a waste management strategy in which the ultimate step is still to be done.

Typically, stores have been designed and licensed for periods of decades, in one case (the HABOG in the Netherlands) for a century. In more recent years, the question has been asked whether storage periods might be extended to provide longer-term care of the radioactive waste.

All countries that have so far made a policy decision on a final step for the management of long-lived radioactive waste (and spent fuel if it is declared a waste) have selected geological disposal as the endpoint. This statement applies worldwide, not only to OECD member countries.

Some countries are undertaking research on the feasibility of long-term storage (up to several hundred years).

In two countries, Canada and the United Kingdom, formal consultations are currently taking place or have been recently completed with a view to defining policy within the next few years, and long-term storage is an option under consideration. In France, long-term storage is amongst the axes of research the consideration of which is required by law.

In one country, the Netherlands, a policy decision has been taken to store radioactive waste for at least 100 years, and a facility (HABOG) has been commissioned for this purpose.

4.2 The conventional roles of storage

Storage occurs within the context of a radioactive waste management strategy designed to ensure the safety and security of the radioactive material, and the protection of man and the environment, while permitting re-use of materials if desired. Storage is carried out for reasons generated by the requirements of the strategy, never for its own sake.

Storage is valuable:

- to allow the levels of radioactivity and heat to decline before the next step or process of the waste management strategy can be enacted (*decay storage*);

- to provide stock for an ongoing process, transport step or disposal (*buffer storage*);
- while waiting for a waste management step for which the required facility or transport capability are not yet available, or while waiting for a decision to be made on the next step for the particular waste or material (*interim storage*);
- for materials that, while not immediately required, have some potential future use or value and, therefore, have not been declared as a waste; this applies to spent nuclear fuel in several countries (*strategic storage*).

Long-lived solid radioactive waste and spent nuclear fuel has been stored safely and securely in all OECD member countries now for several decades. Such storage could continue for many more decades, given proper controls and supervision as well as repackaging of some wastes and periodic refurbishment of stores.

Extensive experience and technical knowledge related to storage exists in OECD member countries. Storage activities are firmly regulated and the principles for regulation are developed at international level.

However, maintaining good quality long-term storage is a complex technical activity that presents ongoing challenges. Worldwide, there are examples of both satisfactory and unsatisfactory radioactive waste storage conditions. To maintain satisfactory storage, the facilities must be carefully planned and operated to avoid degradation of facilities, to maintain supervision and to avoid loss of materials and radiation exposures. It should also be noted that storage facilities, as any other industrial facilities, are vulnerable against terrorism with increasingly destructive weapons.

Thus, safety and security are not automatic characteristics of storage. Rather, continued safety and security rely on a suite of technical and organisational requirements (cf. Box 3). To be effective in the long term, these technical and organisational requirements must be underpinned by secure financial resources and an ongoing political and societal commitment to take care of the waste.

Finally, risks to storage facilities from terrorist activities have to be given much more serious consideration than in the past.

4.3 Considerations on the expanded roles of storage

Conventionally, storage is needed in a management strategy for long-lived solid radioactive waste and spent nuclear fuel, expected to lead in a timely fashion to geological disposal, or re-use and disposal of the residues. In recent years, there have been developments that lead, in some countries, to use storage, or consider storage, for roles that are beyond those conventionally considered.

The most significant development is the discussion of alternative strategies for the long-term management of spent nuclear fuel and long-lived radioactive waste, i.e. that geological disposal is not necessarily the endpoint or it might be implemented only after an extended period.

This may lead to long-term storage (i.e. 100 years or more) to provide time to investigate alternatives, to make a decision on endpoints, or even to wait for certain developments in science and technology. Some stakeholders consider that long-term storage itself is an acceptable endpoint.

Various motives have been put forward for extending storage periods including:

- immediate and practical reasons, e.g. related to public acceptance and (in countries with smaller amounts of radioactive waste) that disposal would be more economical if a larger volume of waste is accumulated;
- future strategic reasons, e.g. related to the possible development of regional or multi-national solutions or developments in technology.

Different stakeholders may favour, or not favour, longer-term storage. The reasons used to support their position may be partly based on subjective judgement, and their opinions concerning the future and how this generation should limit the liabilities that it will leave for future generations.

It is not clear that storage facilities are necessarily more acceptable to the public than disposal facilities in general. Rather, in many countries, there are difficulties gaining acceptance of any new facility related to radioactive waste.

Importantly, if long-term storage is being considered then the technical challenges associated with this strategy must be taken into account. These challenges will increase the longer into the future that storage is contemplated. As mentioned above, storage for several decades is an established practice in OECD member countries and elsewhere which, if properly implemented, surveyed and maintained, is demonstrated to be safe and secure for such timeframes. There is also one example of an existing storage facility which is licensed for a century (the HABOG in the Netherlands) and for which an even longer storage period (up to three centuries) is considered an option. Storage times of several centuries are explored in France, where innovative facility designs are considered in order to ensure the longevity of materials, structures and installations over such timeframes. Beside of these technical considerations, enduring control and maintenance has also to be ensured over these timeframes. The most optimistic assumptions and regulatory requirements about the duration of institutional control periods for waste management facilities do not go beyond 300 years. In any case, these periods of centuries are considerably shorter than the period for which long-lived waste presents a hazard and needs to be managed. It should also be noted that storage facilities – especially if they are at the surface – as any other industrial facilities, are vulnerable to acts of terrorism with increasingly destructive weapons.

Consequently, it is important to define the time period for which storage is expected under the strategy. This is needed to enable design, to allow estimation of costs, for licensing, and to indicate the organisational commitment entailed.

To maintain the technical assurances of safety and security, it is essential to provide secure financial resources and stability for the organisations and agencies that are charged with carrying out and supervising the storage. This will require continued political and societal commitment and, also, national economic stability to maintain these organisations and resources. Such factors become harder to guarantee the further into the future that is considered.

If a policy of long-term storage is adopted in view of possible future developments, e.g. solutions based on technology development or multi-national facilities, then the country adopting that policy must work actively to investigate and develop these possible solutions. Waiting, on its own, is not enough.

By definition, storage cannot be an endpoint for radioactive waste management. Further, it is observed that planning for very long periods of storage, involving multiple renewals of storage facilities is unrealistic and introduces significant uncertainties over which the present generation can have no control. One of these uncertainties is the possibility that such storage might become the endpoint by default, which would be unsatisfactory.

If a responsibility is handed to future generations, then so must the means to deal with the responsibility, so that future generations can at some point discharge the responsibility. This is a matter of financial and intellectual responsibility. It is our duty to understand the problem and provide solutions according to our understanding now.

An "open" solution, such as indefinite storage, is not sustainable, because it implies unquantified (and probably unquantifiable) impacts and use of resources. To be sustainable, it is essential to define a complete waste management strategy that does not rely on speculations concerning future societal, scientific or technological developments. To be complete, the strategy must have a well-defined endpoint and the path (or alternative paths) to reach that endpoint must be specified. To be successful both this and future generations will need to continue working to ensure storage can be ended at an appropriate time.

Future generations may choose to follow the waste management strategy that is defined today, to amend it or to adopt some alternative strategy. In making their decisions they will take into account the increased knowledge that they may then have, and their constraints and preferences. If flexibility is built into a radioactive waste management strategy, then future generations will be able to exercise more judgement for themselves. This, however, should not distract us from the importance of our responsibility, to implement as much of the plan as can be done now.

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Appendix 1

THE IAEA POSITION PAPER AND THE VIEW OF THE RWMC

The IAEA Position Paper

The International Atomic Energy Agency (IAEA) commissioned an *ad hoc* international group to investigate the viability of extending storage in a sustainable programme of radioactive waste management, and especially the implications for safety. This group, working mainly during 2002, prepared a Position Paper that was published in 2003 (IAEA, 2003b). The Position Paper examines the sustainability of radioactive waste storage with regard to a number of factors including safety, maintenance and institutional control, retrieval, security, costs, community attitudes and transfer of information. Key statements from the conclusions of the Position Paper are reproduced below.

Concluding statements from the IAEA Position Paper on long term storage

- Storage is a necessary phase in safely managing most types of radioactive waste.
- Storage has been carried out safely within the past few decades, and there is a high degree of confidence that it can be continued safely for limited periods of time.
- The safety of long term storage requires the maintenance of industrial, regulatory and security infrastructure.
- Long term safety also requires that future societies will be in a position to exercise active control over these materials and maintain effective transfer of responsibility, knowledge and information from generation to generation.
- Long term storage is only sustainable if future societies can maintain these responsibilities.
- Active controls cannot be guaranteed in perpetuity because there is no guarantee that the necessary societal infrastructure can be maintained in perpetuity. Therefore, … perpetual storage is not considered to be either feasible or acceptable.
- Storage and disposal are complementary rather than competing activities and both are needed.
- The timing and duration of the process of moving from storage to disposal is influenced by many factors, not only the sustainability of long term storage. Strategies for storage and disposal need careful consideration in the light of the many issues involved. These include transport … , security … , retrievability of the waste from storage, safe packaging and conditioning … , availability of suitable disposal sites, confidence that adequate levels of safety can be achieved, and the availability of finances.

Statements from Chapter 5 (IAEA, 2003b.)

The view of the RWMC

The RWMC has discussed overall waste management approaches and the incorporation of extended periods of waste storage, for example, at a Topical Session of the Committee (NEA, 2002). The RWMC agrees with the general arguments and conclusions reached in the IAEA Position Paper. Moreover, the RWMC notes these conclusions are consistent with its 1995 Collective Opinion (NEA, 1995), which considered that:

> "from an ethical standpoint, including long-term safety, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed;"

and:

> "after consideration of the options for achieving the required degree of isolation of such wastes from the biosphere, geological disposal is currently the most favoured strategy;"

While we consider that geological disposal is currently the best technical solution for the long-term management long-lived radioactive wastes, we acknowledge that decisions on the strategy for the long-term management of a country's radioactive waste must ultimately be taken by politicians acting on behalf of society. These decisions take account of a range of non-technical factors, especially the acceptability of geological disposal both in general and among communities that may be the potential host for a geological disposal facility.

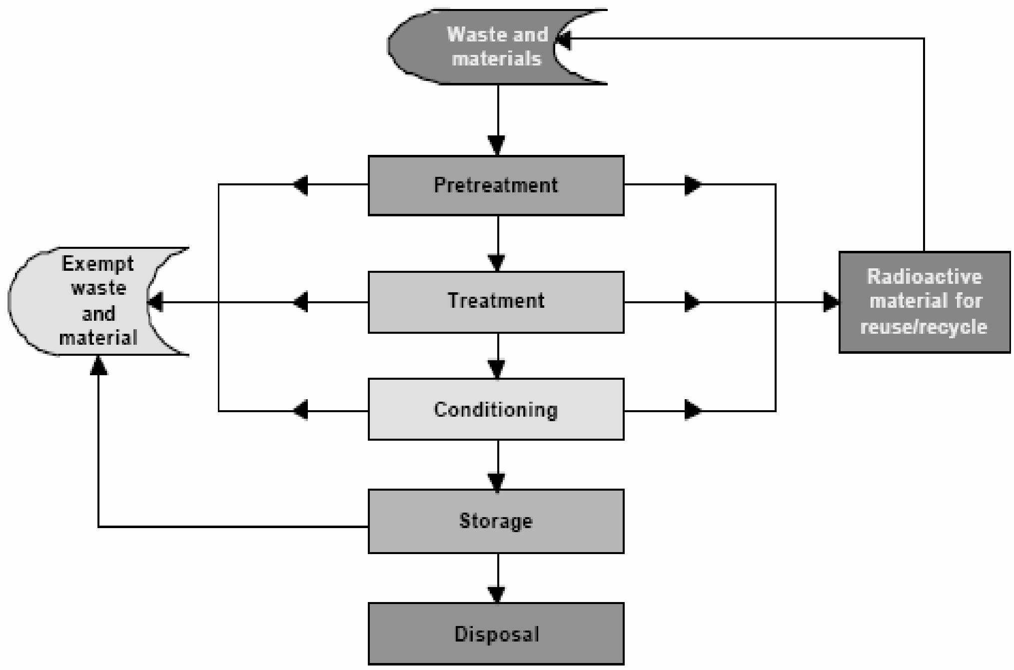
In any case, storage has important roles to play from the perspectives of safety, practicality, cost management, allowing time for disposal solutions to be implemented, and safe preservation of materials for which future use is anticipated. In addition, storage is an interim solution for countries in which no decision has yet been made on final management strategy and a temporary fall back solution if a currently planned disposal solution proves to be unsatisfactory.

Appendix 2

INFORMATION FROM SELECTED OECD MEMBER COUNTRIES

Strategy for the management of spent fuel and radioactive waste in the Netherlands[1]

The basic steps in spent fuel management are not fundamentally different from those in radioactive waste management. For radioactive waste management the steps identified and internationally agreed upon are pre-treatment, treatment, conditioning, storage and disposal (see scheme below).



For spent fuel management pre-treatment should be taken as temporary storage with the aim of cooling down in the storage pool at the reactor site. Treatment is to be understood as reprocessing, while conditioning and (temporary) storage of spent fuel are steps aimed to keep the extracted resource material in a suitable condition for reuse in case this is the preferred option. The latter two management steps are so far occurring at the reprocessing plants. The policy of reprocessing is consistent with the Netherlands' decision to store the residues above ground for an interim period of

1. Excerpts from: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. National Report of the Kingdom of the Netherlands. First review conference (November 2003). Ministry of Foreign Affairs, Ministry of Housing, Spatial Planning and the Environment, Ministry of Economic Affairs. The Hague, April 2003.

100 years. Reprocessing residues are produced in packages which facilitate their long-term storage without significant maintenance. The fuel from the non-power reactors is also packed in sealed canisters consistent with maintenance-free storage.

So far no decisions have been taken that would foreclose any of the available management options.

…

For spent fuel from the NPPs the decision has been taken to subject it to reprocessing with the aim to recover resource material from it and to immobilise the fission products into a stable glass matrix of High Level waste (HLW). The medium level reprocessing residues will also be packed in such a way, that long-term safe and maintenance-free handling is possible. Consequently, it is envisaged that future generations will not have to be concerned with the management of spent fuel from the NPPs. The “burden” for future generations is limited to finding a final destination for the HLW, which according to prevailing expert views is already in a suitable condition for disposal.

Spent fuel from the research reactors will be conditioned, packaged and subsequently stored in the facility for the treatment and storage of high-level waste at COVRA. The care for that material will be passed on to the next generation. However, not only the burden of this care will be passed on to the next generation, but also financial resources and technical knowledge required to set favourable conditions for a good management of the spent fuel. It is also left to the judgement of the next generation whether there is any benefit in extracting the resource material from it in a later stage.

…

For the HABOG facility an active operating phase is foreseen that will last until 2014, which was based on the assumption of a shut-down in 2003. This date will change, however, if the operational life of the NPP at Borssele is significantly extended, and more HLW will be generated. During this active period waste will be accepted and actively stored in the facility. From 2015 until 2130 (design basis ~100 years) the facility will be in its passive phase. No new waste will be brought into the building. Only maintenance and control will take place. After 2130 a final disposal route should become operational. The money needed for this passive period (as well as for the disposal) will be paid in advance and is calculated as discounted value. The money is put in a capital growth fund. When the money is available support can be purchased.

…

No formal decision has been made regarding disposal of spent fuel. The spent fuel which originates from the research reactors will be stored at the HABOG-facility. In a later stage it will be decided whether the fissile material will be extracted for further use or whether it will be conditioned in a suitable form for disposal.

…

Since the Netherlands has adopted the strategy of long-term storage (at least 100 years, …) in dedicated buildings at the surface, there is no immediate urgency to resolve this matter [of retrievable disposal] in the next decade.

…

Because of the long term storage requirement a system was chosen that is as passive as possible and where precautions are taken to prevent degradation of the waste packages. The heat generating waste is stored in an inert noble gas atmosphere and cooled by natural convection. In the design of the storage vault all accidents with a frequency of occurrence larger than once per million years were taken into account. The design must be such that these accidents do not cause radiological damage to the environment.

The non-heat generating waste is, remotely controlled, stacked in well-shielded storage areas. The heat generating waste such as the vitrified residues will be put into vertical storage wells cooled by natural ventilation. This method is proven technology in the storage facilities of BNFL at Sellafield and of Cogéma at La Hague.

The spent fuel elements of the research reactors are delivered to COVRA in a cask containing a basket with circa 30 elements. The basket with elements is removed from the cask and placed in a steel canister, which is welded tight and filled with an inert gas. These sealed canisters are placed in wells, in the same way as the vitrified residues. The wells will be filled with an inert gas to prevent corrosion of canisters with spent fuel elements or vitrified waste.

…

Also it should be realised that the waste volume that is actually present right now is only a few thousand cubic meters, and for such a small volume it is not economically feasible to construct a deep geologic disposal facility. The waste volume collected in a period of 100 years can be judged as large enough to make a disposal facility viable. So a period of at least 100 years of storage in buildings will be required. This creates at least six positive effects:

1. Public acceptance is quite high for long term storage. The general public has more confidence in physical control by today’s society than in long-term risk calculations for repositories even when the outcome of the latter is a negligible risk.

2. There is a period of 100 years available to allow the money in the capital growth fund to grow to the desired level. This brings the financial burden for today’s waste to an acceptable level.

3. During the next 100 years an international or regional solution may become available. For most countries the total volume of radioactive waste is small. Co-operation creates financial benefits, could result in a higher safety standard and a more reliable control.

4. In the period of 100 years the heat generating waste will cool down to a situation where cooling is no longer required.

5. A substantial volume of the waste will decay to a non-radioactive level in 100 years.

6. A little bit more than 100 years ago, mankind was not even aware of the existence of radioactivity. In 100 years from now new techniques or management options can become available.

A dedicated solution for the Netherlands is therefore to store the waste in buildings for a period of at least 100 years and to prepare financially, technically and socially the deep disposal during this period in such a way that it can really be implemented after the storage period. Of course at that time society has the freedom of choice between a continuation of the storage for another 100 years or to realise the final disposal.

The research on long-term storage in France[2]

Strategy

In France, the "Loi Bataille"[3] requires research in the area of management of long-lived HLW along three main themes in parallel:

- research on partitioning and transmutation of long-lived radioactive elements in the waste;
- evaluation of options for retrievable or non-retrievable disposal in deep geologic formations, particularly through the creation of underground laboratories;
- study of immobilisation processes and long-term surface storage techniques for the waste.[4]

Andra and CEA have sent their final reports to the government by the end of the year 2005.

The aim is to achieve a parliamentary decision on how to proceed in 2006. A draft law ("Projet de Loi") about the management of radioactive waste and materials has been established and is currently being debated at the French Parliament (the draft law was passed by the National Assembly after its first reading, on 12 April 2006).[5]

The draft law establishes a National Plan that estimates the future needs for storage and disposal facilities and set up objectives. It should comply with the following orientations:

- reduction of the quantity and toxicity of the waste;
- interim storage in dedicated facilities of radioactive waste to be processed or ultimate radioactive waste;
- after interim storage disposal in deep geologic formations of all those wastes for which surface or shallow disposal is not feasible for reasons linked to nuclear safety or radiation protection.

According with the draft law, and as far as storage facilities are concerned, studies and research should be carried out about the creation of new storage facilities or about the modification of existing facilities in order to meet the objectives set up by the National Plan.

The possibility of safe and robust long-term storage of radioactive materials (storing final waste while waiting for disposal, in particular so as to benefit from thermal decay, interim storage of

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2. Based on: Philippe Leconte, "Long Term Interim Storage: An Emerging Approach for Waste Management Policy in France". Presentation at RWMC's Topical Session on Overall Waste Management Approaches, Paris, France, 14 March 2002 and on: Alain Marvy and Dominique Ochem, "Issues at Stake when Considering Long Term Storage of HLW, A Comprehensive Approach to Designing the Facility", WM'03 Conference, February 23-27, 2003, Tucson, Arizona, United States.

3. Loi 91-1381 du 31 décembre 1991 relative aux recherches sur la gestion des déchets radioactifs, République française, Journal Officiel Lois et Décrets.

4. These bullets are quoted from the official English translations; the original text refers to the disposal theme as "stockage réversible ou irréversible dans les formations géologiques profondes" and to the storage theme as "entreposage de longue durée en surface".

5. Assemblée nationale (2006), Gestion des matières et des déchets radioactifs. www.assembleenationale.fr/12/dossiers/gestion_dechets_radioactifs_programme.asp.

reusable material while awaiting recycling) may bring some useful flexibility to fuel cycle backend management strategies, provided its safety is understood and well under control. Therefore, CEA was mandated to explore this alternative route which looks into the design of facilities which could stand long term operation from the start up to three centuries long periods. Such time periods, far exceeding a few human generations, push researchers and engineers through challenging issues and also raise unique societal questions that Society would have to address.

Research on extended storage

Spent Nuclear Fuel (SNF) is not considered as a waste in France under the current regulation. It contains potentially valuable energy resources that it may be worth securing for future generations. In the framework of the 1991 law the research looks into how SNF could be held secure in a long-term storage facility, should this need arise in the future. It appears to be a matter of paramount importance to store it in a way that can guarantee its retrievability and in a manner acceptable with regard to risk level and cost. In addition SNF contains all the radionuclides produced during irradiation. As such, it is the most challenging nuclear material to deal with when addressing its long-term storage management. These reasons have led to focus the research described here on SNF although plutonium from MOX fuel or other materials are also considered with regard to storage for strategic reasons.

The main principles guiding the conception of extended storage are very similar to those of industrial storage facilities with a particular emphasis on long lifetime, thus passivity and robustness. The confinement of the waste must be guaranteed permanently. The packages must remain clean, strong and movable at any time. This means a special care on corrosion and on maintenance. The long term perspective raises some juridical problems ("Who is running the facility?"). Provision must be made to guaranty the existence of a relaying institution.

Extended storage could be chosen for some kind of waste or for all waste, as an element of flexibility in a global fuel cycle. Providing a large cooling time brings some clear benefit for HLW. And, finally, the society may bet on important scientific improvements which would modify the radioactive waste landscape. It should be emphasised that any decision on LTIS requires a strong and conscious commitment by the society as such a facility must be always watched and maintained rigorously until it is emptied. Special attention must be provided to avoid that a LTIS transforms itself surreptitiously into a bad disposal. The logic of intergenerational responsibility requires that some financial provision be made for long-term maintenance and final operation.

Two major guiding principles have been devised as key design goals for the storage concepts under consideration. One is the paramount function of *retrievability*, which must allow the safe retrieval of any HLW package from the facility at any given time. Next is the *passive containment philosophy* requiring that a *dual-barrier system* be considered.

Main functions of the Storage Facility (SF) are:

- protection of the SF canisters from external aggressions;
- management of thermal output;
- provision for a humidity controlled atmosphere as mentioned above.

Though a storage facility must be monitored during its entire lifetime passive systems are preferred. The first design step is to select the cooling mode. SF storage in pool has been operating for decades in many countries. Dry facilities are also used. An example is the CASCAD facility in France

(Cadarache) cooled by natural air convection. It was granted a license for forty years in 1990. The natural convection system option has been proposed for the long-term storage facility since it seems obvious that it qualifies as the most passive one.

Dealing with potential external events, subsurface facilities seem to provide more protection than concrete vaults built above ground. These two options have been explored and evaluated against criteria like safety, cost, and other technical aspects.

Research programmes have been performed on long term behaviour of concrete structures.

A short tunnel was constructed to illustrate this concept at the CECER (Expertise Center on Conditioning and Storage of Radioactive Material) at Marcoule, and to conduct thermal demonstration studies from 2005 onward which, due to their global nature, will secure the validation of the operating models produced.

Of paramount importance is to provide dry conditions in a passive way in order to limit corrosion. In current air-cooled, dry facilities, SF packages are cooled by an axial cooling airflow. However transverse cooling airflow seems to be a promising technique to lower temperature gradients and therefore to prevent both condensation on cold areas and excess of heat on others. Nevertheless, the modelling of such a cooling mode is not yet sufficiently proven to insure that design goals can be met throughout the facility lifetime particularly after 100 years when canister temperature has dropped significantly. In that case temperatures range would have to be kept within a rather narrow gap limited on one hand by the long term behaviour of structural materials at high temperature (maximum of 80°C for concrete structure), and on the other hand by the obligation to meet the dry corrosion conditions (minimum of 40°C on the canister outer wall). Current thermo-aeraulic models together with existing data are not able to fit such conditions during more than 100 years. Therefore the controlled axial airflow along SF canister is the design option currently under consideration.

SF canister design must meet containment and retrievability goals. A two-barrier system design is considered. First, each SF assembly is put inside an airtight steel case. Several cases fill one canister. That second barrier must provide the best possible protection against corrosion. Materials chosen are cast iron or carbon steel since in case of an incident leading to wet conditions they tend to corrode uniformly and corrode in a generally predictive way. Wall thickness has to be adjusted according to the expected lifetime and the mechanical specifications. Calculations show that the prevailing parameter is mechanical which leads to a 45 mm thick wall. The steel case is made of stainless steel, protected against internal and external corrosion by inert gas (He) which fills up voids within the case and the canister.

The case design remains compatible with the possible future SNF reprocessing. It also allows the safe and contamination-free handling of each SF assembly. The number of cases put inside a canister is primarily limited by thermal considerations. In the case of UOX SF assemblies, it may be limited to seven. Cases and canister must be closed tight using electron beam welding techniques. A full scale demonstrator of the canister has been manufactured and demonstration of the long term behaviour has been performed.

Long-term storage – an option under consideration in Canada

In 1998, an independent federal panel concluded that "from a technical perspective, safety of the deep geological concept (as developed by the federal Crown company, Atomic Energy of Canada Limited) has been, on balance, adequately demonstrated for a conceptual stage of development, but from a social perspective it has not, and has not been demonstrated to have broad public support". The Panel stated that it is "unethical to ask people to accept one approach without informing them of other options and the consequences of rejecting the current proposal." The Panel recommended that the possibility should exist to make informed comparisons and a considered choice among reasonable alternatives. The principal reasonable alternatives to which attention was drawn at the Panel hearings were deep geological disposal, long-term storage at nuclear reactor sites or at a central site.

In 2002, the Government of Canada passed a law, the *Nuclear Fuel Waste Act*, in which it required nuclear energy corporations to form a not-for-profit association to carry out the next steps for the long-term management of nuclear fuel waste. One of the first tasks of this association, the Nuclear Waste Management Organisation, was to prepare a study comparing various long-term waste management options, focussing principally on options for long-term storage and deep geological disposal. The study was completed in November 2005 and submitted to the federal Minister of Natural Resources. The Government of Canada will make the final decision on the long-term management approach for used nuclear fuel.

Long-term storage options as compared with disposal

Under routine conditions, studies show that used fuel with undamaged sheaths should maintain its integrity in storage casks for at least 100 years, with damaged sheaths, 50 years, and could be replaced with new ones as needed. Above or below ground (about 50 metres depth) facilities could be constructed and refurbished or replaced as required. Used fuel storage would continue indefinitely.

Examples of comments sometimes expressed by the public in Canada concerning the benefits of long-term storage included storing the waste near the beneficiaries of nuclear energy, keeping the waste near the seat of governments thereby avoiding out of sight/out of mind mentality, and making possible the integration of new scientific advances. In general though, the most frequently noted benefits of long-term storage included better control of the performance of a waste facility (effective monitoring and remediation as required), and when desirable, easy waste retrieval. These features, combined with fear and uncertainty about the long-term safety of disposal and hopes for a future technological solution to the waste problem, made this option for the long-term management of nuclear fuel waste preferred by some Canadians as expressed in country-wide public consultations.

On the other hand, other Canadians were not convinced: long-term storage forces future generations to make a choice and transfers to them the responsibilities and risks of caring for the waste; there is a risk of loss of institutional controls possibly due to social or economical factors; the performance of the waste facility is riskier as affected by extreme natural and man-made events likely over extended time and security threat conditions over the long term; maintenance and costs are high; wastes at aboveground level are more vulnerable to earthquakes and terrorism.

Attachments 1 and 2 provide a detailed look at storage at reactor sites and central storage as described in the 2004 NWMO report "Understanding the Choices". Over 2004, the NWMO engaged Canadians in a dialogue on the relative advantages and limitations of the deep geological repository option and long-term storage options. As a result of that dialogue, NWMO made the following observations:

1. Taken individually, no one of the management approaches specified in the NFWA perfectly addresses all of the objectives which citizens said were important for any management approach for Canada to address, particularly when both the near term (the next 175 years) and the longer term are considered.

2. Each of the three main approaches has distinct advantages and limitations in light of these objectives.
3. How any approach is implemented will be every bit as important as which approach is selected. The manner in which any approach is implemented will affect the effectiveness and the extent to which it is responsive to societal needs and concerns. Implementation plans must include, at a minimum, consideration of such issues as: oversight and monitoring systems; ongoing societal involvement; institutional design, including human resource capacity; ownership and liability; dispute management; principles to guide site selection and education and information programmes.
4. The dimensions of a preferred management approach emerged from the dialogue. Canadians want to see the development of a long-term strategy or plan. But they also want action to be taken now on the first steps of that plan. This needs to be done in a way that ensures that future generations will be able to make decisions that reflect their own values and priorities. The preferred approach must be adaptable, able to incorporate new knowledge as it becomes available. This might best be accomplished by a phased approach that provides for decisions to be taken in steps over time. Finally, the preferred approach must include a robust system of governance and measures to ensure that citizens understand the issues, remain informed and have a voice in decision making.

On 3 November 2005, the NWMO submitted its study of options to the federal Minister of Natural Resources. The management solution proposed by NWMO called "Adaptive Phased Management" (NWMO, 2005) includes storage at reactor sites, option for shallow underground storage at the central long-term management site, and placement in a deep geological repository with monitoring, access and retrievability for an extended period of time.

A government decision on which approach will be adopted in Canada is expected in 2006.

Attachment 1: Storage at reactor sites

Extended storage is permanent or indefinite storage with the necessary ongoing maintenance and facility refurbishment conducted on an ongoing basis (www.nwmo.ca/reactorstorage). Canadian industry now has some 40 years of experience with wet storage facilities and more than 25 years of experience with dry storage systems. Today's dry storage containers are designed to last at least 50 years, but their expected life is much longer – 100 years or more. With periodic refurbishment, extended storage can be used indefinitely.

Long-term storage at existing reactor sites would involve the expansion of existing dry storage facilities or the establishment of new, long-term dry storage facilities at each of the seven existing reactor sites in Canada. In the latter case, used fuel would be transferred from the existing interim storage facilities to newly designed storage containers and storage facilities are designed to last about 100 years. Additional and replacement capacity would be provided by the construction of required facilities on a rolling program.

There are both surface and just-below-surface design options for reactor site storage, involving the use casks, vaults and/or silos. Table A1.1 shows the alternative designs considered in the development of the conceptual designs. The difference in designs considered by geographic location reflects the different methods currently used for interim storage at each location.

Table A1.1. Concept alternatives considered for storage at reactor sites

ONTARIO Pickering, Darlington and Bruce	• Casks in storage buildings • Surface modular vault • Casks in shallow trenches
NEW BRUNSWICK Point Lepreau	• Surface modular vault • Vaults in shallow trenches
QUEBEC Gentilly	• Surface modular vault • Vaults in shallow trenches
AECL Chalk River (Ontario) and Whiteshell (Manitoba) Sites	• Silos in a storage building • Silos In a shallow trench

Storage in casks. A cask is a mobile, durable reinforced concrete and steel container for enclosing and handling nuclear fuel waste for storage or transport. The cask wall shields radiation; heat emitted by the used fuel is transferred by conduction through the wall.

Storage in vaults. The vault concept would involve the storage of fuel baskets confined in reinforced concrete vaults. The vaults would be constructed in the open on a concrete foundation slab. Natural circulation is used to cool and regulate the used fuel basket temperature inside the vault.

Storage in silos. Canada and other countries store used fuel inside sealed steel baskets, which are housed within a reinforced concrete silo or canister. The outdoor silos are passively cooled.

The long-term storage facilities need ongoing maintenance, inspections and security systems once the used fuel is transferred. If the storage systems do not perform according to specification, it would be possible to retrieve the used fuel from storage and undertake necessary repairs or transfer it to a new storage facility. The long-term storage facilities would be designed to allow safe retrieval of used nuclear fuel from the storage buildings at any point during the life of the facility.

All reactor site extended storage options include an ongoing, cyclical programme of regular replacement and refurbishment activities. Complete refurbishment or replacement of all components of the storage facility is assumed to occur every 300 years.

These refurbishment and component replacement activities include:

- build new used fuel storage facilities;
- establish a used fuel transfer system to remove the fuel from existing storage containers and transfer it to new storage containers, and then to a new storage building;
- repackage the used fuel storage containers; and

- refurbish or demolish old storage facilities. This approach would require:
  - **Siting and approvals.** For new storage alternatives, this would involve identifying specific locations at each of the reactor sites and obtaining approvals – from the Canadian Nuclear Safety Commission for the construction and operation of the facility, and an environmental assessment under the Canadian Environmental Assessment Act. This would take approximately 5 years.
  - **Design and construction.** This would involve preparing the final design considerations, storage container production and storage facility construction. Preliminary estimates say this would take approximately 5 years, including the initial phase of construction.
  - **Operations.** This would involve removing the fuel from the existing storage facilities, and placing it in the long-term storage facilities. Preliminary estimates say that the transfer of used fuel from existing interim storage facilities to new long-term storage facilities would occur over a period of approximately 35 to 40 years.
  - **Monitoring.** Once all the used fuel from the reactor site was placed in the long-term storage facility, it would require on-going monitoring to ensure that facility safety was being maintained as well as ongoing preventive maintenance and repair.
  - **Building refurbishments and repackaging.** Eventually the storage containers would need to be replaced, as would the storage building. This would involve construction of new storage buildings, transfer of the used fuel from the long-term storage containers to new packages, and transfer of the containers to the new building. The old buildings and waste storage containers would need to be refurbished or demolished. These activities would take approximately 10 years and complete refurbishment of all components and repackaging of the fuel storage system is assumed to be repeated every 300 years.

Figure A1.1 provides a general perspective of the project timeline for reactor site extended storage. A government decision in 2006 to adopt reactor site storage, followed by immediate implementation would lead to the earliest possible availability of long-term storage facilities in 2016 - 2020 (the variation reflects the different design options). The long-term storage facilities would likely require complete refurbishment or replacement by the year 2300. The cost estimates are based on this assumption.

A decision to implement reactor site long-term storage after the existing interim facilities reach the end of their design lives would lead to the earliest possible availability of long-term storage facilities in 2042 (at Point Lepreau) and 2057 (at Darlington).

The cost estimates for long-term reactor storage are based on the following assumptions:

- long-term reactor site storage would operate indefinitely;
- the facilities and the fuel packaging would be refurbished or replaced on a regular basis and would be carried out indefinitely; and
- the facilities are intended to operate in cycles of approximately 300 years; the cost estimate below addresses the first cycle.

Depending on the specific design, preliminary cost estimates suggest this approach would cost between $17.6 and $25.7 billion (2002 $) for one 300-year cycle. The present value impact of the first repeat cycle is approximately $2.3-$4.4 B (2004 $) based on current long-term economic factors. The calculation of costs beyond this, far in the future, requires the use of long-term economic forecasting, with its inherent uncertainties. (www.nwmo.ca/reactorcosts)

Figure A1.1. Summary of reactor site extended storage project timeline

	Duration, Years								
Project phase	10	20	30	40	50	100	200	300	400
Siting and approvals									
Design and construction									
Initial fuel receipts									
Extended monitoring									
Building refurbishment and repackaging									

Notes:

1. Extended monitoring and building refurbishment/ repackaging activities continue in perpetuity, based on a 300-year cycle.
2. Schedule based on implementing a surface modular vault (SMV) at the Pickering site.
3. Schedules for other RES alternatives at various sites will vary, depending on the type of storage concept and the quantity of fuel being stored.

Attachment 2: Centralised storage

Technologies for centralised dry storage of used fuel include metal casks, concrete casks, silos and vaults. Four storage alternatives were selected to represent a range of possible designs for the Centralized Extended Storage Facility concept (www.nwmo.ca/centralstorage). The selected alternatives are: Casks and vaults in storage buildings; Surface modular vaults; Casks and vaults in shallow trenches; and Casks in rock caverns.

Site conditions should not be a major constraint in implementing these alternatives. Two alternatives comprise surface facilities, where storage buildings are built above grade. The remaining two alternatives are below-ground facilities: one near-surface and mounded over, and one at about 50 metres below ground surface in bedrock. The near-surface alternative, casks and vaults in shallow trenches, would be passively ventilated, with the deeper alternative, casks in rock caverns, ventilated using a forced system. Three of the alternatives would minimize repackaging of fuel upon receipt at the centralised storage facility, which would allow higher fuel throughput and minimise costs, the surface modular vault being the exception.

Centralised storage could be built at a nuclear plant site or at a fully independent site. For assessment purposes, it is assumed that the centralised storage facility would be located on an undeveloped site. The centralised storage facility would not rely on support from other nuclear facilities and would be considered as a stand-alone facility. For all of the alternatives, additional capacity would be provided by the construction of storage facilities on a rolling programme.

Long-term centralised storage is assumed to involve creating new, long-term dry storage facilities at one site in Canada. Used fuel would be transferred from the existing interim storage facilities at the reactor sites, to newly designed storage containers and facilities. Additional storage facilities would be built as needed, on a rolling programme.

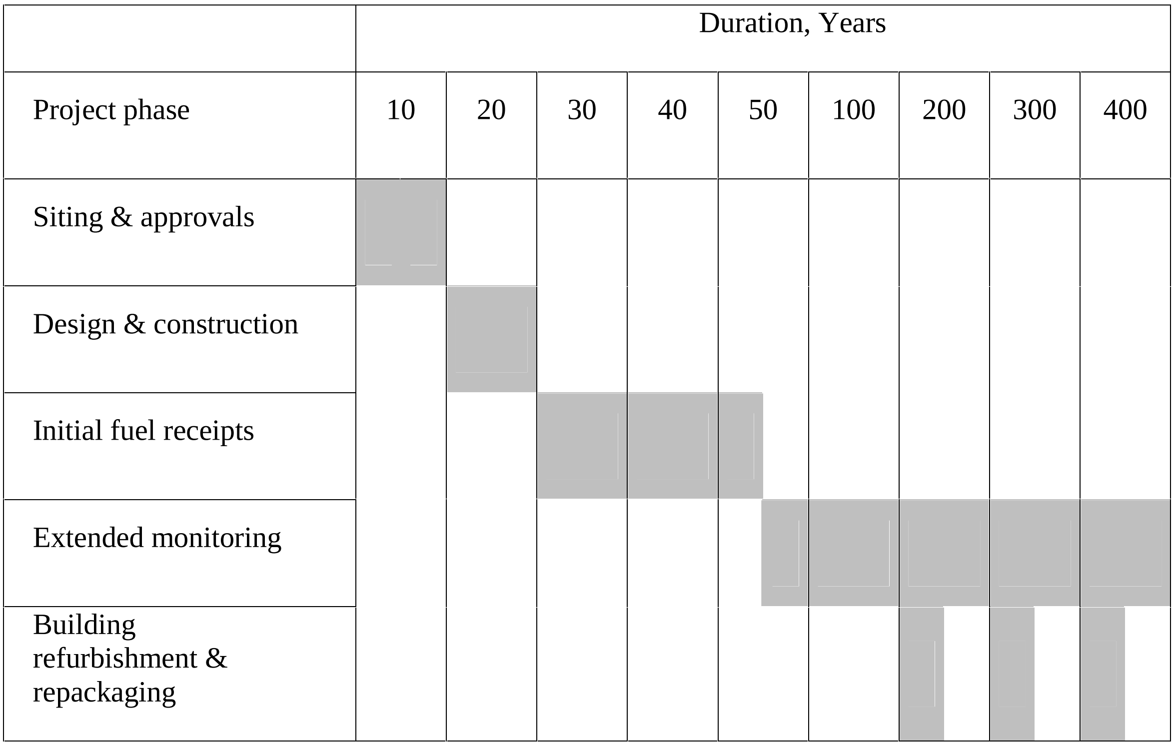
Once all of the used fuel is transferred to the long-term storage facilities, ongoing maintenance, inspections and security systems would be required. If the storage systems do not perform according to specification, it would be possible to retrieve the used fuel from storage and undertake necessary repairs or to transfer it to a new storage facility.

The long-term storage facilities would be designed to allow safe retrieval of used nuclear fuel at any point during the service life of the facility.

The centralised extended storage option would include an ongoing, cyclical programme of regular replacement and refurbishment activities. The storage containers and storage facilities are designed to last up to100 years. Thus, it would be necessary to periodically:

- build new used fuel storage facilities;
- establish a used fuel transfer system to remove the fuel from existing storage containers and transfer it to new storage containers, and then to a new storage building;
- repackage the used fuel storage containers; and
- refurbish or demolish old storage facilities. Implementation of this approach would include:
  - **Siting and approvals.** A specific location would need to be identified and approval would be required from the Canadian Nuclear Safety Commission for the construction and operation of the facility. This would also involve an environmental assessment under the Canadian Environmental Assessment Act. This siting and approval phase would take approximately 10 years to complete.
  - **Design and construction.** This would involve preparing the final design considerations, storage container production and storage facility construction. Preliminary estimates say this would take approximately 10 years, including the initial phase of construction.
  - **Transportation and operation.** The operation of a centralised long-term storage facility would involve removing the fuel from the existing storage facilities, packaging it and transporting it and placing the fuel in the long-term storage facilities. Preliminary estimates say this would occur over approximately 25 to 40 years.
  - **Monitoring.** This would require on-going monitoring to ensure that facility safety was being maintained, as well as ongoing preventive maintenance and repair.
  - **Building refurbishments and repackaging.** Eventually the storage containers would need to be replaced, as would the storage building. This would involve construction of new storage buildings, transfer of the used fuel from the long-term storage containers to new storage packages, and transfer of the storage containers to a new storage building. The old buildings and waste storage containers would need to be refurbished or demolished. Complete refurbishment of all components and repackaging of the fuel storage system is assumed to be repeated every 300 years.

Figure A1.2. Summary of centralised storage project timeline



Note: Extended monitoring and building refurbishment/ repackaging activities continue in perpetuity, based on a 300-year cycle.

Under a government decision in 2006 to adopt centralised storage, followed by immediate implementation, the new, long-term storage facilities are assumed to be available in approximately 2023 at the earliest. These facilities would require refurbishment or replacement approximately starting by the year 2300.

The cost estimates for long-term centralised storage are based on the following assumptions:

- Long-term centralised storage would operate indefinitely;
- The facilities and the fuel packaging would be refurbished or replaced regularly and would be carried out indefinitely;
- The facility would be located in Ontario (for transportation cost-estimating purposes); and
- The facilities are intended to operate in cycles of approximately 300 years; the cost estimate below addresses the first cycle.

Depending on the specific design, preliminary cost estimates suggest this approach would cost between $15.7 and $20.0 billion (2002 $) for one 300-year cycle, including any transportation costs. The present value impact of the first repeat cycle is approximately $3.1 – $3.8 B (2004 $) based on current long-term economic factors. The calculation of costs beyond this, far in the future, requires the use of long-term economic forecasting with its inherent uncertainties. (www.nwmo.ca/centralstoragecosts)

The review of options for radioactive waste management in the United Kingdom

The Government's consultation process

In September 2001, the UK Government announced the publication of a consultation paper "Managing Radioactive Waste Safely" (DEFRA, 2001). This followed up the Government response (DETR, 1999) to the House of Lords Select Committee report on the Management of Nuclear Waste (House of Lords, 1999), which had recommended a detailed and wide ranging consultation to begin the process of finding a long-term strategy for the management of all the UK's radioactive waste.

The Executive Summary of "Managing Radioactive Waste Safely" (DEFRA, 2001) introduced the problem by stating:

> "More than 10 000 tonnes of radioactive waste are safely stored in the UK, but await a decision on their long-term future. This will increase to 250 000 tonnes when nuclear material currently in use is converted into solid waste. Even if no new nuclear power plants are built and reprocessing of spent nuclear fuel ends when existing plants reach the end of their working lives, about another 250 000 tonnes of waste will arise during the clean-up of those plants over the next century. Most of this waste results from the work of Government agencies or publicly owned companies since the 1940s. Some of the substances involved will be radioactive and potentially dangerous for hundreds of thousands of years."

and

> "We must decide how to manage this waste in the long term. Implementing that decision will take decades. So now is the time to start planning for our future."

The paper stated that the Government wanted "to inspire public confidence in the decisions and the way in which they are implemented" and in order to do this it proposed "to set up a strong, independent and authoritative body to advise us on what information there is, what further information is needed, and when enough information has been gathered for decisions to be made on how the UK's radioactive waste should be managed."

The paper also set out a proposed programme of action for reaching decisions, consisting of five stages.

The UK Government's consultation process

Stage one, 2001-2002:	This consultation on the proposed programme; considering responses; planning the next stage.
Stage two, 2002-2004:	Research and public debate, to examine the different options and recommend the best option (or combination).
Stage three, 2005:	Further consultation seeking public views on the proposed option.
Stage four, 2006:	Announcement on the chosen option, seeking public views on how this should be implemented.
Stage five, 2007:	Legislation, if needed 2007.

Following the close of the Stage one consultation period, a summary of the responses to "Managing Radioactive Waste Safely" was published (DEFRA, 2002), and an announcement was made that a review of all options for the long-term management of radioactive waste should proceed, overseen by an independent appointed body. That body was named in December 2002 as the Committee on Radioactive Waste Management (CoRWM).

CoRWM began its work in November 2003, and is charged with completing its work and making recommendations to the Minister by July 2006, see below. The Government will then consider CoRWM's recommendations and may consult further on the recommendations and how the recommendations might be implemented, before making a policy statement and bringing forward any legislation needed in 2007.

The work of the Committee on Radioactive Waste Management (CoRWM)

CoRWM has been asked to review options for managing solid radioactive waste in the UK and to recommend the option, or combination of options, that can provide a long-term solution, providing protection of people and the environment. A priority task is to recommend what should be done with the wastes for which no long term management strategy exists – that is, high level and intermediate level waste (HLW and ILW) now in storage and likely to arise over the next century or so, and some low level waste (LLW) unsuitable for disposal at Drigg.

The Committee is working through a programme of public and stakeholder engagement.

CoRWM's programme of public and stakeholder engagement	
November 2003 – September 2004	Information gathering, listening and trialling.
November 2004 – January 2005	Identifying issues. Reviewing of CoRWM's phase 1 work (the inventory, the long list of options, the short-listing criteria).
March 2005 – May 2005	Reviewing the proposed short list and the criteria used to reach it. Identifying criteria for the detailed assessment of short-listed options. Commenting on the proposed methodology for detailed assessment of short-listed options.
October – January 2006	Participating in the assessment of options.
April 2006 – May 2006	Commenting on recommendations

CoRWM identified a "long list" of 15 options, stating that not all options on the list can necessarily be compared "like with like".

The "long list" of 15 options identified by CoRWM	
1. Storage	9. Disposal in subduction zones
2. Near surface disposal	10. Disposal in space
3. Deep disposal	11. Dilute and disperse
4. Phased deep disposal	12. Partitioning and transmutation
5. Direct injection	13. Use in reactors
6. Disposal at sea	14. Incineration
7. Sub-seabed disposal	15. Melting
8. Disposal in ice sheets	

The options, and the issues that are associated with them, are all described more fully in an Options Report (CoRWM, undated). With respect to storage, CoRWM identified the following sub-categories:

- above ground interim storage;
- above ground indefinite storage;
- below ground interim storage;
- below ground indefinite storage.

The key feature of all storage options is that the waste remains accessible and is easy to monitor. It also allows changes of plans for the future management of waste.

CoRWM then used a number of criteria (screening criteria) in order to arrive at a short-list of options. The screening criteria were:

1. Proof of concept.
2. Breach our duty of care to the environment outside national boundaries.
3. Harm to areas of particular environmental sensitivity.
4. Unacceptable burden (in terms of cost, effort or environmental damage) on future generations.
5. Risk to future generations greater than that to the present generation that has enjoyed the benefits.
6. Unacceptable risk to the security of nuclear materials.
7. Unacceptable risk to human health.
8. Cost is disproportionate to the benefits achieved.
9. Breaches internationally recognised treaties or laws and there is no foreseeable likelihood of change in the future.

In February 2005 CoRWM published a short-list of four options, which was confirmed in August 2005. These are (CoRWM, 2005):

Long-term interim storage

Interim storage is not permanent storage. It is a temporary management solution, though it could last for many decades, or even centuries. Waste could be stored above the ground or just below the surface.

Deep geological disposal

Deep geological disposal is the process of permanently putting the waste at between 300 metres and 2 km underground in an area of suitable geology where the rocks act as the protective chamber.

Phased deep geological disposal

Phased deep geological disposal is the same process as deep disposal except the waste will be monitored and retrievable for a period of up to several hundred years.

Near-surface disposal

Near surface disposal of short-lived waste with short-lived radioactivity (primarily reactor decommissioning waste) is buried just below the surface within engineered barriers.

These short-listed options underwent detailed discussion and evaluation by CoRWM, who plan to make recommendations to Government on the option, or combination of options, to be pursued, by July 2006. The recommendations of CoRWM will not cover siting aspects. In April 2006, the committee announced an integrated package of draft recommendations for the long-term management of the UK's radioactive waste. The package envisages that, in the long term, radioactive waste will be disposed of deep underground. It recognises, however, that the process leading to the creation of suitable facilities for disposal may take several decades and should therefore be underpinned by robust interim storage.

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