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Considerations on Possible Spent Fuel and High Level Waste Management Options

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Spent fuel (SF) and high level waste (HLW) management is a national problem of international dimension. To find sufficient options for handling and disposing of SF and HLW different networks have been established within as well as between countries.

From several years ago international organizations such as NEA (Nuclear Energy Agency of OECD), IAEA (International Atomic Energy Agency) and Euratom deal with international problem regarding radioactive waste management.

Recently an International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) has been created. The ten countries and organizations involved are Belgium (ONDRAF/NIRAS), Canada (Ontario Power Generation), Finland (POSIVA OY), France (ANDRA), Germany (DBE) (BFS), Spain (ENRESA), Sweden (SKB), Switzerland (NAGRA), United Kingdom (NIREX), and the United States of America (DOE-OCRWM).

This report has been promoted by these organizations and its purpose is to carry out an analysis of different issues regarding the management of SF and HLW. The analysis pretends to be realistic and it has been based on the current state-of-the-art and on the expected future development of the technologies foreseen by the technical and scientific communities.

When evaluating SF and HLW management options different criteria or issues can be selected depending upon the decision-makers or the stakeholders involved. The issues selected here, i.e. ethics, technology, safety, safeguards, society, economy and timing, which are not hierarchically ordered, pretend to be at least the minimum ground from which a proper analysis can be oriented and worked out.

One summary table sums up the most relevant statements regarding the extended storage, geological disposal, and partitioning and transmutation options. A more detailed summary for each of the issues considered is also included in accompanying tables.

ENRESA wrote the first draft report, which was presented at the EDRAM's meeting in May 2000, and made the edition of this final report including the received comments.

1. Introduction

1. Introduction

Radioactive waste needs to be managed in a safe, economical, and environmentally and publicly acceptable manner.

A dominant characteristic of spent fuel (SF) and high-level waste (HLW) is the period of hundreds of thousands of years over which they must be effectively isolated from people and the environment. It is a challenge to achieve the needed level of technical assurance and it may difficult to achieve public acceptance.

The development and implementation of strategies for the long-term management of radioactive waste is a necessity in all countries with nuclear programmes. The scale of the problem, in terms of volume, radioactive content and diversity of physical and chemical forms of the waste depends on the size of the country's civil and defense nuclear programmes. The problems are greater in countries that now have, or had in the past, a substantial civil programme and a defense programme. In all these countries one important component of the problem is the waste which already exists, especially that arising from plants designed and processes carried out in the 1940s, 1950s, 1960s and early 1970s, when much less attention was paid to long-term waste management than in more recent times.

A second important component is the 'committed' waste, that is the waste which is bound to arise from the operation or decommissioning of plants, which are operating now (and that which is expected to arise from plants which are under construction or for which there is a commitment to start construction). However, the time scale of the problem is the same for the various countries irrespective of the size of their nuclear programmes.

This legacy of waste –existing and committed– is very much greater than any current projections of wastes from future nuclear programmes. It has to be dealt with, whether there are future nuclear programmes or not.

Choosing a SF and HLW management strategy is not just a technical question or an economical one. It is also a question of ethical judgements, political and social debates, and decisions as to what should be done now and what can be postponed until the future.

The objective of this report is to examine issues and considerations that may result from the implementation of possible SF and HLW management options. Ethical, scientific and technological, safety and licensing, social political, and timing and economic issues have been analysed and are discussed below.

2. Waste Management Options

2. Waste Management Options

Over the approximately three decades since the start of major research and development programmes world-wide, a variety of disposal concepts and waste management practices have been suggested.

Several of the options were only seriously considered for high level wastes (SF and HLW from reprocessing). R&D initially focused on these wastes because it was felt that they would be the most difficult to deal with.

2.1. Disposal Concepts

A number of different disposal concepts have been considered, implemented, or are being developed to manage the radioactive wastes, namely:

- Disposal in space: space shuttle technology and rockets.
- Disposal in ice sheets: meltdown, anchored emplacement, and surface storage.
- Deep-sea disposal: disposal into the ocean, subduction zones, and seabed disposal (free-falling penetrators and emplacement in boreholes).
- Land-based disposal concepts: hydrofracturing and in-situ bulk grouting, near-surface repositories, shallow disposal, and deep geological repositories.

The main types of disposal concepts that have been implemented or that are currently being developed for radioactive wastes are land-based –including near-surface repositories, shallow burial in trenches or below-ground vaults, and geological repositories. Other disposal concepts– including disposal at sea (seabed or sub-seabed), in ice sheets, and in space– have also been considered over the years. Currently none of these latter disposal concepts are being pursued as feasible waste management strategies for different technical, political or social objections. International agreements or treaties rule out some of them.

Geological disposal of SF and HLW in deep formations on land has always been and still is the 'front-runner'. In some countries it is the only option which has ever been considered. It is suitable for all long-lived wastes and relies on the expected stability of geological and hydrogeological conditions over millions of years.

In recent years, the waste management programmes have primarily focused on technical aspects related to deep underground disposal of long-lived radioactive waste. There is a consensus among experts that sites can be properly identified and characterised, that geological repositories can be designed so that no short-term detriment to populations will result from the waste disposal, and that an acceptable level of safety can be provided for times far into the future. It is also agreed that the current generation, who has benefited from the nuclear energy produced, should place no undue burdens on future generations and provide them with the means to permanently dispose of the waste.

The confidence of the experts in the short- and long-term safety of the geologic disposal option has been confirmed, in different national programmes, by a number of technical and licensing reviews of safety assessment studies of deep repository systems, but is not necessarily matched by an equally favourable attitude within non-expert groups. In particular, several repository-development programmes have recently undergone increased public scrutiny and despite notable exceptions, this has resulted in delays in the implementation of some disposal programmes.

2.2. Alternative Waste Management Options

Over the years, a number of practices and possible options have been developed or are being considered for radioactive waste management. Some of these alternative methods may supplement –though ultimately they do not replace– the need for disposal.

Extended storage differs from disposal in that further handling or retrieval of the waste is intended at some time in the future. Continued storage of these wastes is necessary until a long-term waste management option is put in place. Spent nuclear fuel world-wide is presently stored either in water-filled pools or in dry concrete or metal structures. Surface storage systems have design lifetimes on the order of several decades, and they require in different extents continued surveillance, maintenance and probably periodic replacement of systems.

Although there is a general recognition that storage must be considered as an interim measure in waste management, in some countries the debate continues to address the possibility that it is short-sighted to pursue a strategy of immediate geological disposal rather than a prolonged or extended storage. Long-term, or even indefinite, surface storage is favoured by those who reject geological disposal as unsound and unproven, and who wish to leave to future generations the freedom to develop better methods for managing wastes in the very long term.

Reprocessing refers to the practice of extracting plutonium and uranium, from fission products and minor actinides. The plutonium is available for re-use as fuel. The uranium may be recycled as fuel or may be used for other applications. The fission products and remaining actinides, which comprise only a small fraction of used fuel, are incorporated into a suitable matrix, such as a glass, for eventual disposal.

Although reprocessing changes the characteristics of the waste form, it does not alleviate the need for geological disposal.

Decisions on whether to reprocess fuel or not are determined by the need to balance considerations such as the cost of the different fuel cycle management options, the availability of indigenous fuel resources, the desire for maximising the energy extracted from uranium resources, the capacity of interim storage for used fuel, and the energy value of recovered uranium and plutonium as feedstock for the manufacture of new fuel. Therefore, the question of whether or not to reprocess used fuel from power reactors is thus not fundamentally a waste management issue.

Partitioning and transmutation (P&T) technology is intended to reduce the inventories of minor actinides and long-lived fission products in HLW. Transmutation would first require reprocessing the used fuel and partitioning the waste stream to separate the resulting species according to the nuclear methods to be used to transmute the different radionuclides.

Different developments in reprocessing along with advances in reactor design and robotics as well as changes in the regulatory and public environment have recently led to renewed interest in transmutation, particularly in France, Japan, USA and Russia. Different aspects of P&T continue to be investigated in many other countries, including Belgium, China, Germany, Italy, India, Korea, the Netherlands, Spain, Sweden, Switzerland and the United Kingdom.

Different expert groups of IAEA and OECD/NEA nevertheless have emphasised that the current and proposed P&T programs are long-term projects that do not impact on the present fuel cycle strategy, and that the concept cannot avoid the need for eventual deep geological disposal.

If spent fuel is to be reprocessed for the purpose of recycling U and Pu, and if transmutation of some long-lived radionuclides can be effectively incorporated in the fuel cycle, then P&T may eventually be worthwhile. However, the need for geological disposal would still remain for other long-lived radionuclides. Thus, the current perspective is that disposal of SF and HLW and other material containing long-lived radionuclides will be required whether or not used fuel is reprocessed, and whether or not practical techniques can be developed for separating and transmuting some of the long-lived radioactive isotopes in the waste components.

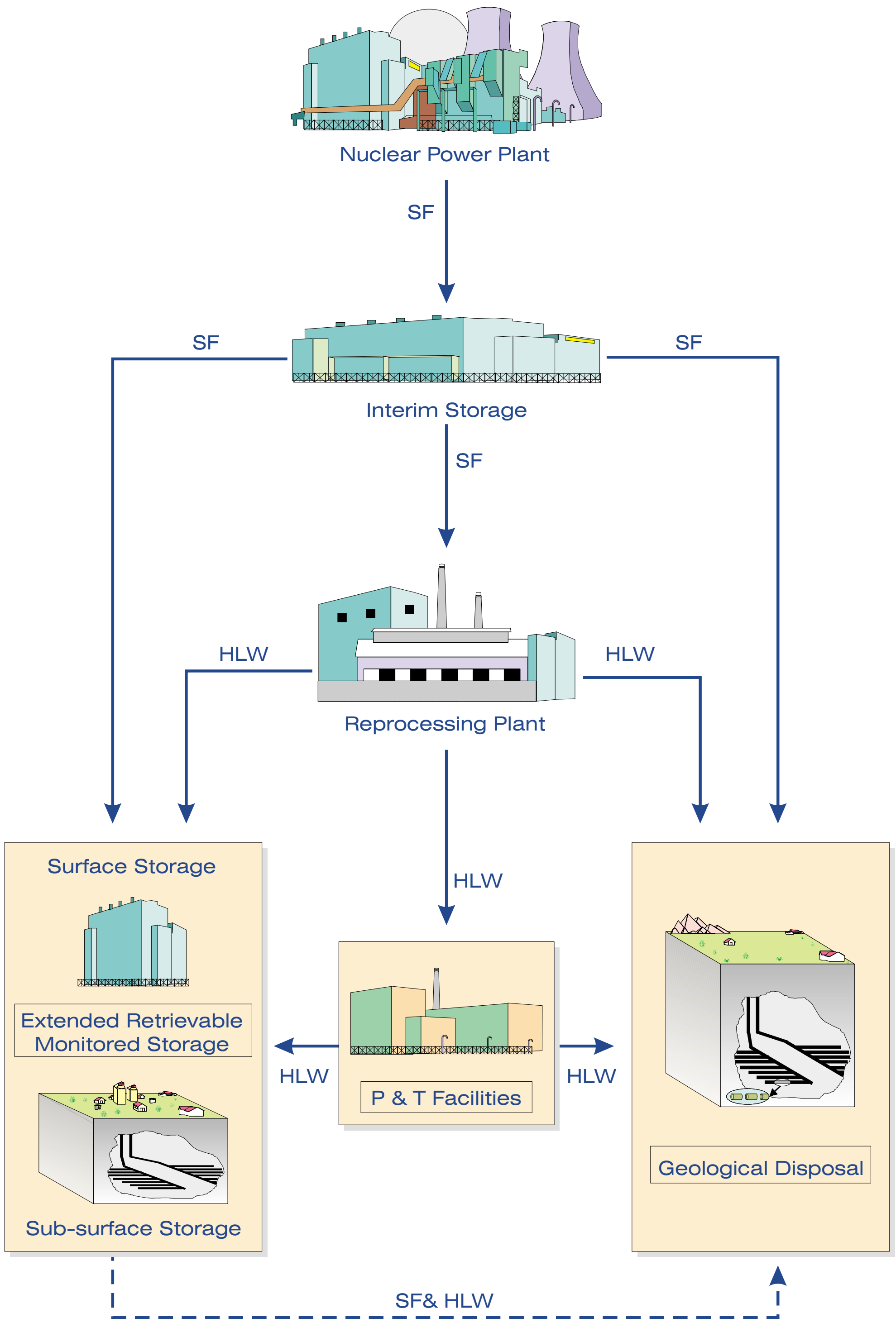
2.3. Spent Fuel and High-Level Waste Management Strategies

As it can be seen in the following figure, long-term surface storage, reprocessing, and partitioning and transmutation are potential components in an overall waste management strategy eventually leading to disposal. From the picture different waste management strategies for SF and HLW can be envisaged, namely:

- extended or indefinite storage,
- direct disposal (interim storage followed by deep geological disposal with or without waste retrievability),
- conventional closed cycle (SF interim storage followed by reprocessing and deep geological disposal with or without waste retrievability). After spent fuel reprocessing, a geological disposal decision could be deferred leading to the extended or indefinite storage of the resulting high-level liquid wastes (HLLW) or the conditioned vitrified high-level wastes (VHLW),
- advanced closed cycle (interim storage followed by reprocessing, partitioning and transmutation of minor actinides (MAs) and long-lived fission products (LLFPs), and deep geological disposal with or without waste retrievability). After waste transmutation, a geological disposal-decision could be deferred leading to the extended or indefinite storage of the resulting reprocessing, partitioning and transmutation residues.

To simplify the analysis the different waste management options have been shortened as: extended storage, geological disposal, and partitioning and transmutation.

Spent Fuel and High Level Waste Management Options



3. Ethical Issues

3. Ethical Issues

3.1. Responsibility

The objective of radioactive waste management is 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 and keeping the options open for them.

In the management of SF and HLW having a long-term potential for harm, interest focuses on two classes of ethical concerns, i.e. intergenerational equity (fairness and equity considerations between successive generations) and intragenerational equity (fairness and equity considerations within contemporary generations). The consideration of these concerns led the NEA Radioactive Waste Management Committee in 1995 to identify, in its "Opinion on the Environmental and Ethical Basis of Geological Disposal", a set of principles to be used as a guide in making ethical choices about waste management strategy:

- the liabilities of waste management should be considered when undertaking new projects;
- those who generate the wastes should take responsibility, and provide the resources, for the management of these materials in a way which will not impose undue burdens on future generations;
- wastes should be managed in a way that secures an acceptable level of protection for human health and the environment, and affords to future generations at least the level of safety which is acceptable today; there seems to be no ethical basis for discounting future health and environmental damage risks;
- a waste management should not be based on a presumption of a stable societal structure for the indefinite future, nor of technological advance; rather it should aim at bequeathing a passively safe situation which places no reliance on active institutional controls.

The principle of intergenerational equity requires that we should show care for future generations by not placing them under any undue burden to care for our waste as well as that the generation deriving the benefit should pay its costs and that the current generation should not limit the options available to future generations. We therefore have to provide them with a solution. We could leave the decision to close the repository up to them, but we have to prepare the way for such closure.

3.1.1. Extended Storage

More recently, question marks have been put to the disposal strategy by a fraction of the radioactive waste management community. Thus, a reconsideration of the merits of a strategy of ongoing monitored and controlled storage of the wastes, for which one is free to choose a disposal or even a further option in the future, is being considered.

There are pros and cons for the option of extended storage. On one hand,

- storage passes the obligation for continuous supervision and maintenance to future generations.
- storage offers no protection against the long-term risks arising from loss of social stability and control.
- postponing decisions may not end the conflicts related to this issue, but even deepen them in time,

and on the other hand

- the postponement of disposal gives decades to further develop the final disposal method and to consider any change of plans,
- all in all further work on preparations for final disposal gives future generations more freedom of choice.

3.1.2. Geological Disposal

The basic motivation for the development of permanent disposal systems is an ethical one: the generation that benefited from the activities that produced the radioactive waste has an obligation to future generations to bear the financial and political costs of providing them the capability for permanent disposal in a way that does not depend upon continued care and maintenance by future generations.

That obligation can be met by providing at a minimum a repository site and design approved by national regulatory authorities, and the funds required to construct, operate, and close the repository. At the same time, there is an obligation to future generations not to prematurely foreclose their options for dealing with radioactive waste by taking irreversible steps too quickly. Consequently, it is appropriate to explore measures to preserve the ability to retrieve waste emplaced in repositories for extended periods, to the extent compatible with protection of health and safety in the very long term. Stepwise approaches for developing repositories may also be useful in allaying concerns about premature irreversible actions.

Once the repository is closed, the avoidance of the continuous maintenance obligation speaks in favour of implementing the option of final disposal. Geological disposal would mean that future generations would not have to undertake any measures to protect their health or the environment. Nevertheless, future generations would be left with an option of being able to retrieve the SF and/or HLW if they so wanted.

To respect future generations means to respect all future generations, starting with the next one and the following ones after that. It is in fact during the next centuries that the waste will remain most active. Future generations should therefore be able to intervene, notably in the following cases: interest for reuse, interest for repackaging, and, even if unlikely, in case of unexpected poor performance of the system. However, future generations would only be burdened with passive monitoring and they would even be able to forget about the waste.

Constructing a geologic repository ensures that the current generation pays most if not all of the financial and social costs of disposing of nuclear waste generated by the electricity it used.

Retrievability of waste allows future generations to decide if there is a better alternative to geological disposal. Monitoring for an extended period allows future generations to confirm that it is operating as expected before fully closing it and facilitates retrieval of waste, if deemed necessary. However, the benefits of postponing the closing and sealing of the repository have to be considered together with the possible risks that such delay may give rise to.

Retrievability is an important ethical consideration since deep geological disposal should not necessarily be looked at as a totally irreversible process, completely foreclosing possible future changes in policy. In this context, it should be noted that sealing of a site and its access will always require a specific decision and that such a decision could be delayed until well after the end of the waste emplacement operations to allow for reversibility and flexibility in the process if considered necessary. Under such circumstances, the incremental process leading to the implementation of the geological disposal strategy incorporates the advantages of a temporary storage phase, as advocate by some, without letting this phase extend indefinitely.

3.1.3. Partitioning and transmutation

Even if the level of risks posed by geologic disposal is considered very low, there is some interest in investigating whether a further reduction of the future potential hazard of the waste can be achieved by P&T and at what cost this can be accomplished. It should be kept in mind that the exposure risk in the present or in the near future could appreciably increase due to the complexity of the fuel cycle. The strength of a P&T process would be that it would drastically reduce the hypothetically possible future consequences of unforeseen events. On the other hand, a broad commitment to the development of P&T processes will obscure the fact that the future risks posed by a well-executed deep repository are already deemed to be very small. In addition, the possible deployment of P&T processes far into the future should not be used as an excuse to postpone development of geologic disposal, which will be needed anyway.

3.2. Sustainability

The concern for the protection of human health and the environment in a developing world has been illustrated by the concept of *"sustainable development"* put forward by the World Commission on Environment and Development, "the Brundtland Commission", in 1987. This concept, which is principally an ethical one, was defined as *"satisfying the needs of the present, without compromising the ability of future generation to meet their own needs"*.

It is evident that there is a heightened awareness in society for the role of energy in the context of sustainable development, with emphasis on conservation of resources, the possible adverse environmental impact of the exploitation of natural resources, and long-term protection of the environment.

3.2.1. Extended Storage

The use of indefinite and monitored storage systems has indeed a number of ethical arguments in its favour, particularly if it were to be accompanied by suitable efforts to ensure continued development or improvement of options for final solutions (or to have the resources available for future use) and to ensure that financial resources would be available when needed at all times in the future.

One interpretation of the concept of sustainability would support such an approach, wherein one generation would pass on to the next generation a world with "equal opportunity", and so on for the generations coming after, thus preserving options and avoiding the difficulty of predicting the far future.

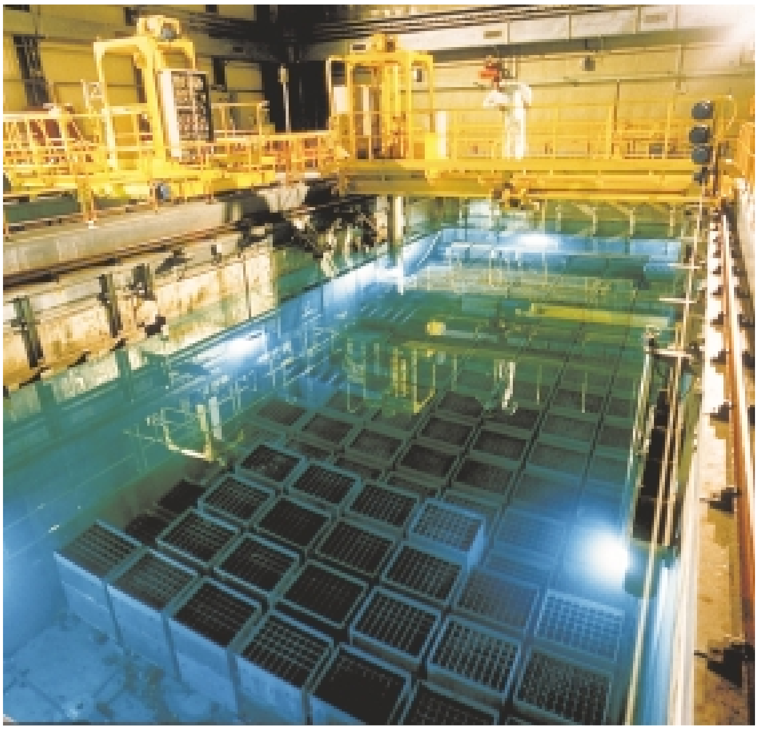
According to this idea of a "rolling present", the current generation would have a responsibility to provide to the next succeeding generation the skills, resources and opportunities to deal with any problem the current generation passes on. However, if the present generation delays the construction of a disposal facility to await advances in technology, or because storage is cheaper, it should not expect future generations to make a different decision. Such an approach in effect would always pass responsibility for real action to future generations and for this reason could be judged unethical. Whatever the selected waste management option could be, it could always be improved (during eternities), but a decision could never be taken unless a set of minimum performance requirements is defined.

A most significant deficiency of the indefinite storage is related to the presumption of stability of future societies and their continuing ability to carry out the required safety and institutional measures. There is also a natural tendency in the society to become accustomed to the existence and proximity of storage facilities and progressively to ignore the associated risks.

Such risks would actually increase with time in the absence of proper surveillance and maintenance, leading at some indefinite future time to possible serious health and environmental damage. There are many well-known examples of serious environmental situations inherited from the past which show that this deficiency of a waiting strategy should not be underestimated. In case of societal breakdown, future generations may not have the resources to properly manage the waste.

One important factor is the argument that we cannot be sure that the future society will maintain the knowledge and the institutions necessary for the protection of humans and the environment from hazards inherent in a strategy of monitored storage.

Spent Fuel Wet Storage



Perhaps more important is the assertion that present generations have the direct benefits of nuclear power production and applications of radioisotopes in medicine and industry, and should not leave future generations to bear burdens of responsibility and resource cost if that can be avoided by action during the lifetime of current generations. Action can nevertheless be spread over several decades to resolve technical uncertainties about long-term waste isolation methods, or issues of social acceptability.

3.2.2. Geological Disposal

The principle of sustainable development requires a balance between the needs of present and future generations. In this context many countries favour a step-wise approach to repository development, whereby the present generation establishes a facility for long-term management of the waste, whilst allowing future generations the option of adopting different management strategies if they wish.

Designing the repository so that it can remain open for an extended period and the contents can be retrieved, even after closure, ensures that future generations can recover emplaced SF and HLW for economic purposes if they so choose.

Each waste management option may have adverse effects on the future availability or utilisation of natural resources, these are expected to be greater for deep geological options. The location of a deep facility may have implications for future extraction of raw materials. It is usual to consider siting such facilities in areas away from known deposits of currently raw materials. However, it is difficult to judge the raw material requirements for future generations. Other natural resources, which could be affected, include ground water and agricultural land. It is generally accepted that sites, which minimised impacts on these resources, would be chosen for such facilities. Furthermore, all the information related to the repository existence and potential associated risks would be organised, kept and transmitted, as far as possible, in time.

3.2.3. Partitioning and Transmutation

Spent fuels contain a significant amount of slightly enriched uranium and plutonium. These materials are lost in the event of direct disposal. They are recovered in the event of reprocessing and provide an economy of more than 25% of natural uranium by first recycling in LWR´s. Besides entering in the fabrication of mixed oxide (MOX) fuel, plutonium can be used to feed fast breeder reactors with the possibility of reaching self-sufficiency without significantly drawing on natural uranium resources.

The development of new nuclear technology may also have the goal of more efficiently utilising the energy content in the uranium extracted from the earth's crust. In this case, transmutation may be an interesting and important "by-product" that will considerably influence the future management of the spent nuclear fuel.

Waste management strategies are somehow linked to the question of the future energy supply. An investment in reprocessing and recycling is not realistic without the prospect of continued use of nuclear power in the future. This is also true for transmutation, which not only requires reprocessing but also a large investment in new nuclear power technology.

There might be a potential for wide spread use of P&T technology if there is a new upswing in nuclear power development and construction programmes in leading industrial countries. In this way, the European Union, Japan and France in particular are investing heavily in P&T techniques. The technology could then improve the possibilities to use global nuclear fuel reserves and facilitate nuclear waste handling. In any case huge investment would be required to build such facilities.

To date, transmutation is a possibility for the future. Its practical applications, if successful, would be implemented over several decades ahead. So far, there are insufficient grounds to make any reliable assessment of the potential of transmutation technology in spent fuel nuclear management. Experts, however, do not consider that P&T eliminates the need for deep geological disposal.

4. Scientific and Technological Issues

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4.1. Status of Technology Development

4.1.1. Extended Storage

Interim storage of spent fuel is and will remain an important activity for all countries with nuclear power programmes because fuel after its discharge from the reactor is required to be stored before reprocessing or final disposal. The duration of the storage period is highly dependent upon the individual national strategies for the back-end of the nuclear fuel cycle.

Wet storage continues to predominate as an established technology and the primary method for storing most LWR fuel. This technology has proven to be extremely well suited in meeting the shielding and cooling requirements for spent nuclear fuel.

For LWR that use zirconium alloy clad fuel, pool storage times appear technically unlimited. Data exists for continuous pool storage for more than 30 years. This data indicates cladding corrosion to be extremely low (virtually not measurable) and therefore corrosion of the cladding is not viewed to limit storage below 100 years. The only limitation related to pool storage might be the capacity of the pools, or economic considerations that may dictate the closure of the pool at the time of a reactor shutdown.

Dry storage is complementary to wet storage, since it requires initial spent fuel cooling in a pool prior to storage. It has become a mature technology used in many countries also for the long term and the quantities being placed into dry storage are beginning to increase significantly. More than 20 years of favourable experience exists with dry storage of power reactor fuel and about 30 years with research reactor fuel.

Dry storage experience exists with fuel from a variety of reactor types (HWR, PWR, BWR, WWER, RBMK, AGR, MAGNOX and HTGR). Since its conception, dry storage of spent fuel has evolved into a wide variety of storage systems, e.g. concrete canisters, steel lined concrete dry storage containers, metal casks, concrete modules, vaults, etc. At the present time, many countries are engaged in the dry storage of spent fuel. Some of these countries are actively pursuing a dry storage research and development programme. So far, the results of the research indicate that fuel can be stored safely under the present conditions for many decades.

The choice of storage technologies is heavily influenced by the chosen fuel cycle strategy for each specific country and by economic considerations. For example, the storage requirements for a country involved in a closed fuel cycle using reprocessing is vastly different than in an open, once-through fuel cycle where storage may be planned for 50 years or more prior to geological disposal. Also, different storage techniques may be chosen where there is a single nationally-dictated storage strategy as opposed to a situation where each utility is making its own plan for how to deal with its spent fuel prior to reprocessing or disposal.

4.1.2. Geological Disposal

Research activities over the last 30 years have brought considerable experience in various fields of SF and HLW management regarding deep geological disposal. The main objective of this research has been to evaluate the viability of constructing, operating and sealing the repository, and to evaluate the long-term safety of the repository.

Techniques for site investigations to dispose SF and HLW are well advanced and allow obtaining the information and data needed to characterise and evaluate the suitability of sites for repositories.

Core research in deep geological disposal of spent fuel and HLW is carried out in complex research programmes in underground laboratories, located in different types of host rock (clay, granite, salt, volcanic tuff).

With respect to the construction of repositories, various mining techniques have been tested on their potential for meeting stringent specifications. Moreover, experience has been obtained with equipment for underground waste transport and emplacement so that one is rather confident that engineering questions are or can be solved.

To demonstrate and gain confidence in the long-term behaviour of the disposal system, predictive models are developed and applied in performance assessments, covering not only the behaviour of individual components of the system but also the overall multi-barrier system. Many elements of the repository system can be adequately modelled today. Extensive international programmes and co-operation in this field are underway to improve performance assessment methods (e.g. scenario development, sensitivity/uncertainty analysis…) and with a view to "validate" performance assessment models. In this latter context, natural analogue studies and results from in-situ experiments will contribute to a better understanding of processes and to build confidence in the models.

Overall, the scientific and technical effort made in geological disposal is remarkable for the breadth and also, in key areas, for the depth. Large resources have been expended and many aspects have been investigated in order to ensure that sound technical solutions are available underpinned by good scientific understanding.

4.1.3. Partitioning and Transmutation

Spent fuel reprocessing is a proven technology that is offered commercially on an international basis by France and United Kingdom. Japan is actively developing plans to build a commercial reprocessing plant. In Russia, a multi-purpose reprocessing plant has been in operation for nearly 20 years and a commercial reprocessing one has been proposed.

MOX fuel has been manufactured on a semi-industrial scale for nearly 25 years and has been recycled in several thermal and fast reactors (FRs). Production and recycling of MOX in LWRs has reached industrial maturity during the last ten years, as is evidenced by the recent large LWR recycling programmes. Today, considerable experience has already been accumulated.

The reprocessing options may alter the waste form; however, HLW will require ultimate disposal, as will the spent MOX fuel that is produced as a result of the Pu recycling.

The VHLW currently in stock was quickly discounted from consideration since the application of P&T to this waste is not considered to be technically feasible. If P&T were to be applied to HLLW it would have to be done before the vitrification.

After a considerable research effort in 1970-80, there has been a renewal of interest for P&T of long-lived radionuclides in several countries and international organizations since the beginning of the nineties. The purpose of transmutation is to greatly reduce the quantity of long-lived radionuclides that have to be disposed of. P&T involves three steps: (i) partitioning of long-lived radionuclides (minor actinides (Np, Am and Cm) and fission products (I, Tc, Cs)); (ii) fabrication of fuel and targets containing these elements in view of their (iii) transmutation in different burners (fast reactors and accelerator driven systems).

Partitioning, a prerequisite for transmutation, is the first cornerstone in a P&T strategy and strongly influences possibilities for elimination of the MAs and/or LLFPs. Further reductions of MAs can be achieved by the interplay of P&T in dedicated processing facilities combined with dedicated reactors or accelerator driven systems (ADS) and could have an important impact on the radiotoxicity inventory of a repository.

Hydrometallurgical and pyrochemical processes are the potential methods for partitioning. The hydrometallurgical process for the separation of Np, Am and Cm is becoming a known technology making upscaling to prototype pilot facilities possible. However, the final performance of radiotoxicity reduction after P&T could be strongly limited by the hydrometallurgical process because of the cumulative losses in a multiple recycling scheme. Severe reliance on very high efficiencies of separation is therefore required. The pyrometallurgical process, being less mature and facing a renewal of interest, could be more adapted to an in-line, and as such, multirecycling P&T process of highly irradiated and short-cooled fuel and targets but this route will impose the burden of radiotoxicity reduction on the transmutation step.

The second cornerstone of P&T consists of the irradiation, and as such, transformation of the MAs and/or LLFPs in other nuclides having shorter life-times or even being stable. This transmutation involves the inclusion of separated nuclides in a form that is compatible with the irradiation device used. Transmutation can be done in LWRs, in FRs and in ADSs. The last two options provide a homogeneous, as well as a heterogeneous, mode of introduction of MAs in the system, but also provide the potential to use pyrochemical processes.

Accelerator-driven system (ADS) is currently the alternative line of development for transmutation that is attracting a great interest. It can be distinguished by its potential of surplus neutron availability, providing higher transmutation capability for LLFPs, and its potential of higher reactivity losses per cycle and thus higher transmutation rates achievable without hampering core safety characteristics.

In general, transmutation studies involve a multitude of aspects (e.g. target fabrication and irradiation tests, reactor physics and nuclear data, safety studies, etc.). Furthermore, the development of plants is very costly and heavily dependent on international collaboration. A number of fundamental technical questions need to be further clarified by research before major projects with accelerator-driven transmutation can be started.

4.2. Future Challenges

4.2.1. Extended Storage

The experience of the past 30 years indicates that wet storage of spent fuel is a well-developed technology to which no major technological problems are associated. Different designs have been developed, ranging from a few hundred tons to 10,000 tons of spent fuel.

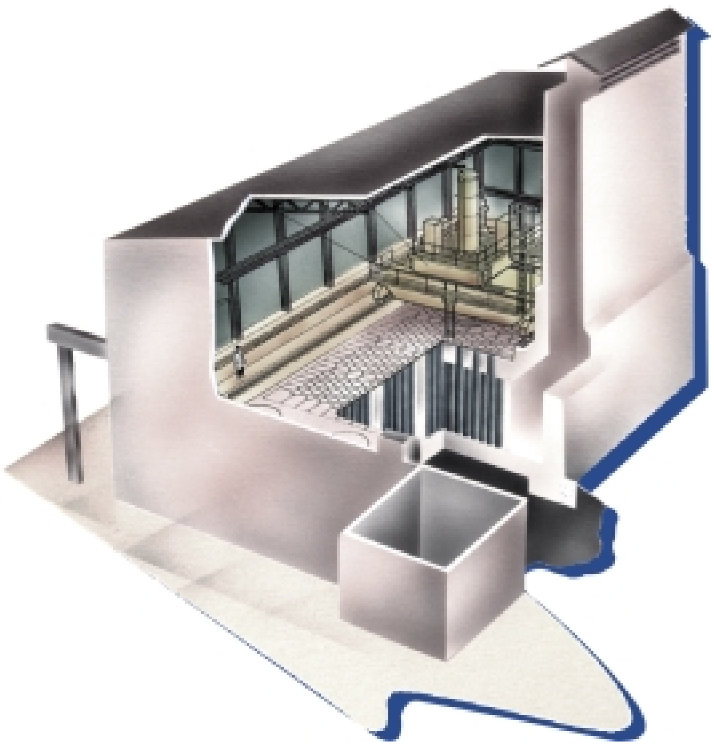
Fuel storage in casks is one of the most mature methods available for dry interim storage and different designs have been developed. Storage only, dual purpose (transport and storage) or multipurpose (transport, storage and final disposal) casks can make the option attractive to the system operator if these casks can be incorporated into the waste management system in time.

Spent fuel storage is therefore a mature technology in the back-end of the fuel cycle. However, the effects of extended burnup on the behaviour of the fuel in store conditions need to be assessed since there is a tendency to achieve increasingly higher burnups. In addition and although there is a positive storage experience so far, the extrapolation of current results for very long storage times (more than 100 years) has yet to be confirmed.

Additional aspects, which may need to be considered for the long-term storage, are the following:

- technical problems associated with storage periods longer than 100 years,

Conceptual Spent Fuel
and Vitrified High Level Waste Dry Storage



- identification of potential material property changes in the fuel and in the storage system that may affect future performance
- regulatory requirements.

4.2.2. Geological Disposal

Some progress has been made in the scientific and technical aspects of geological disposal and may components of the necessary technology are available today. This development is backed up by the experience world-wide from underground research laboratories and the underground facilities for disposal of radioactive waste, including waste containing longer-lived radioactive components. Moreover, no radical changes in philosophy of approach has proven to be necessary in the past ten years, confirming the soundness of the basic geologic disposal concept.

Further R&D activities in this field are on the one hand oriented to site selection and characterisation and on the other hand to the refinement of the constructional and operational technologies, process modelling for repository performance, and calculation methods in order to gain an in-depth knowledge of the phenomena involved in the evolution of the repository with time and to gain confidence in the evaluation of the long-term repository safety. Performance assessment studies play an important role in focusing these research activities and setting priorities of investigation of fundamental issues for disposal systems.

Underground laboratories will progressively play a more important role in the definition and acceptance of a waste management strategy for spent fuel and HLW. The programmes undertaken by most of the laboratories will have each time more international participation both in planning and funding. This participation already extends beyond Europe, to include countries such as Canada, Japan, and the USA, who actively participate in European programmes and viceversa. The wide international participation provides for an exchange of experiences which is invaluable for finding the best solutions.

Although significant progress towards implementation has been made in several countries, the rate of progress has been slower than expected ten years ago, and significant set backs have occurred in some countries. The slower progress may be attributable to an earlier technical optimism and problems with public acceptance/public perception and also to the burden of demonstrating with a degree of confidence that very challenging safety standards will be met over long times into the future. The additional time allowed for R&D may give benefits in terms of improved disposal technology and more confidence in safety. In some countries efforts are now being focussed on the characterisation and performance evaluation of specific sites. The associated technologies and scientific developments will be beneficial for the international community.

4.2.3.Partitioning and Transmutation

All operating reprocessing plants use PUREX technology. No particular difficulties are anticipated in dealing with uranium or MOX fuels. The future total reprocessing capacity and throughput will depend on the future demand for reprocessing services. The proven PUREX technology is unlikely to be replaced, although some modifications and improvements may be introduced. The main areas of development in reprocessing are reduction of capital and operating costs, reduction of waste volumes and increased automation.

Separated plutonium poses a significant environmental and security risk and, if accumulated, leaves an open-ended legacy for future generations. In the long term, depending on the evolution of nuclear policies, the following alternatives (alone or in combination) may be considered:

use of MOX fuel in current or ad-hoc new constructed reactors;

plutonium burning in fast neutron or other dedicated reactors; and

if one refrains from further use of Pu, conditioning plutonium to a form compatible for final disposal.

P&T approaches are in the early stages of development. Partitioning is one of the key issues affecting the feasibility of the transmutation approach. The loss of some proportion of the radionuclide to secondary waste streams (from fabrication of target material for transmutation and the recycling/re-fabrication of this target due to loss of efficiency) should be minimised in order for the net gain of transmutation not to be lost. Partitioning technology requires extensive research and development before it is ready for industrial application.

In the past years a number of proposals for ADS applications have been presented, varying from an Energy Amplifier with lumped Th/Pu fuel and fast spectrum with lead coolant, to fission product and actinide transmuters with fast, epithermal and thermal neutron spectra. The ADS concepts are mostly specially designed for transmutation purposes as dedicated transmuters to be deployed in the P&T-cycle. Most of the presented design studies focuses on four categories: sodium cooled solid fuel fast reactor technology, liquid metal cooled options, gas cooled concepts, and finally, the concepts relying on molten salt technologies.

A very important and distinctive part in all ADS-designs relates to the accelerator reliability. The requirements for the accelerator are new for accelerator physicists. Not only the beam energy and intensity are rather high-end, but the reliability of the beam, especially reduction of the troubling beam trips, are key issues for future developments. Material and technological problems related to the beam window are very important issues for the future.

Basic and fundamental research remains one of the cornerstones of P&T, and cross-section measurements and evaluations are key to many transmutation uncertainty assessment studies as the MAs are among the main contributors to reactivity and the nuclear data for these MAs are not so well known as for the main actinides (U, Pu).

Major research and development work is going on world-wide to address the target fabrication aspect. The transmutation of Am in existing LWRs and future fast systems has been the primary focus of much of this R&D. Alternative fabrication routes have been envisaged when fabricating highly radioactive materials (like Am, Cm or LLFPs) is considered. Nitride fuel is a promising candidate for transmutation of MAs.

In summary, most of the R&D work on P&T is related:

- to the development of the appropriate fuels (basic properties, fabricability, irradiation),
- to the development of consistent chemistry processes which can provide the required decontamination factors (e.g. in terms of reduction of the ratio Lanthanides/(Am+Cm) by a factor of about 100), and
- to the experimental validation of the data and methods used in the physics analysis, in order to make more credible an eventual design of a more or less "dedicated reactor" for transmutation.

Regarding R&D Programmes for P&T, several national projects and bilateral or multilateral programmes are being undertaken and huge funding will be needed to construct a demonstration facility for technology verification.

5. Safety and Licensing Issues

5. Safety and Licensing Issues

5.1. Waste Arising and Radiotoxic Inventory

5.1.1. Extended Storage/Geological Disposal

The radiotoxic inventory depends on the source term, which is determined by the type of fuel (LWR-UO_2, LWR-MOX, FR-MOX,...), the burn-up and the cooling time. These fuels contain the main actinides (U, Pu, Np, Am and Cm) and the long-lived and short-lived fission products as major radiotoxic constituents.

The TRUs constitute over a long time period (hundred thousand years) a significant radiological source term within a spent fuel repository.

The fission products are, in the short term, the most limiting factor in designing the facilities due to the gamma radiation and the decay heat emission that increases proportionally with the burn-up. After some 300 to 500 years, the major part of the fission products have decayed except for some long-lived nuclides (Tc-99, I-129, Cs-135,...). Some of these can be relatively mobile in the geosphere, but fluxes are often limited by the time required for the nuclides to pass through the multi-barrier system.

In the short term all radionuclides contribute to the source term. In the long-term the radiotoxic inventory is mostly due to Pu, MAs and some LLFPs. However, the use of engineered barriers is potentially capable of confining the radionuclides for thousands of years. The long-term radiological impact can be controlled by a combination of a man-made system and natural barriers that should provide protection for long periods of time.

5.1.2. Partitioning and transmutation

The recycling of uranium and plutonium from spent fuel has been from the beginning of the nuclear era the standard scenario of nuclear energy production. There has been reduced support for this approach in many OECD countries in recent years owing to economic factors and concerns of non-proliferation policy.

The current separation efficiency of 99,9% obtained for major actinides (U and Pu) is in a first approach sufficient to reduce their content in the HLLW generated by the reprocessing of the LWR-UO_2 fuel to an acceptable level. The only improvement which might have a significant influence on the long-term risk and waste management is the reduction in volume of the medium-level waste which are associated to reprocessing.

The HLLW produced during reprocessing of LWR-UOX and LWR-MOX fuel would require an additional TRU separation module to reduce significantly its radiotoxicity in comparison with non-reprocessed spent fuel.

In a long-term perspective of waste management, the disposal of spent MOX fuel is a major factor in the overall assessment of the radiotoxic inventory in a fuel cycle with Pu recycling. Reprocessing of spent MOX fuel and recycling of recovered plutonium are feasible. However there are important issues which still need to be investigated.

Advanced reprocessing of spent MOX fuel with quantitative removal of Pu, Np, Am and Cm is also beneficial to reduce the long-term radiotoxic inventory of HLW. The main impact of this strategy is a significant reduction in the radiotoxic inventory of the wastes with conversely a transfer of the long-lived actinides to the fuel cycle facilities and reactor core inventories. This long-term benefit has to be weighed against the short-term doses to workers, and the production of additional contaminated wastes, due to the increased complexity of the fuel cycle. An overall assessment of such a new cycle has to be performed and compared with the present cycles.

A generic P&T strategy consists of chemically separating the most toxic long-lived radionuclides from the spent nuclear fuels and, in a second step, to transmute them inside nuclear reactors into short-lived radionuclides which finally decay into stable elements within a period of time during which institutional monitoring should be feasible. For the purpose of reducing long-term environmental and health risks, this P&T strategy has to be applied to:

- long-lived alpha emitters, TRUs, in order to reduce the long-term potential risk due to their high radiotoxicity;
- some long-lived fission products, in order to reduce real risks due to their high mobility in the repository (e.g. Tc, Cs, I).

Regarding TRUs, fast neutron systems, in which an important neutron excess is available as well as an enhanced fission-capture ratio with respect to that in thermal reactors, are the more efficient type of reactor. However, if the aim is only to get rid of plutonium, thermal reactors can play an important role due to higher fission cross sections.

Regarding the long-lived fission products, neutron capture is the only way to transmute them into stable nuclei. Capture cross-section being important in a thermal or epithermal spectrum, fission products transmutation can be envisaged in a locally moderated region of a fast neutron reactor core, taking advantage of its high neutron flux and neutron availability. An alternative is to use the loss neutrons of a lead cooled subcritical reactor. These neutrons would be adiabatically slowed down by the lead until they are captured in the neutron capture's resonance of the long-lived fission products.

Regarding some long-lived activation products (e.g. Zr-93, Ni-59, Ni-63, Sm-151, Cl-36, C-14…), P&T does not seem technologically feasible.

The wastes generated in a generic P&T option, implying multirecycling, include:

- the cumulated quantities of wastes generated within the fuel cycle operations (chemical separation, fuel fabrication, reactor) at each irradiation cycle; and
- the last reactor inventory, at the time when the P&T operations are ended.

Instead of replacing geological disposal, P&T may alleviate the long-term radiological impact, by reducing the radiotoxicity to be disposed of. But, it is fair to say that to have a significant impact, such strategy has to be carried out on a large time scale (at least 100 years), that it involves complex technologies implying continuous efforts in R&D and large industrial investments. Some P&T technologies are presently studied and even proposed to significantly reduce weapons grade plutonium; these technologies can also be used for reducing civilian plutonium stocks.

There is no chemical and/or burning process with a 100% yield, consequently, even with a P&T strategy,

View of a Fuel Reprocessing Plant (La Hague, France)

geological repositories would still be needed. The successful introduction of P&T would reduce the quantities of radionuclides requiring disposal but would not eliminate the need for disposal altogether.

5.2. Operational Safety and Doses to Workers of Associated Facilities

5.2.1. Extended Storage

The construction and operation of a long-term surface store would utilise well-proven technology and would be subject to strict regulatory controls. Therefore, the annual radiation doses to the workforce and the general public (for normal operation and assuming normal evolution of the disposal system) during the lifetime of the facility would be very small.

The potential radiological impacts for long-term storage would stem from: (1) the emplacement of the waste in the store and the amount of years of storage which will result in doses to workers (from handling and maintenance operations) and to the public (by direct radiation from the store), (2) the retrieval of waste from the store following the care and maintenance period, (3) the transport from the store to the repository, and (4) the decommissioning of the stores.

In the event of a significant period of storage longer than 100 years, it could become necessary to repackage the waste it thereby resulting in more significant levels of radiological impact to the workforce during retrieval and repackaging operations. Although doses to individual members of the workforce will remain low (and within criteria for safe operation established by the regulatory authorities), a requirement to repackage wastes together with continued monitoring and surveillance activities over long periods could result in substantial collective doses to the workforce.

As regards an option involving long-term surface or near surface storage, the storage facilities are likely to be significantly more vulnerable to incidents/accidents. Therefore, although it is reasonable to assume that society will remain stable during a period of the order of 100 years, this assumption become more questionable if significantly longer periods of storage are envisaged.

5.2.2. Geological Disposal

Comparing deep disposal facilities with and without enhancements for waste retrieval, there will be some additional impacts associated with the former (mainly as result of the extended operation and maintenance of the facility). Operational impacts associated with retrievability may limit the time during which waste retrieval may be performed safely. As regards the overall level of safety afforded by the facility, the main additional impact results from the risk of being unable to properly seal and close the facility (for example, if society were to become less stable).

There would be doses to repository workers arising from the care and maintenance period. Because the waste would be within sealed and shielded casks, it is assumed that there would be no radioactive atmospheric or liquid discharges. In some host rock formations, there could be releases of radon gas which would be discharged with ventilation air for the care and maintenance period.

In principle, assuming a safety assessment meeting national and international regulatory criteria had been made, the emplacement of waste in a deep geological facility without an intention to recover the waste would minimise the ongoing exposure of the workforce to radiation resulting from a continued requirement for surveillance and monitoring. Similarly, in terms of the inherent level of radiological protection of the public, a deep geological facility should in principle provide most protection assuming both normal evolution of the repository system and the occurrence of abnormal events.

5.2.3. Partitioning and Transmutation

Transmutation would entail a further reduction of a relatively small, perhaps only hypothetical, risk far into the future. But on the other hand, the risk of exposure and therefore doses to workers in the present or in the near future would be considerably bigger due to a great increase in the handling of short-lived radioactive materials and the complexity of the fuel cycle involved.

For partitioning of some actinides (e.g. Am-241, Cm-244) with a high dose rate, there is e.g. more shielding required than in current MOX-related facilities. For significant quantitative transmutation, a "once-through"-burning is probably impossible due to the limited lifetime of involved materials. Additional partitioning/recycling leads to additional doses and risks.

5.3. Impacts on Long-Term Safety

It is clear that whichever SF and HLW management concept is selected, it has to be judged to be safe in the long term by both the repository implementer and the regulator. Any comparison between the options should be made on the basis of a similar time scale.

5.3.1. Extended Storage

Surface facilities, regardless of how secure and safe they may appear when constructed, are vulnerable to long-term degradation, future intrusion, abandonment and mis-use. Therefore, safe extended storage is possible provided that active control and maintenance of the storage facilities and the fuel is continued

Without perpetual human care and control, surface facilities will degrade and release radionuclides into the human environment, thus endangering human health and the environment. If, for any reason, maintenance were to end, the storage facilities would pose a considerable threat to the human health and the environment. History shows that the possibility of loss of societal stability and control cannot be ruled out, although it is difficult to assess its likelihood of occurrence. Consequently, the long-term safety of extended storage is vitally dependent on human action. It would thus require commitment by future generations to continue using resources to take care of the storage facilities.

Opinions as to the impact of extended storage on the environment and human life and of their time-related dimensions vary. According to some estimates, an interim storage facility would not pose a threat to human life or the environment as the storage facility could be controlled for possible emissions and leaks. Nevertheless, other opinions see an interim storage facility as posing a threat to human life or the environment because there would be no guarantee of the continuous undisturbed functioning of the society. In the long term, it is also possible that social anxiety about the safety of storage and the fears surrounding it may increase as the storage facilities age.

5.3.2. Geological Disposal

There will always be a certain amount of uncertainty in projecting long-term performance and therefore it is essential to increase the confidence in our future predictions. Some believe that an assessment of the probable long-term behaviour of a geologic repository is beyond the analytical capabilities available. How we deal with this is crucial to the success of geologic repositories.

In case of an extended operational period of the repository to facilitate retrievability, continued access to the waste would inevitably mean that some of the barriers providing long-term protection would be put in place significantly later than when the waste itself is emplaced. In these circumstances long-term performance of the disposal system would be reliant on future generations having the will and the technological capability to put adequate barriers in place as long as the operational phase lasts.

It is worthwhile to mention here the conclusions reached by EKRA from Switzerland (Expert Group on Disposal Concepts for Radioactive Waste) in the evaluation of different waste management concepts:

- The safety systems of interim storage facilities are designed for short storage periods; they do not fulfil the key requirement of long-term safety.
- Waste disposal facilities located at the surface (for permanent storage, long-term storage and disposal) and open facilities at depth (for permanent deep storage), all of which require to be monitored, also fail to meet the long-term safety criterion.
- Based on current knowledge, geological disposal is the only method for isolating radioactive waste that fulfils the requirement for long-term safety (up to more than 100,000 years). This concept is based on a combination of engineered and natural safety barriers that ensure isolation of the waste. Reversibility, i.e. the possibility of retrieving the waste from a closed repository, is feasible in principle but does not form an integral part of the concept.
- Social demands concerning waste disposal are oriented towards the principle of reversibility. Therefore EKRA has developed the concept of monitored long-term geological storage, which

combines disposal with the possibility of reversibility and takes into account requirements for both long-term safety and reversibility. Provided there is no reason to retrieve the waste beforehand, geological disposal will thus be realised in a stepwise manner.

- The way in which the concept of geological disposal is extended to include elements of monitored long-term geological storage is determined by safety considerations.

  The advantages, in terms of safety, of monitored long-term geological storage during the observation phase are:

  - possible enhancement of safety as a result of increased knowledge and technological advances,
  - early recognition of unexpected and undesirable developments,
  - easy retrieval of the waste or, if necessary, repair of the facility.

  Possible disadvantages of monitored long-term geological storage during the observation phase are:

  - longer exposure times, especially for operating personnel,
  - an increased risk due to undesirable intrusion by third parties,
  - negative consequences arising from unforeseen socio-political developments which are difficult to predict (such as war, system changes, social and technological collapse, epidemics),
  - not all the host rocks are equally suitable for long-term monitoring.

  Compared with geological disposal, introducing the concept of monitored long-term geological storage would involve higher construction and operation costs.

5.3.3. Partitioning and Transmutation

The doses and hazards related to P&T operations need to be carefully balanced against the very low doses very far in the future from geologic repositories. Calculated releases from a HLW repository show very similar peak doses for the HLW residues resulting from the reprocessing of an ADS fuel and of a LWR fuel. This is because in both cases the fission products dominate the dose curves; the contribution of the actinides is insignificant also in the LWR case due to their low mobility.

In order to further decrease the doses from a geologic repository, it would be necessary to transmute key fission products such as Tc-99, I-129, Cs-135, etc. Transmutation of most of these fission products is not yet feasible.

5.4. Surveillance and Monitoring Requirements

5.4.1. Extended Storage

Without perpetual human care and control, surface facilities may degrade and release some radionuclides into the human environment. Thus, a policy of continuous surveillance and monitoring is an essential component of an extended storage option

5.4.2. Geological Disposal

Many parties within the international HLW community are now reconsidering the merits of a strategy of ongoing monitoring and the eventual retrieval, if so decided, as opposed to a program that involves closure of a repository and absence of planned activities thereafter.

There are several reasons for ongoing surveillance and monitoring rather than closing the repository as soon as the SF and HLW has been emplaced. It provides society with enough time to develop a political opinion and to come to a well-informed decision.

The counter arguments are that safe disposal is already now feasible and that delaying closure for long time presents a greater hazard. For example, operational expertise and funding in the future are not guaranteed. Retrieval from a closed geological repository remains in principle possible for very long times. Nevertheless, it may be appropriate to consider strategies for extending the time between emplacement of waste and closure of a repository, and to regard an underground repository in a deep geological formation as a monitored, retrievable SF and HLW storage facility, until societal agreement exists in the adequacy to close the repository.

It should be mentioned here the key points arising from the 5th International Workshop on Design and

Construction of Final Repositories –Repository Monitoring, Oxford 20-22 September 1999:

- The safety of a repository should not be reliant on monitoring or intervention as a means of achieving safety but that monitoring could take place during phases of repository development and operation to confirm that the repository conforms with the performance predictions made in the repository safety assessments.
- It is not viable to use monitoring to gain radiological evidence for validation of repository performance, due to the high level of efficiency of the engineered barriers. The migration of radionuclides away from the repository is not expected to occur over the period of institutional care.
- Difficulties in monitoring long-term safety might result in repository operators having to maintain operational monitoring for longer periods than might be ideal.
- Initial approach to monitoring is one of confirming confidence in and refining some of the models used to predict performance. It was recognised that it was not viable to confirm all the predictive models within viable time-scales for monitoring (particular reference was made to the very long time-scales for radionuclide migration). After initial monitoring, there may be a case for redefining monitoring requirements with reduced intensity. Revised arrangements could be linked to indicators and intervention levels.
- Although monitoring can be considered to be provided to satisfy imposed regulatory requirements or to provide demonstration of suitable science, societal needs in relation to confidence building were recognised. It was felt that tailoring monitoring programmes to address societal concerns at an early stage would enhance confidence in the science.

5.4.3. Partitioning and Transmutation

The development of a P&T option would require additional nuclear facilities, which should be subjected to the surveillance and monitoring required for nuclear installations. The standard measures should be strengthened due to the nature of the materials to be managed in the partitioning or recycling facilities as well as in the transmutator devices.

5.5. Impacts on Proliferation Risks

Any step of the back-end fuel cycle, irrespective the fuel be reprocessed or not, requires consideration of measures to manage proliferation risk. The plutonium inventory in spent fuel is generally difficult to access, with barriers to diversion or theft provided by size, weight and high radiation fields.

Fraudulent diversion may be made by directly accessing materials already isolated and stored, or by covert use of a plant in the cycle. The first case gives rise to physical protection measures, the second to control measures exerted by international entities in the frame of international agreements (IAEA in the framework of TNP, EURATOM and IAEA inspections, etc.).

5.5.1. Extended Storage

Spent fuels have no direct military value. They do, however, contain plutonium, which must be controlled. Effective techniques for applying safeguards on storage facilities have already been established.

A key issue is the extent to which large stores of separated plutonium constitute a proliferation risk. Some seek to minimise accumulated stockpiles of fissile materials. However, the nuclear industry is typified by large capital projects with long lead times that are subject to considerably public and political consultation process. Accordingly, even though balancing supply and demand is the objective of all modern manufacturers, in the context of the uncertainties of a global nuclear market it may be difficult, in some countries, to achieve it. It is unlikely that supply and demand in the nuclear fuel cycle will always be in balance. Similar constraints and uncertainties are resulting in the accumulation of large stocks of spent fuel held in interim storage pending a final decision on disposition.

5.5.2. Geological Disposal

Closing the nuclear fuel cycle by direct disposal of spent nuclear fuel makes difficult the diversion of nuclear materials for harmful purposes.

For the conditioning phase and the final disposal of spent fuel, safeguards considerations must be taken into account at an early stage with full cognisance that, as the fuel ages, its radioactivity decreases and the fissile material loses a major layer of inaccessibility. If the fuel is retrieved, then the fissile material could be separated by reprocessing.

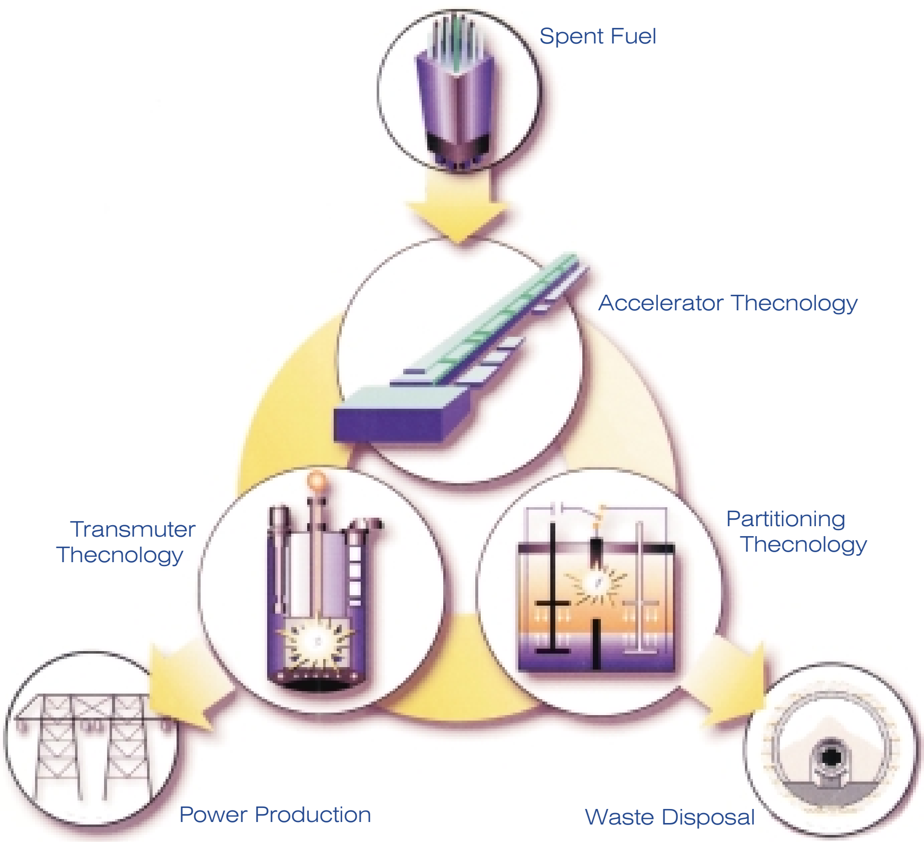
The second report of the IAEA Working Group on "Principles and Criteria for Radioactive Waste Disposal" addressed the topic of nuclear material safeguard related to the long timescales requiring consideration in safety assessment of radioactive waste repositories. The report concludes that it may be necessary to continue safeguarding spent fuel, even after it has been emplaced in a deep geologic repository but with much less effort involved to do so. The duration of such safeguards should be decided by future generations and will depend upon the future development of society. It is possible that safeguarding of nuclear materials may continue to be high priority for hundreds of years or millennia. The report notes that the requirement for open-ended surveillance contradicts ethical considerations of radioactive waste disposal by imposing a burden on future generations, and would also involve costs which cannot be reliably estimated.

5.5.3. Partitioning and Transmutation

Reprocessing is a technology that can be used to recover fissionable material for nuclear weapons manufacture. On the other hand, the recycling that follows on reprocessing would lead to the burning of more fissionable material in nuclear reactors under more controlled conditions than does direct disposal in deep repositories.

P&T activities would increase the risk of spreading technology that could be used for production of nuclear weapons material. It is expected that the non-proliferation regime, created by the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

Components of a Partitioning and Transmutation System (DOE, USA)



and extended indefinitely in 1995, will continue to provide in the foreseeable future a major basis for the required nuclear development necessary for P&T.

Safeguards and physical protection techniques are likely to continue evolving in order to keep pace with developing technologies and political evolution, on the basis provided by existing agreements. Moreover, safeguards should evolve in parallel with new technologies, and it is reasonable to expect that the new technical processes involved in P&T technologies will be safeguardable as earlier technical processes have been.

6. Social and Political Issues

6. Social and Political Issues

The decisions made in the course of a waste management programme vary in that they are the responsibility of different groups (politicians, implementors, regulators and general public). The decisions that are the responsibility of technical specialists and managers within an implementing organization, and the regulatory bodies that oversee their activities, are likely to require technical arguments that give confidence in the feasibility and long-term safety of the proposed concepts.

Non-technical stakeholders (political decision-makers and the public) also require confidence in the technical aspects of the waste management development, but this confidence may be based on less technical, more qualitative arguments. In addition, the wider audience of scientists, politicians and the general public require confidence in non-technical aspects of waste management development and must agree on the implementation process.

The difficulty in assessing the different alternatives lies in the long life span of the project, making it hard to evaluate matters far into the future. This concerns particularly the social effects, which also depend on future generations, their decisions and the practical measures taken. On the other hand, any changes of attitudes taking place in society, particularly in attitudes towards nuclear power in general, can influence the social environment and especially approval of both the geological disposal and P&T alternatives.

6.1. Political Acceptability

National governments need to define both a policy that outlines the principles under which SF and HLW will be managed in a safe, environmentally sound, and cost-effective manner, and a clear decision-making process. The government also needs to ensure the organizational, financial and regulatory arrangements to carry through the policy.

6.1.1. Extended Storage

From a political point of view, the selection of the extended storage alternative may be the easiest decision to be taken but it is not per se and it does not assure any future solution to the management of the nuclear fuel cycle' back-end.

Although the extended storage alternative would include the follow-up of other new developments such as P&T, it would still need at some stage geological disposal. This is because the HLW produced as a result of reprocessing or nuclide partitioning would almost certainly have to be finally disposed of in a geological repository.

6.1.2. Geological Disposal

Geologic repository programs in a number of countries face a potential loss of political will and momentum resulting from a desire to avoid the politically difficult steps required to develop geologic repositories, fed by growing public concerns about taking irreversible steps and by the seductive promise of technologies such as transmutation

Deep geological disposal may be implemented in a stepwise manner, with well-defined stages interspersed with decision points that allow opportunities for technical, regulatory, policy and, public review.

Geological disposal must pass not only stringent technical and environmental safety requirements but also the test of political and, for sure, social confidence. Decision making in stepwise approach to the repository planning and development should be based on:

- general agreement regarding the ethical, technological, political and economical aims of the geological disposal option,
- confidence in the organizational structures, and legal and regulatory framework for the step-by-step approach to repository development, and
- confidence in the technical feasibility and long-term safety of geological disposal.

Repository planning and development should include some degree of flexibility. Any repository programme should respond to:

- new technical information regarding the site and design,
- new technological developments relevant to SF and HLW management,
- changes in political and social conditions and acceptance, and
- changes in regulatory guidance, or even, basic safety standards.

A flexible approach should allow reversibility in repository planning and implementation. Therefore, the geological repository should be designed in such a way that future attempts to change the repository or retrieve the waste should not be impaired. However, a decision to reverse should consider (i) the resources already invested, (ii) an assessment of the political, social, and technical impacts and confidence, and (iii) the financial cost.

It may be appropriate to consider strategies for extending the time between emplacement of waste and closure of a repository, and to regard an underground repository in a deep geological formation as a monitored, retrievable HLW storage facility, until sufficient societal confidence can be developed and the repository closed.

In summary, several countries appear to be converging on a similar approach, which involves continuing the development of repository programs while providing for longer retrievability periods (to deal with concerns about irreversibility), supporting some research on alternatives such as P&T, and using stepwise processes for repository development.

6.1.3. Partitioning and Transmutation

In the course of a long-term nuclear programme, there might be a gradual shift from LWR-UO_2 fuel to LWR-MOX fuel to be followed by the introduction of FRs in the NPP park and by the use of accelerator-driven systems. Obviously, this option demands a political commitment with the continued use of nuclear energy for P&T.

P&T is a long-term venture that faces different institutional challenges such as siting new nuclear facilities, long-term funding, etc. Furthermore, it needs long lead times and requires large investments in extension of reprocessing plants, construction of remotely manipulated fuel and target fabrication plants, and dedicated fast neutron spectrum devices (FRs and ADSs that may complement or substitute the operating LWRs).

6.2. Public Acceptability

Public perception, confidence and acceptability are not specific issues to radioactive waste management but also to the broader acceptance of nuclear power as part of the future energy mix. Furthermore, the “public” is not a homogeneous group, and its various components and the concerns they have need to be better identified and understood.

A scrutiny and openness approach will help to ensure the technical adequacy and credibility of any waste management program, and to enhance public confidence in the scientific basis and management of the program.

Public acceptance of a national plan for the management of SF and HLW is essential and it has to be achieved at the local level (i.e. close to potential repository sites), as well as within the country as a whole. As mentioned before, after a lengthy period of reflection, with the opportunity to consider what may be unfamiliar concepts in an unhurried manner, the public will be in a position to make a well-balanced and informed decision. An appropriate information strategy during this period will help to establish credibility for the disposal concept.

The decision-making process involves representatives of the technical community and competent authorities at the national level, decision-makers at local and regional levels, and representative of various public interest groups.

Openness and transparency in decision-making are necessary in order to gain public trust, but they are not in themselves enough. Mechanisms must be used to include groups representing a wide spectrum of views, in decision-making. This open process is required to ensure that ethical and social considerations are properly taken into account, necessitating, therefore, a broad range of participants in the process.

6.2.1. Extended Storage

Extended, or even indefinite, storage on surface is favoured by those who consider it a preferred means of isolation, who reject geological disposal as unsound and unproven, and who wish to leave future generations the freedom to develop better methods for managing wastes in the very long term.

A reconsideration of the merits of a strategy of extended storage is under debate. However, this option has not been the subject of much R&D and no countries with major nuclear programmes have adopted indefinite storage as a SF and HLW management strategy.

6.2.2. Geological Disposal

Public perception, confidence and acceptability have been most critical in gaining approval for development of repositories for SF and HLW at specific sites, which raises the question of how to achieve confidence with a non-specialist audience regarding the ethical, economic, political and technical aspects of disposal projects.

The public does not feel familiar with the idea of a repository and is afraid to take irreversible decisions. Immediate backfilling/grouting of the caverns when emplacing the waste is perceived by the public as being an irreversible decision (despite assurances that the waste could also be retrieved in such a case). Therefore, measures such as an appropriate information strategy as well as a stepwise approach towards constructing the repository, which could be designed with a flexible approach to allow for retrieval for several hundreds of years, would enhance public confidence.

All national geological disposal programmes recognise the need for such procedures, notably to allow the communities affected by the selection of specific sites to be consulted and to participate appropriately in decision-making.

6.2.3. Partitioning and Transmutation

Multiple partitioning or recycling needs additional facilities, partly at least comparable to current MOX facilities. Financing and public acceptance is more than questionable. Furthermore, financial limitations and probably missing public acceptance could be also foreseen for the required park of FRs and/or hybrid systems, even for subcritical facilities. In addition, the necessary timescales and investments regarding transmutation technologies are for decades and possible changes in societal attitude are unpredictable.

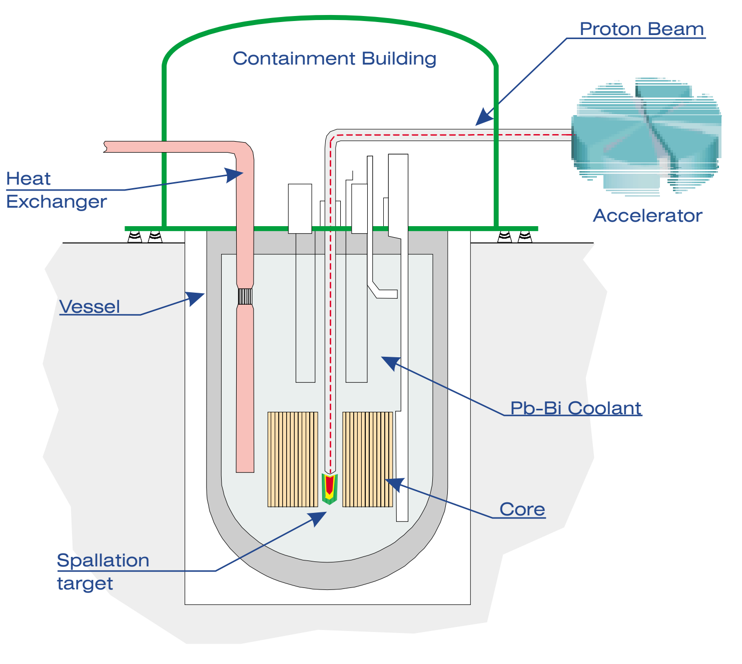
6.3. Complementarity among Options

6.3.1. Extended Storage/Geological Disposal

Geological repository should not only be considered by itself, but within the radioactive waste management system as a whole.

There is a spectrum of possible actions which could follow for the management of SF and HLW, from "early disposal" in a deep repository to indefinite

Conceptual Accelerator Driven System



surface storage. In an early disposal strategy a repository would be constructed as soon as a suitable site could be found and the repository would be finally sealed. In some cases, this strategy may not have sufficient flexibility and may not provide enough opportunities to build technical and societal confidence. A strategy of indefinite storage on the surface relies too heavily on human intervention and societal stability over many centuries.

The strong preference could be for a phased approach to geological disposal, in which wastes are stored on the surface whilst a site is found and a repository is constructed, and then emplaced in a repository in such a way that they can be monitored and the wastes in principle be retrieved. The repository would be kept open while data are accumulated from the monitoring and from additional research and the decision-making process is brought forward. When there is sufficient confidence to do so the repository would be backfilled and sealed. Monitoring would then continue and it would still be possible to retrieve wastes.

6.3.2. Partitioning and Transmutation

The technical and scientific communities are unanimous in their view that P&T technology would not eliminate all nuclear waste. Even if it were at all possible, it would in any case be extremely expensive to destroy all radionuclides. It should also be remembered that transmutation facilities, like existing reactors, would produce new radioactive materials (activation products) and medium and low level nuclear waste inevitably accumulates from losses during the partitioning process.

Whilst it is perhaps possible to shorten the lifetimes of nuclides contained in nuclear waste, it will never be possible to fully eliminate radioactive material, and extended storage or/and geological disposal facilities will always be needed.

7. Timing and Economic Issues

7. Timing and Economic Issues

7.1. Timing Perspectives for Development and Implementation

Time aspects enter into a SF and HLW management programme in different ways. One crucial question is whether today's generation has to solve the waste problem or whether the responsibility may be transferred in all or in part to future generations. This question ties in with the pace of technical development: Which technologies and methods will be available in the future? How can a programme that is devised today be flexible enough to adapt to new developments?

7.1.1. Extended Storage

Existing interim storage facilities can continue to be safely used for tens of years with relatively low service and maintenance.

7.1.2. Geological Disposal

There are differing views on how rapidly waste should be disposed of, and whether it should be disposed of irreversibly. Some argue that waste should be stored for several generations to allow scientists to learn more about geologic disposal and to take advantage of new and better technologies that may come along such as future technological advances that may be able to neutralise the waste. Long-term monitoring would keep all options open for future generations, but it would also require them to bear all the costs of exercising those options.

The timing of the incremental process leading to the emplacement of the waste, which in many national programmes would not occur until well into the next century, is another important element of any geological disposal strategy. The main successive phases of this process consist of conceptual and technological development, site-screening, selection of a site, surface and in-situ characterisation studies, construction and operation of an underground facility and, eventually, sealing of all the accesses, dismantling of surface installations and closing of the facility to leave it in a passively safe state.

Each phase of this long sequence will last many years, if not decades, and will be subject to public debate and close scrutiny by the regulatory authorities, who will have to be satisfied with the results obtained before giving authorisation to proceed to the next phase.

A decision to implement the deep geological disposal does not mean that actual final disposal would start forthwith or even within the next few years. A fairly long research period would precede actual construction work and the operations would start only after a couple of decades. In any case, separate licenses will be required to both build and operate the facility. The main question is whether to progress with preparations for final disposal: how important is it in view of the safe management of spent nuclear fuel if the decision is made to proceed with research and planning work or if the decisions are postponed?

7.1.3. Partitioning and Transmutation

Although there has been considerable progress in P&T development over the past ten years, it remains true that P&T is a long-term venture. The development and application of P&T would be, with a view towards time and costs, much more likely in a scenario with continued use, renewal and possible expansion of the nuclear energy.

New impetus has been imparted to P&T research by the development of Accelerator Driven Systems (ADS) which provide high neutron fluxes suitable for transmutation. Such systems may be more effective for this purpose than existing nuclear reactor designs although they are still many years from industrial scale application. Good progress has been made with the separation of actinides and long-lived fission products from HLW, using both aqueous and non-aqueous processes.

The introduction of P&T will require long lead times and large investments in dedicated fast neutron devices, extension of reprocessing facilities, and remotely operated facilities for fuel and target fabrication. All this is feasible only in the context of a strong programme that includes fuel reprocessing.

P&T is more likely to be implemented in future decades as part of a radically new type of fuel reprocessing, probably pyrochemical, rather than as an extension of the current aqueous (PUREX) reprocessing. However, pyrochemical reprocessing of spent fuel reactor fuels remains to be demonstrated on an industrial scale.

This view reflects a broad international consensus that P&T is a technique to be incorporated into future cycles, rather than a technique which can be applied to historical wastes. If new power stations were planned at any time in the future, then P&T would merit serious consideration as part of an integrated energy and waste management strategy.

7.2. Costs and Funding

The cost of radioactive waste management is very high but, however, only amounts to a few percent of the value of the electricity production that has given rise to the waste. Costs are dominated by the management of the high-level wastes. On the basis of the current estimates, the total costs of radioactive waste management are dominated by the cost of encapsulating and disposing of the high-level wastes, whether in the form of vitrified high-level wastes from reprocessing or unreprocessed spent fuel. The corresponding costs for other waste categories are in many programmes typically a factor of 10 lower.

Most countries seek to finance costs on the principle of "waste producer pays". Application of this principle is intended to ensure that the nuclear operator makes proper provision for dealing safely with the waste and the costs are passed on to those who benefit from the electricity that gives rise to the wastes, through the price they pay for the electricity. This is relatively easy to achieve for short-term operations, which can be financed directly from operating income. Longer-term operations require special funding provisions that allow for the longer period between waste generation and disposal, as well as taking into account the uncertainties and the precise nature and timing of the activities concerned.

The overall funding of waste management activities is likely to involve a combination of several financing methods –direct contributions, payments to waste management agencies, loans, and the establishment of funds to cover long-term commitments.

The main reason for developing special solutions to the funding of long-term management operations is ultimately a concern for the safety of future generations, providing a reasonable assurance that adequate funds will be available to implement the necessary technical and institutional actions as and when required.

In practice, the funding method varies from country to country, depending on the waste management strategy selected and on how nuclear programmes develop. Extended storage of spent fuel or HLW, even for a period exceeding 50 years, should not give rise to real financing problems provided it is set up fairly quickly after production. The costs of maintaining such stores, even over long time periods, are too small to create financial difficulties. Nor should disposal in a deep underground repository present any serious financing problems provided the repository is in existence or could be established within a relatively short period. The possible costs of surveillance of such repository, even for periods of a 100 years or more, would again be low enough to cause financial difficulty.

On the other hand, the disposal of VHLW or spent fuel after a long period of storage poses different questions. This time between the generation of the waste and its disposal would be far too long to consider direct participation by the nuclear operators who actually generated the wastes in the costs of moving the wastes, and constructing and operating the disposal sites. Moreover, particularly if nuclear programmes are stopped, there is also the possibility that the responsible organizations themselves will no longer exist.

7.2.1. Extended Storage

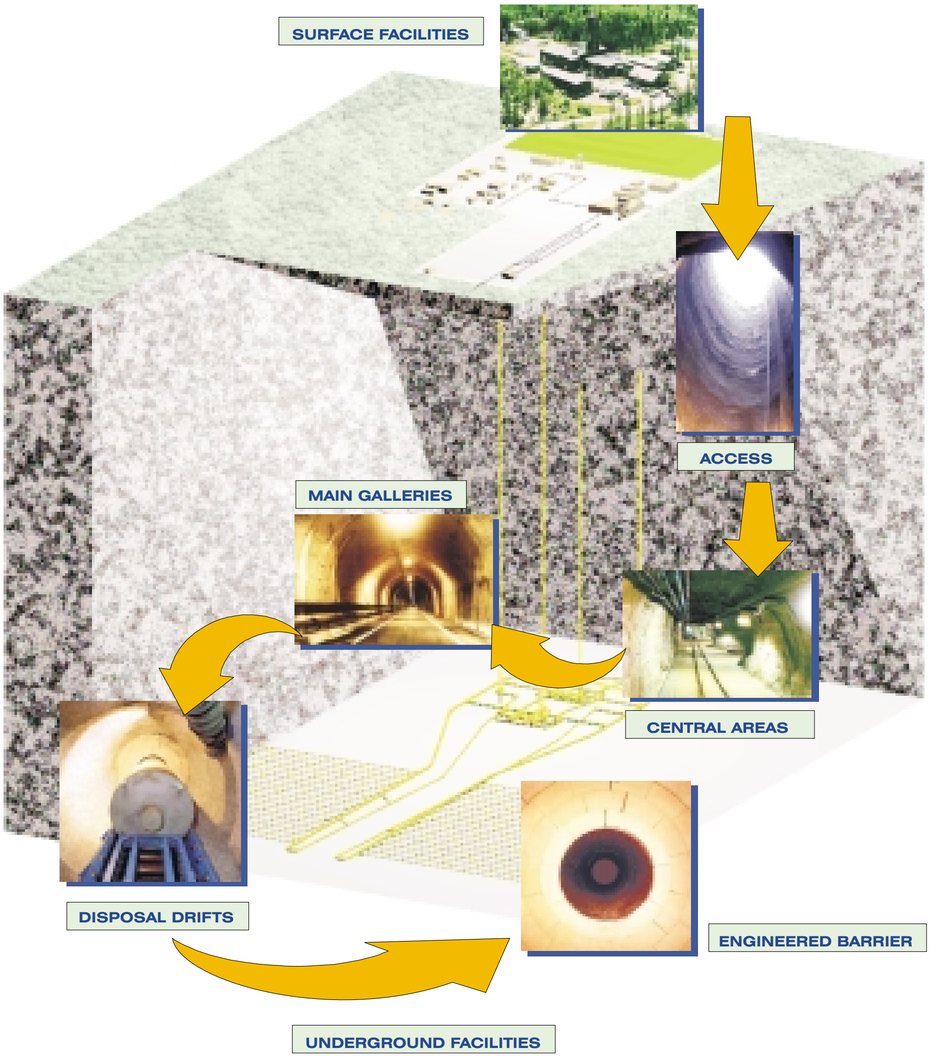
Opting now for interim storage facilities, which are less expensive than deep repositories, can give apparent financial savings due to standard accounting practices. However, the costs of repository construction are postponed, not avoided and the continuing uncertainty in the liabilities associated with far future disposal is a financial disadvantage. In addition, in time the costs of continuous storage would probably exceed the cost of deep geological disposal.

7.2.2. Geological Disposal

Financial pressures that affect the whole nuclear-fuel cycle, (e.g. resulting from deregulation of the electricity market) may tend to favour short-term goals (storage), at the expense of long-term objectives (disposal).

In particular, even though at the technical level, a wide acceptance has been achieved that deep geological disposal represents a safe and ethical path, (i) short-term economic factors may tend to favour delaying final disposal, and (ii) political factors may tend to favour the proposition of indefinite or very-long term surface storage of all types of long-lived waste.

Conceptual Deep Geological Disposal



The monetary and material resources are available today to implement deep disposal of nuclear materials. The nuclear power stations, which are the source of much of the wastes, are still producing electricity and revenues; the will and the resources to remove excess weapons materials both exist. Furthermore, the human knowledge and experience required to design, implement and operate repositories has been built up at great cost; this capability should be used for the present programmes of disposal development and not allowed to wither away.

7.2.3. Partitioning and Transmutation

Regarding P&T, there is the need for long-term financing of basic research for large scale partitioning and burning (neutronics, chemical behaviour, core designing) with uncertain outcome. The additional facilities for multiple partitioning or recycling and the required park of FRs and/or hybrid systems, even for subcritical facilities, will impose financial limitations to P&T technologies because the timescales and investments are for decades.

The cost of P&T are of course very difficult to calculate with any certainty before it has been decided which approach will be used. In the USA a total life-cycle cost of about $280B ($2B R&D, $9B demonstration, and $270B post-demonstration design, construction, operation, and decommissioning) has been estimated to treat 87,000 tonnes of commercial spent fuel. Over the lifetime of ATW plant operations, much of the capital, operational, and development and demonstration costs may be offset by the sale of electricity.

However, when the time value of money is considered, this offset may be small. A total processing time of 117 years is needed, of which R&D (initial 8 years) and demonstration comprise the first 27 years, and post-demonstration period activities comprise the following 90 years.

8. Summary Tables

8. Summary Tables

Summary Table on SF and HLW Management Options

Issue	Extended Storage	Geological Disposal	Partitioning and Transmutation
Ethics	Options for dealing with SF and HLW are not foreclosed, but it passes responsibility for real action to future generations, which are burdened with societal, technological and financial risks.	The generation that benefited from the activities that produced the SF and HLW bears the financial and political costs and provides the future generations with a solution.	A further step in the back-end of the nuclear fuel cycle to be developed and implemented by future generations.
Technology	Technology is available. No major showstoppers are envisaged.	Technology is being developed. Extensive international research programmes and co-operation. No major showstoppers are envisaged.	The technology is at the early stage of development. It faces great technological challenges.
Safety	Safety requires active control and human care of the storage facilities. Long-term safety is vitally dependent on human actions.	Low doses predicted very far into the future. The uncertainties in projecting long-term performance and the prediction of future events are two major issues.	It would entail a further reduction of a relatively small, perhaps only hypothetical, risk to workers far into the future. The exposure risk in the present or in the near future would increase appreciably due to the complexity of the fuel cycle.
Safeguards	Safeguards are not an issue in the short or medium-term.	Disposal prevents the diversion of nuclear materials for harmful purposes because it is arduous, costly and easily discernible.	Increased risk of spreading technology that could be used for production of nuclear weapons material.
Society	The easiest decision to be taken from the political and sociological points of view.	Loss of political will and momentum. Increase of public scrutiny resulting in delays in repository development.	A political commitment with the continued use of energy is demanded. Public acceptance is more than questionable by the required additional nuclear facilities.
Economy	Favoured by short-term financial pressures. It does not avoid the cost of repository development and create financial uncertainties	Monetary and material resources to implement geological disposal are available today.	A long-term venture, which faces institutional challenges and requires long lead times and large investments.
Timing	It is not per se a long-term definitive solution and it does not assure any future solution to the spent fuel and HLW management.	A convergence is observed on: ❑ a stepwise process interspersed with decision points for technical, regulatory, policy and public review, and ❑ a flexible approach to facilitate the reversibility in repository planning and implementation.	Current unanimity in considering that: ❑ it is not a short-term alternative but it could be incorporated into future cycles in a scenario with continued use of nuclear energy, ❑ it might reduce the volume and the radiotoxic inventory of the HLW to be managed , and ❑ it would not avoid geological disposal.

Assessing the SF and HLW Management Options: Ethical Issues

	Extended Storage	Geological Disposal	Partitioning and Transmutation
Responsibility	The options of the future generations for dealing with radioactive waste are not foreclosed. It gives decades to further develop the final disposal methods and to consider any change of plans. Continued care and maintenance of the facilities by the future generations is required for the protection of public health and safety. Protection could be compromised by the long-term risks arising from social circumstances. Postponing decisions will not end the SF and HLW management issue.	It provides the future generations with a solution Continued care and maintenance of the facilities for the protection of public health and safety is not required. The generation that benefited from the activities that produced the radioactive waste bears the financial and political costs. Future generations would not have to undertake any measures to protect their health and the environment.	A further step in the back-end fuel cycle to be developed and implemented by future generations. It could reduce the hypothetically possible future consequences of unforeseen events. A deep geological disposal is also required.
Sustainability	Fissionable material remains and must be monitored. Future generations can recover the spent nuclear fuel for economic reasons if they so choose. Major deficiency related to the presumption of stability of future societies. Risk of societal breakdown. Unethical because it passes responsibility for real action to future generations.	A significant amount of slightly enriched uranium and plutonium are lost in the event of SF direct disposal whenever means to retrieve the wastes are not foreseen. The present generation doesn't pass responsibility for real action to future generations. A step-wise approach can be implemented allowing future use of the site. The location of the deep repository may have implications for future use of the site.	More efficiently utilisation of energy resources (U and mainly Pu) in fast-breeder reactors and in accelerator-driven systems. It matches with the awareness in society about conservation of resources, environmental impact of the exploitation of natural resources, and long-term protection of the environment. The development of new technologies could improve the possibilities to use nuclear fuel reserves. A continued use of the nuclear energy in the future is required.

Assessing the SF and HLW Management Options: Scientific and Technological Issues

	Extended Storage	Geological Disposal	Partitioning and Transmutation
Status of technology development	Spent fuel storage is a mature technology in the back-end of the fuel cycle. Interim storage of spent fuel is and will remain an important activity of the nuclear fuel cycle. Wet storage continues to predominate as an established technology and the primary method for storing most LWR fuel. Data exists for continuous pool storage of spent fuel for more than 30 years. Dry storage has become a mature technology and the quantities being emplaced are beginning to increase significantly. Almost 20 years of experience with dry storage of spent fuel are available.	Considerable experience over the last 30 years has been accumulated in investigation techniques for: ❑ repository siting, ❑ repository construction techniques, ❑ waste transport and emplacement methods, and ❑ long-term behaviour of the disposal system. Core research is being carried out by complex research programmes in underground laboratories. Extensive international programmes and co-operation are underway to improve performance assessment methods and models.	Spent fuel reprocessing is a proven technology that is offered commercially. Hydrometallurgical processes for minor actinides separation are becoming a known technology making upscaling to prototype pilot facilities possible. Pyrometallurgical processes, being less mature, are facing a renewal of interest. Transmutation involves a multitude of aspects (e.g. fuel and target fabrication and irradiation tests, reactor physics and nuclear data, safety studies, plant development, etc.) which need to be further cleared up before major projects can be started. Technology is at a very early stage of development. There exist significant uncertainties regarding industrial feasibility.
Future challenges	Aspects to be confirmed: ❑ Effects of extended fuel burnup on the behaviour of the stored fuel. ❑ Extrapolation of results for very long storage times has yet to be confirmed.	Further R&D oriented to the refinement of: ❑ constructional and operational technologies. ❑ process modelling and calculation methods for repository performance assessment and safety assessment. Major role of underground laboratories in a stepwise approach to repository development	Management of separated plutonium is a major challenge. The proven PUREX technology is unlikely to be replaced, although some modifications and improvements may be introduced. Moreover, partitioning technology requires extensive research and development before it can be ready for industrial application. Most of the R&D work is related to: ❑ the development of the appropriate fuels (basic properties, fabricability, irradiation), ❑ the development of consistent chemical processes, and the experimental validation of the data and methods used in the physics analysis aimed to an eventual design of a dedicated transmutator. A number of proposals for ADS applications have been presented and, some of them, are being investigated to reach in the future the status of demonstration plant. Requirements for the accelerator reliability are far away from current performance.

Assessing the SF and HLW Management Options: Safety and Licensing Issues

	Extended Storage	Geological Disposal	Partitioning and Transmutation
Waste arising and radiotoxic inventory	All radionuclides contribute to the source term. The long-term radiotoxic inventory is mostly due to Pu, MAs and some LLFPs. Increased storage time will result in cooler wastes for disposal	All radionuclides contribute to the source term The long-term radiotoxic inventory is mostly due to Pu, MAs and some LLFPs. Environmental doses due to I, Cs and Tc could be important.	The removal of MAs and LLFPs from HLLW might reduce the residual radiotoxicity of the HLW. P&T may alleviate the long-term radiological impact by reducing the waste volume and the initial radiotoxicity to be stored. Production of additional secondary wastes due to the increased complexity of the fuel cycle.
Operational safety and doses to workers of associated facilities	Annual radiation doses to the workforce and the general public during the lifetime of the facility would be very small. Collective doses will increase as result of the longer period of storage and the likely activities of refurbishment and repackaging. Additional doses to operators in case of society disruption, abnormal events or major accidents.	Annual radiation doses to the workforce and the general public (for normal operation and assuming normal evolution of the disposal system) during the lifetime of the facility would be very small. The risk of human intrusion and the doses to workers are greater the longer the facility remains open.	The risk of exposure in the present or in the near future would increase appreciably due to a great increase in the handling of short-lived radioactive materials and the complexity of the fuel cycle. Additional partitioning/recycling leads to additional doses and risks.
Impacts on long-term safety	The safety requires active control and maintenance of the storage facilities. Long-term safety is vitally dependent on human action. Commitment by future generations to continue using resources to take care of the facilities is required. Risk of societal breakdown.	A crucial issue is how to deal with the uncertainties in projecting long-term performance and how to increase confidence in our future predictions. Very low doses very far in the future.	It would entail a further reduction of a relatively small, perhaps only hypothetical, risk far into the future. Calculated releases from a repository with the resulting HLW residues show very similar peak doses to the ones produced by LWR fuel.
Surveillance and monitoringrequirements	Storage facilities are vulnerable to long-term degradation, future intrusion, abandonment and mis-use. Continuos human care and control are required.	The safety of a repository should not be reliant on monitoring or intervention. It is not viable to use monitoring to gain radiological evidence for validation of repository performance. It may be appropriate to regard an underground repository in a deep geological formation as a monitored, retrievable HLW storage facility until the repository is closed.	The required additional facilities should be subjected to strengthened surveillance and monitoring requirements due to the nature of the materials to be managed in the partitioning or recycling facilities and in the transmutator devices.
Impacts on Proliferation risks	Spent fuel have no direct military value but it must be safeguarded. Safeguards could be affected by the future development of the society.	Direct disposal of spent nuclear fuel prevents the diversion of nuclear materials for harmful purposes, because it should be arduous, costly and easily discernible. A requirement of open-ended surveillance impose a burden on future generations and an additional cost.	Separated plutonium must be safeguarded. Reprocessing is a technology that can be used to recover fissionable material for nuclear weapons manufacture. Increased risk of spreading of technology that could be used for production of nuclear weapons material.

Assessing the SF and HLW Management Options: Social Political Issues

	Extended Storage	Geological Disposal	Partitioning and Transmutation
Political acceptability	It could be the easiest decision to be taken but it is not per se and it does not assure any future solution to the SF and HLW management.	Loss of political will and momentum resulting from a desire to avoid the politically difficult steps required to develop geologic repositories. A convergence is observed on: ❑ a stepwise process for repository development interspersed with decision points for technical, regulatory, policy and public review, ❑ a flexible approach to facilitate the reversibility in repository planning and implementation.	Renewal of interest for partitioning and transmutation of MAs and some LLFPs. A long-term venture, which faces institutional challenges and requires long lead times and large investments in additional facilities. It demands a political commitment with the continued use of the nuclear energy.
Public acceptability	Favoured by those who reject geological disposal as unsound and unproven, and who wish to leave future generations the freedom of managing wastes.	Public perception, confidence and acceptability are critical in gaining approval for repository development at specific sites. Increased public scrutiny has resulted in delays in the repository development. Growing public concern about taking irreversible steps suggest the need to develop a stepwise and flexible approach to repository construction aimed to gain public confidence.	Public acceptance is more than questionable for the required additional nuclear facilities for multiple partitioning or recycling as well as for the required park of fast reactors and/or hybrid systems.
Complementarity among options	It could include the follow-up of other developments, e.g. partitioning and transmutation. At some stage it would still necessitate a final disposal alternative because it is not a long-term definitive solution.	It could include the follow-up of other developments, e.g. partitioning and transmutation. The strong preference could be a phased approach to geological disposal, in which wastes are stored in surface, whilst a site is found and a repository is constructed, and emplaced in a monitored and retrieved way. The underground repository could be regarded as a monitored, retrievable HLW storage facility until sufficient confidence is developed to close the repository.	Current unanimity in considering that P&T will not eliminate all the HLW. At some stage it would still necessitate coming back to a final disposal alternative, because the resulting final wastes coming from the partitioning/recycling processes and the transmutation facilities have to be stored and eventually finally disposed of.

Assessing the SF and HLW Management Options: Timing and Economic Iissues

	Extended Storage	Geological Disposal	Partitioning and Transmutation
Timing perspectives for development and implementation	Interim storage facilities can be safely operated for tens of years. Interim storage facilities are not intended as a final solution.	The incremental process leading to waste emplacement will last many years, if not decades. A decision to implement geological disposal does not mean that actual final disposal would start forthwith or even in the next few years	P&T is a technique to be incorporated into future cycles in a scenario with continued use, renewal and possible expansion of the nuclear energy.
Costs and funding	Apparent financial savings due to standard accounting practices. In time, the costs would exceed the cost of geological disposal. The costs of repository construction are postponed not avoided creating a financial disadvantage due to continuing uncertainty in the liabilities associated with far future disposal.	Not favoured by short-term financial pressures. The monetary and material resources are available today to implement geological disposal of spent fuel and HLW. Knowledge and experience required to design, implement and operate repositories has been built up at great cost	Costs are very difficult to calculate with any certainty. Timescales and investments are for decades which impose financial limitations with uncertain outcomes.

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