

The Economics of the Back End of the Nuclear Fuel Cycle

Executive Summary

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Executive summary

Objectives of the study on the economics of spent nuclear fuel management

Of all civil radioactive waste generated by various industries (including medicine, agriculture and research), the largest portion comes from nuclear power generation and related fuel cycle processes. Only a small part of this is high-level waste (HLW), consisting by and large of packaged spent nuclear fuel (SNF) or HLW from reprocessing.

The feasibility and costs of SNF management and consequent disposal of the ultimate waste continue to be the subject of public debate in many countries, with particular concerns often being raised about the slow progress in implementing final disposal for civilian HLW.

In some cases, very large estimates are given for future waste management and disposal costs, ranging up to many tens of billions of dollars. In a few instances, these high estimates have a large component for the costs of clean-up and waste disposal from military nuclear facilities, although they are often quoted without this caveat. Claims have been made at times that costs for SNF/HLW management are completely unknown and that, consequently, there is no accurate way to establish the size of funds or assess their adequacy.

Several studies on SNF/HLW management costs have been carried out in individual countries, but they inevitably reflect national policy choices and practices, and hence their results are not directly comparable with those of other countries. In addition, many useful reports have been produced, describing national waste management approaches or making suggestions on how to analyse disposal costs. Of particular note is the extensive effort being undertaken by the Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency (NEA). Since 1975 the RWMC has provided a platform for international co-operation in the management of radwaste from nuclear installations (including long-term waste management and facility decommissioning) – a neutral forum for policy makers, regulators and implementing organisations to discuss state of the art and emerging issues, and develop solutions that meet the diverse needs of its participants. Through its wide-ranging programme of work the committee helps to establish a common ground for national regulatory frameworks, to share and advance best practice (e.g. by supporting international peer reviews) and to contribute to progress on scientific and technical knowledge (e.g. through joint projects and specialist meetings). Current subjects addressed by the RWMC span among disposal issues, including safety case preparation and licensing of geological repositories, decommissioning and societal confidence. Comprehensive country reports and/or country profiles have been compiled and are regularly revised and made available online.

These materials have formed a broad base of reference for the present study, which, nevertheless, takes a different but complementary approach to that of the RWMC. It provides:

- A review of the cost estimations undertaken in NEA member countries, together with an assessment of processes for the establishment and management of funds.
- A high-level assessment of the costs of the full cycle and its components, in the case of three idealised strategies (current and potential) for managing the back

end. This assessment includes a sensitivity analysis, which helps to identify the principal cost drivers for the economics of the back end.

The report does not analyse or reproduce the details of the costing approach used in individual countries or their project management process, nor does it make judgments on the appropriateness of costs derived within a specific national context. Moreover, given the distinctive features and needs of specific national programmes, the results of the cost assessment cannot simply be transposed to individual countries without a more detailed and adapted cost analysis. The analysis presented here aims to assist policy makers in OECD/NEA member countries who have specific responsibilities for making strategic choices about back-end options and for ensuring the adequacy of the funding.

In 2011, the OECD/NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) established the Ad hoc Expert Group on the Economics of the Back End of the Nuclear Fuel Cycle to conduct the study and mandated it with the following specific objectives:

- To understand economic issues and methodologies for the management of SNF in NEA countries, including the funding mechanisms in place or under consideration, how the funds are managed and the extent of any unfunded liabilities.
- To assess the available knowledge from different countries on the costs of the various options for the long-term management and final disposal of radioactive waste, and, to the extent possible, compare the cost estimates of different countries on a common basis.
- To evaluate, in particular, the impact of uncertainties, e.g. variations in cost estimates for SNF interim storage, reprocessing, encapsulation, and final disposal.

It has been noted that considerable volumes of legacy waste have been accumulated in some countries from earlier activities, primarily of a military nature. While it is recognised that legacy waste clean-up may entail substantial costs, this study does not attempt to address the issue, since the information obtained was insufficient to make a comprehensive analysis.

Conclusions from the study are given in the boxes outlined in each section, while recommendations are brought together at the end of this summary.

Current status and progress of national policies and programmes

All the waste deriving from the SNF management must be managed safely and in a manner that protects humans and the environment, taking into account a broad and complex range of issues, sometimes interrelated: science and technology, safety and environmental protection, non-proliferation and safeguards, economics and finance, and ethical and societal aspects.

In addition to HLW, short-lived and long-lived low- and intermediate-level radioactive waste is generated at all stages of the fuel cycle.¹ In countries with a sizeable fleet of nuclear power plants (NPPs), considerable experience is available on waste and materials processing, conditioning, storage, transport and disposal of low- and intermediate-level waste (LILW). In many countries all steps have been implemented on a commercial scale for their management. However, in some cases there are still issues related to special types of radioactive waste (e.g. mixed waste and graphite) that require further consideration. Technological developments remain to be achieved in the future, but they are not expected to strongly influence LILW management options.

1. For the back end, long-lived low- and intermediate-level radioactive waste is derived almost exclusively from reprocessing.

Industrially available options for SNF management

For the long-term management of SNF, two major options have been adopted commercially to date:

- Direct disposal, where the fuel is used once and is then regarded as waste to be disposed of.
- Partial recycling, where the spent fuel is reprocessed to recover unused uranium and plutonium for recycling in light water reactors, in the form of reprocessed uranium oxide (REPUOX) and mixed-oxide (MOX) fuel, respectively. Irradiated MOX and REPUOX bundles can be either stored (with the perspective of their reprocessing and recycling in future fast reactors – FRs) or disposed of after encapsulation.

Advanced systems and fuel cycle concepts for the longer-term future have been studied theoretically or on a pilot scale, principally with the dual objective of reducing the mass and radioactivity of waste destined to final disposal and optimising the use of natural resources. However, the deployment of fast neutron systems and associated advanced fuel cycles (FCs) will still require increased investment and the development of new infrastructures for advanced systems and processes, as well as significant adaptation efforts, including in legal and regulatory frameworks. The first commercial Generation IV systems² are not likely to be available before the 2030s, and they are not expected to become a major part of installed nuclear capacity until well after 2050.

A number of countries with major nuclear programmes operate or have plans to develop reprocessing and fuel fabrication facilities, and some have the capacity to also provide these services to other countries (currently, however, only France and the Russian Federation offer continued services to other countries). Some 10% of reactors worldwide have been licensed to use MOX, and uranium recycling is being carried out by a few reactor operators on a limited scale. With the significant experience accrued to date, plutonium and uranium extraction (PUREX), reprocessing and MOX recycling can be regarded as mature technologies. Continuous advancements in the PUREX process have led to a decrease of solid waste volumes, effluents and consequential environmental impacts, while MOX fuel performance has matched the performance record of uranium oxide (UOX) fuel.

Regardless of the specific strategy adopted, the final disposal of HLW or SNF (treated as HLW in the once-through fuel cycle) is the ultimate stage of the fuel cycle. There is general agreement that deep geological repositories (DGRs) offer the best solution in this regard. The development of advanced fuel cycles (including those which use accelerator driven systems) could also significantly reduce the amounts of SNF and HLW to be disposed of. However, the need to manage residual actinides (from losses) and fission products (FP) will remain since the process is not completely efficient. There will still, therefore, be a need for disposal facilities, although they could be smaller and/or fewer in number. Hence, progress towards implementation of DGRs remains a high priority for the future use of nuclear energy.

Both industrial fuel cycle options, direct disposal or partial recycling, as well as any prospective advanced option, will ultimately require an operational repository for final disposal. The major difference in the deep geological repository needed for the different options will be in relative size.

2. www.gen-4.org/Technology/evolution.htm.

Long-lived solid radioactive waste and SNF have been safely and securely stored in NEA countries for several decades now. In most cases, interim storage facilities were initially designed to operate for periods up to 50 years, but extended intermediate storage is becoming an increasingly adopted practice, and operational periods of 100 years or longer are being considered. This is sometimes due to the long time frames needed for the deployment of final repositories, but can also be considered as a strategic choice. In a few cases, political and societal hurdles have challenged the establishment of a national strategy for spent nuclear fuel, with significant policy shifts over time. Other factors can also influence continued long-term storage, including for example the small volumes of waste accumulated in the country, difficulties with transport or site selection, or inadequacy of available funding. By prolonging spent fuel storage, fuel cycle options are kept open and further study and consideration can be given to alternatives, before reaching a final decision on a national strategy. However, longer-term interim storage gives rise to questions related to the long-term integrity of fuel elements, which is raised as a concern by the public.

Progress in DGR implementation

While there is one operational deep geological repository, the Waste Isolation Pilot Plant (WIPP), in the Delaware Basin of New Mexico, which has been receiving military transuranic radioactive waste for permanent disposal since 1999, no civilian DGR for SNF and HLW from NPPs and their FCs has yet been built in the world. However, national legal and regulatory frameworks and programmes are in place in many countries for the implementation of the necessary steps in SNF/HLW management. Three DGRs are expected to become operational in the next decade so as to provide disposal for SNF (in Finland and Sweden) and HLW and LILW from reprocessing (in France). In other countries, longer time horizons are envisaged, spanning from two to many decades. Countries where the most significant advances in disposal programmes have occurred are generally those with a long-term continuity in policy positions.

Waste Management Organisations (WMOs) have been established in most NEA countries. WMOs are generally separate non-commercial entities that can hold various responsibilities, from the centralised collection of SNF/waste and the related processing capabilities to the final disposal. They can be either state-owned organisations or organisations that are owned by the waste producers. Their responsibilities require a combination of attributes: technical capability, accountability and, ideally, organisational stability and political independence, as well as the ability to negotiate with relevant stakeholders and elicit consent, primarily for DGR siting.

Stakeholder engagement at the different stages of programme implementation is crucial to the success of DGR implementation, and stepwise approaches that foster partnerships with potential host communities are increasingly favoured, resulting, in some countries, in improved public acceptance. Specific studies have also addressed societal issues (at the international level, e.g. various reports by the NEA as detailed in Section 2.3.3, and at the national level, e.g. the 2005 Iribarne's report published in France³).

Advances have occurred in national programmes for HLW and SNF disposal. Conditions favouring progress include the maturity of the industry, the long-term continuity in policy positions and a high degree of emphasis on community partnerships in the implementation of strategies.

3. www.ladocumentationfrancaise.fr/var/storage/rapports-publics/054000355/0000.pdf.

Funding and costing

Most countries perform assessments of the costs for SNF/HLW management, encompassing the different stages of the back end (e.g. interim storage, encapsulation, transport). Factors influencing such costs are manifold and often country specific (e.g. different physical and technical conditions, individual national regulations, economic conditions and the different itemisation, boundary conditions and inclusion of costs). Thus, variations of cost estimates obtained in different countries can be quite large, and comparisons between assessments are very difficult.

Assessments of the costs for managing spent fuel and radioactive waste from the civil fuel cycle are essential to establish the size of liabilities and guarantee their financing. Cost assessments are performed regularly in most countries, encompassing the various stages of the back end. However, differences across individual assessments can be quite large, making direct comparisons very difficult. Variations are attributable to disparate factors including differences in assumptions, technical solutions and national conditions.

Much of the expense for managing SNF and HLW can appear long after electricity and revenue generation has ended. Hence, it is important that future waste management costs are estimated and funds are accrued to adequately cover these costs when they arise. Funding systems have been established in most countries, in line with existing international instruments⁴ and agreed principles. The waste producer is generally held responsible for accumulating the funds, in accordance with the “user/polluter pays” principle. The most common mechanism of accrual is through the revenues obtained from electricity generation. The fees and levies are accumulated in internally or externally managed funds.

The established financial arrangements cover most existing liabilities. Nonetheless, there is considerable variability in the level of funds accumulated in different countries, with no harmonised, generally agreed approach to funding arrangements and to developing the cost estimates upon which funding must be based. It should, however, be noted that the estimation of the future cost is only one component in the determination of the funds required. Other important (and not always predictable) factors include the real rate of return of the funds, scheduling of expenditures and the remaining NPP operational lifetime over which fees can be levied.

As the costs for reprocessing and recycling are normally incurred while the reactors are still in operation and can thus be seen as a part of the operational cost, no segregated funds are mandated to cover such costs on a legal basis. However, in practice, operators establish funds dedicated to reprocessing.

Expenses for disposal will appear over extended periods, with much of the expenditure occurring long after power production and income from electricity generation have ceased. It is important that appropriate financial arrangements are established and that the accrual of adequate and available funds for the eventual implementation of the selected back-end strategy is carefully pursued.

Owing to the long time frames and technical developments required, calculations of back-end costs are subject to significant uncertainties and potential changes. As more accurate knowledge of costs is gained through further progress in the implementation of

4. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and the Euratom Council Directive 2011/70.

programmes, uncertainties should gradually diminish. To help ensure continued fund sufficiency and to address changes, cost estimates and funding requirements are updated at regular intervals, taking into account new technical knowledge and actual fund developments.

Cost estimates for future facilities, including repositories, entail many uncertainties, which will only be reduced as experience is gained in implementing the necessary infrastructure.

To verify continued fund sufficiency and to address changes, cost estimates and funding requirements are generally updated at regular intervals, taking into account new technical knowledge and actual fund developments.

Ring-fencing of funds is also required in order to ensure that funds are only used for the intended purpose. Although segregation of funds is generally pursued by most national legislations, this has not always been the case in every country.

Generally, legal requirements also require that funds should be managed in a low-risk manner, for example, by depositing them in the national account, investing them in government bonds or following a financing strategy established by a designated body. Even these “safer” options, however, do not entirely protect against the financial uncertainties and the instabilities of national economies, as experienced in recent times, which exacerbates the challenges faced by countries. Should unfunded financial liabilities arise (e.g. following bankruptcy of the operator and its parent companies), it is always the state that ultimately remains responsible. Sometimes additional measures are taken to provide further safeguards to the state.

To secure the availability of funds, ring-fencing is required so that resources accrued are only used for the intended purpose. Segregation of funds is pursued by most but not all countries in their national legislations. Some funding systems contain further inbuilt features to minimise risks; for instance, in some countries securities and guarantees may be requested from nuclear operators to protect against unforeseen developments.

Theoretical cost analysis for selected SNF management strategies

One of the primary aims of this study has been to assess the available knowledge from different countries on the costs of the various options for the long-term management of spent nuclear fuel and, to the extent possible, compare the cost estimates of different countries on a common basis. However, owing to major differences and specificities in individual national contexts, a direct cross-country comparison of SNF/HLW management costs was not considered to be feasible in the study. Instead, simulations of generic and theoretical cases for idealised systems were performed based on the cost information provided and through the development and application of a high-level static model. The input data used in the calculations (generally provided by the members of the experts group for their respective countries) were those available at the time when the analysis was performed (end of 2012). However, national cost assessments are subject to continuous reviews and refinements, and since that time some countries have updated (or are revising) their estimates. Although these new estimates were not incorporated, changes in absolute values of some input data are not expected to significantly alter the main outcomes of this analysis, which essentially aims to identify principal cost drivers and not to determine precise absolute values.

The evaluation of the cost for the total fuel cycle (including both the back-end and the front-end components, so that the use of recycled materials and the resulting savings in the requirements of fresh uranium can be taken into account for recycling options), and the breakdown of these costs, as well as a sensitivity analysis of costs associated with the management of spent nuclear fuel from light water reactors (LWRs), were performed for three assumed generic strategies:

- Open or once-through FC, with direct disposal of spent nuclear fuel.
- Partial recycling or twice-through FC, where REPUOX and MOX are recycled once in LWRs and then disposed of.
- Multiple plutonium recycling with LWRs and fast reactors (FRs). This strategy includes single MOX and REPUOX recycling in LWRs and multiple plutonium recycling in FRs.

In addition to parameters defining the system (size of the nuclear fleet, mass flows), the key input data used for the calculations were overnight investment costs and operation and maintenance costs for the various fuel cycle facilities in each strategy (largely based on the country data obtained by means of a questionnaire). All calculations have been performed assuming that all nuclear reactors operate for 60 years, and that all the back-end facilities are constructed exactly at the time when they are required, with no delays.

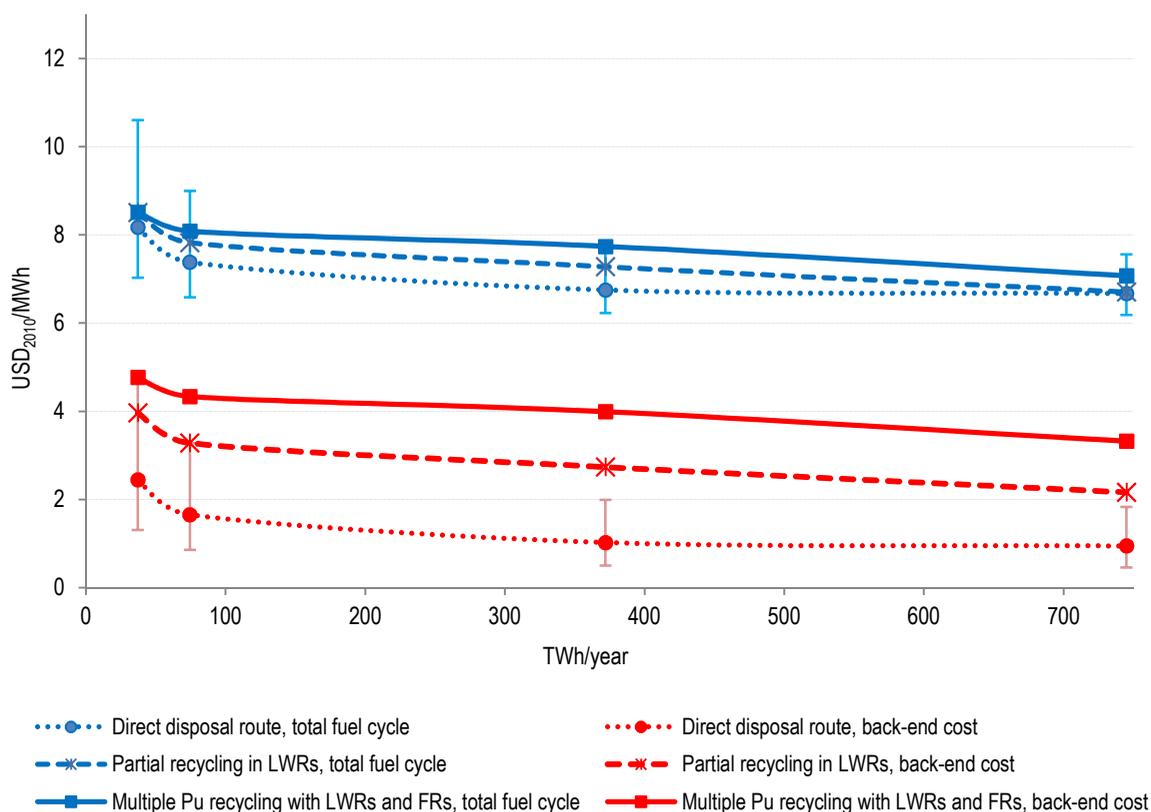
Since low discount rates are more realistic for long-term public benefit projects, the levelised fuel cycle costs were calculated for 0% and 3% real discount rates. The results of the calculation of the levelised cost of the fuel cycle, its detailed breakdown and its sensitivity analysis for the three strategies were performed for different system capacities (from 25 TWh/year to 800 TWh/year – see Figure ES.1). The following general observations can be drawn from the results obtained:

- In all strategies considered, the fuel cycle cost component associated with the management of SNF represents a relatively small fraction of the total levelised costs of electricity generation. For example, the historical cost of electricity generation in France was estimated by the Cour des Comptes at about USD 60/MWh. According to the results of this analysis, the total fuel cycle cost then would represent less than 13% and the back-end cost would be about 6.5% of this historical cost. However, even these small fractions could translate into large absolute costs depending on the size of the nuclear programme and the period of electricity generation. .
- The total fuel cycle costs calculated are lower for the open fuel cycle option, but differences between the three options considered are relatively small and, for this analysis, within the uncertainty bands. These are influenced by the uncertainties regarding input data and by the assumed discount rate. In the recycling options, additional costs from reprocessing are being offset by the savings on fuel costs at the front end. .
- For small systems, fixed costs are more dominant, so costs rise disproportionately as the system size decreases. .
- Since the specific costs decrease with the size of the system, there may be economic benefits in sharing different fuel cycle facilities between countries and/or utilities.

The results of the FC cost calculations performed show that costs calculated for the open fuel cycle option are lower than for the other idealised options assessed. Differences among the three options in the total fuel cycle component of the levelised costs of electricity are, however, within the uncertainty bands, given the uncertainties around some input data. For the recycling options, additional costs from reprocessing are being offset by the savings on fuel costs at the front end. Differences are more noticeable if the back-end component of the fuel-cycle cost is considered in isolation, since the offsetting effects are not taken into account.

It is important to note that, for all options assessed, the FC cost component associated with the management of SNF represents a relatively small fraction of the total levelised costs of electricity generation. However, these differences could translate into large absolute costs depending on the size of the nuclear programme and the period of electricity generation.

Figure ES.1: Total fuel cycle and back-end levelised costs for different reactor fleets and strategies, 3% discount rate*



* Uncertainty bands are only plotted for the direct disposal case. Similar bands apply to the other options.

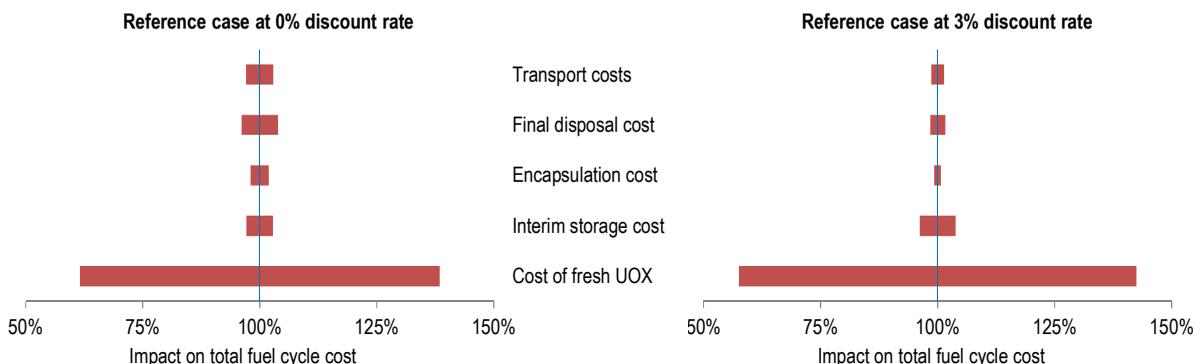
A sensitivity analysis (see Figure ES.2) has been performed in relation to the cost of the fresh UOX fuel, costs of different fuel cycle facilities, the discount rate, the cost premium for fast reactors and the implementation schedule (for the direct disposal strategy):

- Although the uncertainties regarding the future costs for DGR are considerable, in absolute terms, the impact on the total fuel cycle cost is fairly small. As shown in Figure ES.2, a 50% increase in DGR costs (which in absolute terms would be a large sum for larger nuclear programmes) gives rise to an increase in the total fuel cycle costs by a few percentage points.
- In contrast, the total cost of the nuclear fuel cycle strongly depends on the cost of fresh UOX fuel, which in turn depends on the prices of natural uranium, conversion and enrichment services, and fuel fabrication costs. Given uncertainties in the input data, it is difficult to accurately estimate the UOX price which renders one or the other strategy more economical. Advanced recycling options will only be economically advantageous if the price of UOX fuel (and thus the price of natural uranium, enrichment services, etc.) increases significantly from the current values. This would imply an even greater increase in the prices of natural uranium. For example, in the analysis of a system of 400 TWh/year and at a 3% discount rate, the *multiple Pu recycling in LWRs and FRs* would become attractive if the cost of fresh UOX was ~50% higher than those assumed as the reference in the calculation. This corresponds to prices of natural uranium of about USD 270-300/kgU (for unchanged prices of other front-end services such as enrichment), which is more than 100% higher than the reference assumption on the cost of natural uranium defined in this study.
- In both the recycling strategies considered in this study, the second largest sensitivity after the cost of UOX is the cost of reprocessing.
- The fuel cycle cost of the most advanced option, *Multiple Pu recycling with LWRs and FRs*, is also sensitive to the FR cost premium.⁵ The results obtained for the reference cost scenario suggest that this advanced option would be more economical than the direct disposal route only if the FR cost premium is low (i.e. if FRs and LWRs have comparable capital and operating costs).
- Overall, the uncertainties related to the full recycling option remain the largest since only sparse data are available for these systems and no commercial system is in current operation.
- A sensitivity analysis with respect to the implementation schedule was performed for the direct disposal of spent nuclear fuel strategy, assuming delays of 20 and 50 years in the construction of the SNF encapsulation facility and DGR. Delays in the implementation of such facilities lead to extended interim storage of the SNF, and thus the escalation of the back-end component of the fuel cycle cost if using a zero discount rate. However, with positive discount rates, delays lead to lower back-end costs. The impact of delays is significantly smaller than the uncertainty band on the back-end costs. This simple analysis does not take into account the possible increased degradation of SNF due to longer interim storage, which would lead to a further increase of undiscounted back-end costs.

5. Fast reactors are expected to be more expensive than LWRs, thus a special cost premium for their construction and operation has been introduced. This extra cost is attributed to the back-end component since, in *Multiple Pu recycling with LWRs and FRs* strategy, the fast reactors are considered as a means for managing the SNF.

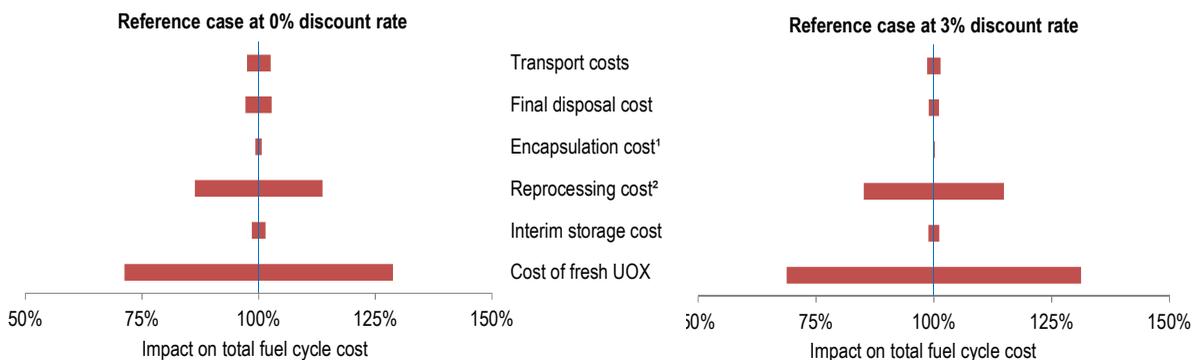
Figure ES.2: Impact on the total fuel cycle cost of ±50% change in costs, for a 400 TWh/year system

Direct disposal route



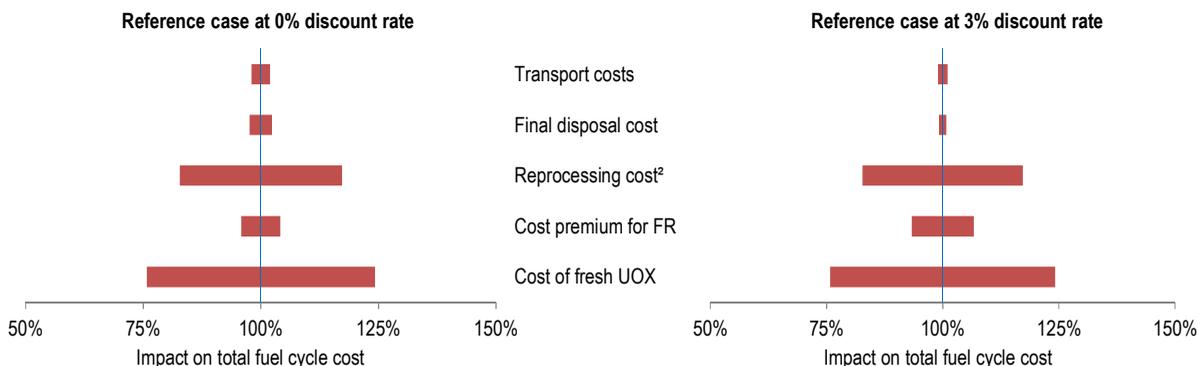
Partial recycling in LWRs

Twice-through (REPUOX and MOX) and disposal of the spent MOX and spent REPUOX



Multiple Pu recycling with LWRs and FRs

MOX and REPUOX recycling once in LWRs and multiple plutonium recycling in FRs



1. Encapsulation of spent MOX and REPUOX.
2. Reprocessing of SNF, MOX fabrication and HLW vitrification.

Sensitivity analyses show that in all three strategies, the total fuel cycle cost is most sensitive to the cost of fresh UOX fuel, which encompasses the price of natural uranium and enrichment services. Other influential factors are:

- interim storage and deep geological repository costs in the direct disposal strategy (though a 50% increase in deep geological repository costs, which in absolute terms would be a large sum for larger nuclear programmes, gives rise to an increase in the total fuel cycle costs by a few percentage points);
- the cost of reprocessing in both recycling strategies;
- the fast reactor cost premium for the multiple plutonium recycling option.

Advanced SNF management options would be economically advantageous only if UOX fuel prices were significantly higher than current values and if FR cost premiums were low.

The assessment conducted in the study is a high-level analysis for idealised systems. Its purpose is to understand the major impacts on back-end costs of the different options and, more specifically, to identify the cost drivers. However, the assessment cannot be simply transposed into a specific national context. This would require a more detailed and adapted cost analysis. In addition, we noted that the cost uncertainties related to the full recycling option are greatest, since this strategy is furthest from commercialisation.

Economics is only one of many factors influencing the decisions regarding SNF management options. It is clear that any evaluation of the comparative merits of the different back-end options will need to be considered in the specific contexts of individual countries and would not be taken purely on economic grounds. A number of qualitative factors may have an important or decisive impact on any decision making regarding back-end options for the nuclear fuel cycle. Some of these factors are discussed in the report. This multi-criteria approach is important in evaluating the relative importance of the various factors in any national context.

Alongside economic considerations, different qualitative factors come into place in the selection of back-end strategies. These encompass:

- political issues, like security of supply and non-proliferation;
- issues of an administrative, governmental infrastructural or social nature, like regulation, safety, public attitudes and transport; along with
- more technical aspects, like environmental protection, retrievability, waste production and future technological developments.

The relative importance of these elements is intricately linked to specific national contexts and may shift over time, so that different factors may outweigh others in different countries and priorities may change with time.

It has been noted that, whatever the determining factors of a national back-end policy are, any significant shift in policy has the potential to induce considerable additional costs, which may even become dominant in the economics of any fuel cycle. This was the case with the added cost of the once-through fuel cycle in the United States, due to the cancellation of the Yucca Mountain project.

Recommendations

The following recommendations from the Ad hoc Expert Group were endorsed by the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) and the Radioactive Waste Management Committee (RWMC). The numbering here follows the order used in Chapter 5:

1. While there may be reasons to extend the interim storage of SNF, these should not prevent governments from maintaining vigorous efforts towards the establishment of deep geological repositories, thereby addressing legitimate public expectations and fulfilling the “intergenerational equity” principle.
2. Public involvement in the establishment and implementation of the SNF management strategy is considered vital, and mechanisms to improve stakeholder participation and transparency should be a high priority.
3. Governments should continue to be vigilant in ensuring that the funding systems adopted are stable and robust and that financial resources accrued by waste producers for the management of their waste will be adequate and available at the time they are needed. The following features are considered essential:
 - Regular and frequent reviews to allow for newly accrued knowledge on technical aspects and actual fund developments, as well as other qualitative factors (e.g. sociopolitical), to be taken into account and for emerging shortfalls to be swiftly addressed through the necessary corrective actions.
 - Ring-fencing of funds to ensure that resources are only used for the intended purpose.
4. For countries that are committed to the ongoing use or development of nuclear energy, comparisons of the costs of different strategies for managing the back end should be drawn on the basis of the full fuel cycle cost. For countries that are phasing out or have already exited nuclear power, a direct back-end cost comparison may be more appropriate. In all cases, assessments made for total or partial FC cost comparisons should be transparent about the assumptions made and the scope of the analysis.
5. In any decision-making process regarding the choice of an SNF management strategy, a multi-criteria approach should be adopted at the national level that expands the quantitative economic considerations to include qualitative factors. These can have an important (or even determining) influence in the final decision and may also have a direct impact on the costs.
6. Where issues of long-term fuel supply and reduction of waste volumes are particularly important (e.g. in countries with larger nuclear programmes) R&D on advanced nuclear systems, including FRs, should be supported by governments, since their implementation holds the potential for enhancing the long-term sustainability of nuclear power, notably in relation to management of waste. In this context, further engineering and cost analyses will be important to reduce the uncertainties in the costs of implementing advanced fuel cycle options.
7. International co-operation and sharing of experience for safe, reliable and economic implementation of back-end strategies should continue. Given the significant economic costs and expertise required for their realisation, sharing FC facilities and infrastructure would especially benefit countries with small nuclear programmes.

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The Economics of the Back End of the Nuclear Fuel Cycle

The feasibility and costs of spent nuclear fuel management and the consequent disposal of ultimate waste continue to be the subject of public debate in many countries, with particular concern often expressed over the lack of progress in implementing final disposal. Uncertainties about back-end costs and the financial risks associated with management of the back end have also been singled out as possible deterrents to investment in new nuclear power plants.

This report offers an appraisal of economic issues and methodologies for the management of spent nuclear fuel and high-level waste from commercial power reactors. It includes a review of different back-end options and current policies and practices, with a focus on the cost estimates for these options and the funding mechanisms in place or under consideration in OECD/NEA countries. A generic economic assessment of high-level estimates of back-end cost impacts on fuel cycle costs is undertaken for selected idealised scenarios, by means of a simple static model. Sensitivity analyses are conducted for the evaluation of uncertainties in major components and the identification of cost drivers. Since factors other than economics are an important part of the decision-making process, an analysis of the influence of key qualitative parameters in the selection of back-end strategies is also presented in this report.