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Ensuring the Adequacy of Funding Arrangements for Decommissioning and Radioactive Waste Management

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Nuclear Technology Development and Economics

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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Foreword

This study by the OECD Nuclear Energy Agency (NEA) consists of three parts: a conceptual framework, twelve country case studies on funding arrangements prepared in collaboration with NEA countries, and some best policy guidelines. The study focuses on the interdependency of costs and funding requirements on the one hand and changes in nuclear policy, such as long-term operation (LTO) or premature shutdowns, as well as technological progress on the other hand. The basic approach is to frame the question of the adequacy of funding arrangements in terms of the transparency, flexibility and political sustainability of the overall institutional set-up rather than in pure accounting terms, where assumptions about discount rates, which are often ad hoc, are usually the only decisive parameter.

The project proposes, in particular, to complement current approaches to assessing financial adequacy, which are based on the linear discounting of estimated future costs for decommissioning and waste disposal, with a circular approach. In the latter, the elements of funding arrangements continuously adapt as new information on costs, social preferences, policy objectives, lifetimes or rates of return on existing assets becomes available. The question of the adequacy of funding for decommissioning and waste disposal thus evolves as it allows changes in parameters.

This approach also includes a somewhat broader interpretation of the Polluter Pays Principle (PPP), which is based on a partial equilibrium framework in which causalities are obvious, parameters are fixed and "damages" can be quantified and monetised. Drawing on an established body of work in the field of Law and Economics on risk management and liability distribution, there will be some reflection on the optimal allocation of ultimate responsibilities with regard to the back-end of the nuclear fuel cycle. Said literature holds, for instance, that responsibilities should always be allocated to the party best placed to reduce risks. Depending on the circumstances of each country, such considerations might lead to funding solutions that are different for decommissioning than for radioactive waste management or its subsets, such as spent nuclear fuel (SNF) management. Nuclear operators can usually manage decommissioning risks as part of their industrial activities. This might not always be the case for nuclear waste management, especially where deep geological repositories (DGR) are the preferred solution as timeframes are likely to exceed the lifetime of any individual operator. Of course, allocating ultimate responsibilities for radioactive waste management to a party other than nuclear operators, e.g. governments or special-purpose vehicles, does not imply absolving electricity producers and their customers from footing the essential part of final costs. Liability transfers necessarily imply a transfer of the funds to cover those liabilities. It might, however, also imply allocating residual risks that result from policy decisions or evolving social preferences to those parties best equipped to handle them.

The study finally explores the theme of incentive compatibility in the sense that funding arrangements should be cost-effective in the long term to make them more politically and socially sustainable in different OECD countries. Clearly, there is a wide range of solutions as national circumstances differ greatly both in economic and technical terms with respect to the historical allocation of responsibilities and social preferences.

The work to produce this report was undertaken under the oversight of the Working Party on Nuclear Energy Economics (WPNE) and the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC). Throughout the preparation of this report the authors regularly briefed the NEA Radioactive Waste Management Committee and its bureau and consulted widely with other international organisations such as the European Commission and the International Atomic Energy Agency (IAEA).

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The NEA Secretariat would like to acknowledge the essential contribution of the experts from NEA member countries to the 12 country case studies: Ms Chantal Cortvriendt (Belgium), Ms Pui Wai Yuen (Canada), Mr Roger Lundmark (Switzerland), Mr Jorma Aurela (Finland), Mr Benoît Lepouzé (France), Dr Fernando Oster (Germany), Mr Yu Nagai (Japan), Mr J.H. Shin (Korea), Mr Jesus Tardon Silvestre (Spain), Mr Peter Stoltz (Sweden), Mr Glenn Vaughan (United Kingdom) and Mr Bill McCaughey (United States). Together with their colleagues, they engaged in a comprehensive review process with multiple iterations of the country case studies and contributed also to the success of the concluding workshop held on 17 and 18 September 2020. The work was overseen by the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) under its Chair, Mr Patrick Ledermann, and the NEA Working Party on Nuclear Energy Economics (WPNE) under its Chair, Professor William D'haeseleer.

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List of abbreviations and acronyms

AECL	Atomic Energy of Canada Limited
AEPC	Atomic Energy Promotion Commission (Korea)
APM	Adaptive Phased Management
ASN	Nuclear Safety Authority (France)
ATI	Almacén Temporal Individualizado (Spain)
BAFA	Federal Office for Economic Affairs and Export Control (Germany)
BEIS	Business, Energy, and Industrial Strategy (United Kingdom)
BMF	Federal Ministry of Finance (Germany)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BWR	Boiling water reactor
CEA	French Alternative Energies and Atomic Energy Commission
CNSC	Canadian Nuclear Safety Commission
CPI	Consumer price index
DETEC	Department of the Environment, Transport, Energy and Communications (Switzerland)
DGR	Deep geological repositories
DOE	Department of Energy (United States)
DWMP	Decommissioning and Waste Management Plan
EC	European Commission
EDF	Electricité de France
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPRI	Electric Power Research Institute
ESG	Environmental, social and governance
FDP	Funded Decommissioning Programme
GRWP	General Radioactive Waste Plan
HANARO	High-flux Advanced Neutron Application Reactor
HLW	High-level radioactive waste
HPC	Hinkley Point C (United Kingdom)
IAEA	International Atomic Energy Agency
ILW	Intermediate-level waste
ISDC	International Structure for Decommissioning Costing
KAERI	Korea Atomic Energy Research Institute
KENFO	German Nuclear Waste Management Fund
KEPCO	Korea Electric Power Corporation
KHNP	Korea Hydro & Nuclear Power
KORAD	Korea Radioactive Waste Agency
LILW	Low-and intermediate-level waste
LLW	Level radioactive waste
LTF	Long-Term Fund
LTO	Long-term operation
MARR	Minimum acceptable rate of return
MEAE	Ministry of Economic Affairs and Employment of Finland

METI	Ministry of Economy, Trade and Industry (Japan)
MOTIE	Ministry of Trade, Industry and Energy (Korea)
MTF	Medium-Term Fund
NDA	Nuclear Decommissioning Authority (United Kingdom)
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Corporation (Japan)
NEA	Nuclear Energy Agency
NFWA	Nuclear Fuel Waste Act
NLF	Nuclear Liabilities Fund
NLFAB	Nuclear Liabilities Financing Assurance Board
NWMO	Nuclear Waste Management Organization (Canada)
NPC	Nuclear Provisions Commission
NPV	Net present value
NRC	Nuclear Regulatory Commission (United States)
NSCA	Nuclear Safety and Control Act
NSSC	Nuclear Safety and Security Commission (Korea)
NUMO	Nuclear Waste Management Organisation of Japan
NURO	Nuclear Reprocessing Organization of Japan
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
ONDRAF	National Agency for Radioactive Waste and Enriched Fissile Material (Belgium)
ONFA	Ontario Nuclear Funds Agreement
OPG	Ontario Power Generation
PDP	Preliminary Decommissioning Plans
PHWR	Pressurised heavy-water reactor
PPP	Polluter Pays Principle
PWR	Pressurised water reactor
RW	Radioactive waste
RWM	Radioactive waste management
RWMA	Radioactive Waste Management Act
RWMC	Radioactive Waste Management Funding and Research Center (Japan)
RWMF	Radioactive Waste Management Fund
SEFV	Swiss Federal Ordinance on the Decommissioning Fund and the Waste Disposal Fund
SIPP	Statement of Investment Policies and Procedures
SKB	Swedish Nuclear Fuel and Waste Management Company
SNDO	Swedish National Debt Office
SNF	Spent nuclear fuel
SNWF	State Nuclear Waste Management Fund
SSM	Swedish Radiation Safety Authority
STENFO	Decommissioning Fund for Nuclear Facilities and Waste Disposal Fund for Nuclear Power Plants (Switzerland)
STUK	Radiation and Nuclear Safety Authority (Finland)
SW	Special waste
TEPCO	Tokyo Electric Power Company (Japan)
TIPS	Treasury Inflation-Protected Securities
TVO	Teollisuuden Voima Oyj
VaR	Value at risk
VLLW	Very low-level waste
WKGT	Warth & Klein Grant Thornton
WLDC	Waste Disposal Centre
WMO	Waste management organisations
WTP	Waste Transfer Price

Executive summary

A new look at the adequacy of funding

This Nuclear Energy Agency (NEA) report proposes to take a new look at assessing the adequacy of funding arrangements for decommissioning and radioactive waste management (RWM). In particular, it argues that the "linear" approach that currently structures the conversation about the adequacy of funding systems should be complemented with a broader "circular" approach. In the former, all elements of the system are based on the discounted value of the estimated future costs of a specific technical solution. In the latter, the interdependent elements of funding arrangements continuously adapt to the extent that new information on costs, social preferences, policy objectives, lifetimes or rates of return on capital become available. The question of the adequacy of funding for decommissioning and waste disposal thus evolves in an adaptive and iterative manner that integrates changes in technical, economic and societal framework conditions. Broadening the conversation in this manner is particularly relevant to the long-term management and disposal of high-level radioactive wastes and spent nuclear fuel (SNF).[1]

This report is part of the Programme of Work of the Division of Nuclear Technology Development and Economics (NTE). It was prepared under the oversight of the Working Party on Nuclear Energy Economics (WPNE) and the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) and benefitted from numerous interactions with experts in NEA member countries. It consists of three parts: (1) a conceptual framework for financially and politically sustainable financing arrangements for the back-end of the nuclear fuel cycle, (2) twelve country case studies on funding arrangements prepared in collaboration with NEA member countries and (3) a synthesis of elements of good policy practice. In particular, the 12 case studies show that many NEA countries are already adapting their funding systems to changing realities. However, they do so in implicit and partial ways. The report aims precisely to provide the language and conceptual framework to consider such adaptations in a more explicit and systematic manner.

This work could not have been undertaken without the large body of work that exists at the NEA, the IAEA and elsewhere on the funding of activities in the areas of decommissioning and RWM and its challenges. In particular, the NEA has repeatedly dealt with the financing of those activities (see, for instance, NEA, 1996, 2003a, 2003b, 2005, 2006 and 2016b). In recent years, it has particularly focused on the estimation of decommissioning costs (see NEA, 2010, 2015, 2016a and 2017). This report builds on these earlier studies. However, its objective is not to provide additional advice on particular technical issues, funding schemes or cost estimates but rather to bring together much of this work and augment it with considerations drawn from the economic literature on efficient liability allocation in order to provide a framework for a broader discussion on the adequacy of funding for decommissioning and RWM. The "circular approach" to the adequacy of funding for decommissioning and RWM that this report is pursuing reflects, in particular, the fact that changes of different kinds will play out between today's decisions and future funding needs. Like the earlier work, however, this report emphasises the need to take into account the specificities of each member country in the design of sustainable funding systems.

1. This report refers to *radioactive waste* as short for spent nuclear fuel (SNF) and high-level radioactive waste. Low-level radioactive wastes and other wastes are not included in this analysis. In referring to radioactive waste management (RWM), the report does not make any judgement with respect to particular strategies, solutions and technologies. While national deep geological repositories (DGR) are considered the appropriate solution in NEA member countries, strategies such as extended interim storage, reprocessing and participation in multilateral repositories are also considered part of RWM.

Guiding principles and the Law and Economics approach

In order to advance towards a broader view of funding issues relating to decommissioning and RWM, the report has drawn inspiration from a branch of economics referred to as Law and Economics. This approach links general economic notions of efficiency and cost minimisation in a flexible and non-dogmatic manner to the working of institutions and the allocation of legal responsibilities. It is often concerned with the optimal allocation of responsibilities, the alignment of incentives and risk management.

Law and Economics aims to improve cost efficiency and welfare maximisation in a world characterised by complexity, asymmetries of information and risk. Concrete institutional circumstances and the evolution of decision-making processes through time all play an important role. It is thus appropriate for studying issues related to decommissioning and RWM as they are characterised by uncertainty, long timeframes, and changing political boundary conditions. Important questions that can be pursued under this approach include:

1. What are the current processes to realign funding requirements and costs to ensure robust adequacy over the long run as new information becomes available or new societal preferences or technical options emerge?
2. How are different risks, in particular fundamental residual uncertainty, dealt with? For instance, what is the role of funding institutions and governments if the electric utilities liable for funding in most countries go bankrupt or cease to exist? Long timeframes and fast changing electricity markets make this a far from hypothetical possibility. Political decisions to shut down reactors before their originally planned lifetime can pose comparable questions.
3. What are the incentives for cost minimisation? Do they differ between private and public actors? Are new technological and socially acceptable options regularly assessed? How can designing solutions towards available assets be avoided? Should it be avoided?
4. Is a narrow interpretation of the PPP ("owner-operators are liable for all costs") appropriate in light of the timeframes and the necessary social and political dimension of decision-making processes? What should be the specific responsibility of owner-operators and their customers in a somewhat wider interpretation?

The Law and Economics approach suggests that financially, socially and politically sustainable funding arrangements will need to be built on two fundamental guiding thoughts. First, the parties that are best capable of managing the costs and risks related to decommissioning and RWM should also ultimately be the ones responsible for funding. This includes the ability to choose between different options and to determine technological choices. For example, in no NEA country do nuclear operators, as liability holders, control the timing of RWM solutions, which is, of course, a crucial parameter in determining the adequacy of financing. If this suggests a higher degree of public involvement and, in specific circumstances, a broader reading of the PPP, this in no way implies releasing nuclear operators and electricity customers from their historical obligations. Any transfer of responsibilities would need to be accompanied by transfers of accrued funds and the rights to future revenue streams as well as by appropriate additional payments.

The second guiding thought is that decommissioning and even more so RWM concern commitments that stretch out far into the future for decades, possibly centuries. It is obvious that economic, political and technical framework conditions both on the asset and on the cost side will change over these periods. As long as commitments for disbursement are far away, maintaining a narrative of stable parameters can be a useful intermediate step to set up funding systems. However, as soon as real disbursements loom, the accuracy of estimates can no longer be taken for granted. In other words, funding frameworks will increasingly need to integrate the conscious and explicit management of change in a sustainable rhythm. Already today funding systems are regularly reviewed to check whether they satisfy particular financial requirements. Yet long-term sustainability also demands periodic reviews of the technical options and their likely costs, liability allocation and institutional arrangements.

Many existing frameworks in NEA countries already respect these two guiding principles to varying degrees. The adequacy of financing for decommissioning and RWM is a major issue that receives significant policy attention. The case studies show that sophisticated and by and large well-funded systems are in place and that much good work is being accomplished, although frequently in an ad hoc and implicit manner, rather than in a systematic and explicit one.

Why reconsider funding systems now?

This a good moment to discuss the adequacy of funding for decommissioning and RWM for at least four reasons. First, as the nuclear power fleet ages, many units will approach the end of their original operating licenses in the coming years with prospects for long-term operation (LTO) varying widely across NEA countries. In nuclear decommissioning, a large number of projects are already under way or will soon be coming on-line. In the area of RWM, large volumes of both inherited and future volumes of radioactive waste need to be disposed. As the issue is being addressed, several NEA countries are having their first experiences of building of deep geological repositories (DGR). Finland has begun construction of a DGR at its Onkalo site and is expected to begin operating the facility in the next few years. Sweden and France have selected sites and are testing conditions in underground laboratories. In both decommissioning and RWM, the world is moving from a state in which the disbursement of funds for projects was a vague future possibility towards one where it is a present reality. Funding systems that will need to mobilise billions, sometimes several tens of billions, of USD will thus be exposed to greater stress and higher scrutiny than in the past.

Second, changes in the macroeconomic environment are questioning many of the assumptions on which, until recently, discussions about funding were predicated. The economic fallout of the Covid-19 health crisis in 2020 and 2021 only highlights long-run trends that can put financial stress on funding systems. For more than a decade, the returns on many financial assets, in particular risk-free or low-risk assets, have been considerably lower than before. This holds, in particular, for government bonds, which in many countries have traditionally made up a large share of the low-risk assets used by the managers of the portfolios of the funds for financing decommissioning and long-term RWM. The idea that the compounding of stable positive returns over many decades will automatically ensure funding adequacy is no longer valid in a world where a sizeable portion of government bonds pays negative returns. The new macroeconomic environment thus requires the adjustment of discount rates and a reassessment of investment strategies, including a diversification of portfolios into new asset classes and the adjustment of risk exposure as disbursement approaches. Reinforcing the general theme of this report, it will also require broad societal agreement on the risk profiles of the funds for financing decommissioning and an understanding that all elements of the funding system may need to be considered for adjustments in order to align resources and liabilities.

Third, changes in funding arrangements are already under way today in a number of NEA countries. This partly reflects the changing macroeconomic context just mentioned, and introduces to differing degrees new arrangements of liabilities or potential solutions. One example is Germany, where in 2017 the liabilities for funding the long-term management of high-level radioactive waste was transferred from the operators of nuclear power plants to the Nuclear Waste Disposal Fund overseen by the federal government. In return, operators transferred all constituted assets plus a 35% surcharge to the Fund. Also in Belgium, Spain, Sweden and Switzerland discussions about the appropriate sharing of responsibilities are under way and funding systems are evolving. These issues are echoed in international fora such as the NEA, IAEA and European Union, where questions about the adequacy of funding systems are discussed with a renewed interest in the sharing of national experiences and mutual learning. However, these changes are taking place in an implicit and partial manner without reference to an overall conceptual framework. An important objective of this report is therefore to supply the conceptual references and elements of language that allow a discussion of these changes in a more explicit and more systematic manner.

Last but not least, decommissioning and, in particular, RWM remain highly sensitive issues in policy debates. While the potential role of nuclear power as a source of dispatchable low carbon electricity in greenhouse gas emission reductions is undisputed, some governments and critics express doubts about its long-term sustainability. This is currently visible in the discussions about a European Taxonomy for financial investments aspiring to be labelled as sustainable, notably so-called "green bonds". The debate about the inclusion or exclusion of nuclear energy is still ongoing but it currently turns on the "sustainability" of RWM.[2] While the most obvious concerns regard technical and environmental sustainability, financial sustainability is an indispensable requisite. Developing long-term RWM frameworks that are sustainable in all relevant dimensions is necessary to ensure that nuclear energy remains an integral part of the energy transition.

Differences between decommissioning and RWM

There are a number of common elements to ensuring the adequacy of funding for decommissioning or RWM, including high levels of public scrutiny and low returns on risk-free and low-risk investments. A closer look, however, reveals that their timeframes, the level of uncertainty regarding costs as well as the level of industrial maturity are quite distinct. These divergences warrant, in the majority of cases, somewhat different approaches. In particular, applying the principle of allocating responsibility to the party most likely to control the process and outcome of any definite solution may lead to very different solutions in the areas of decommissioning and RWM.

Decommissioning is fast becoming a scalable industrial activity. By April 2021, 192 nuclear reactors had been shut down, many of which are at different stages of decommissioning. The largest number of shut down commercial reactors are in the United States, the United Kingdom and Germany. Decommissioning has been fully concluded for 16 reactors, 13 in the United States and three in Germany (NEA, 2016a: p. 25-27). In the area of decommissioning, the required skill set, the profile of potential risks and the timeframes usually match the competencies and risk management abilities of operators as well as the time horizons of their shareholders. The relevant legal obligation, a return to greenfield, is well-defined and unlikely to change. Methodologies for cost estimation are being codified, inter alia at the NEA, experience is being gained and benchmarks exist. The United States is even seeing the emergence of a secondary market, where decommissioning liabilities are traded among industrial entities. While it is too soon to consider decommissioning a standard industrial activity, the evident codification and maturing of the industry suggest that transaction costs could decrease further and the market can ultimately be relied on to minimise both private and social costs.

This is much less the case in the area of RWM. In general, time horizons are far longer and more uncertain. Technological choices are also far more varied. While DGRs are identified as a final endpoint of RWM in many countries, this is a broad category, where individual projects differ widely. Costs will depend on the country, site, technology and timing, as well as on a number of options such as packaging, retrievability, etc. Due to the particular nature of RWM projects, a radical uncertainty prevails for which private enterprises are not very well equipped:

1. There is legal and regulatory uncertainty concerning solutions envisaged for a far-away future. This regards both long-term disposal and interim solutions such as extended interim storage.
2. There is added uncertainty about the costs even when technical options are well characterised due to constellations of bilateral monopoly or oligopoly with few pricing benchmarks.
3. Finally, there is uncertainty about the social preferences that will prevail during the run-up to and at the time of decision-making. The majority of NEA countries has not yet decided on a definite site for the final disposal of its spent fuel and radioactive waste.

In short, future choices in the area of RWM are currently not sufficiently well-defined to allow private actors to assess, manage and diversify the associated risks. In other words, market solutions are some way off and may never be realisable. This points towards a fundamental difference between the appropriate allocation of liability in the case of decommissioning and in RWM. As far as decommissioning is concerned, where technical solutions are relatively well-defined and timeframes consistent with the lifetimes of industrial projects, liability, including the liability for adequate funding, should indeed be allocated to the relevant industrial enterprises. Things are different in the

2. The Technical Expert Group on Sustainable Finance (TEG), which had advised the European Commission on which technologies to include in its Taxonomy, had not conclusively pronounced itself on nuclear energy. The Joint Research Centre (JRC) was thus invited to assess whether the long-term management of high-level radioactive waste and spent nuclear fuel was consistent with the "do no significant harm" (DNSH) criterion contained in Articles 17 and 19 of the EU Taxonomy Regulation. Its report unambiguously states that:

> "For high-level radioactive waste and spent fuel, there is a broad consensus amongst the scientific, technological and regulatory communities that final disposal in deep geological repositories is the most effective and safest feasible solution which can ensure that no significant harm is caused to human life and the environment for the required timespan (Joint Research Centre (JRC), 2021: p. 11)."

case of RWM, where solutions can be far out in the future or subject to evolving political and social preferences. In such a situation, economic theory would suggest turning in the opposite direction, namely integrating the definition of final objectives, technical solutions, funding and possibly even implementation under the responsibility of a single actor.

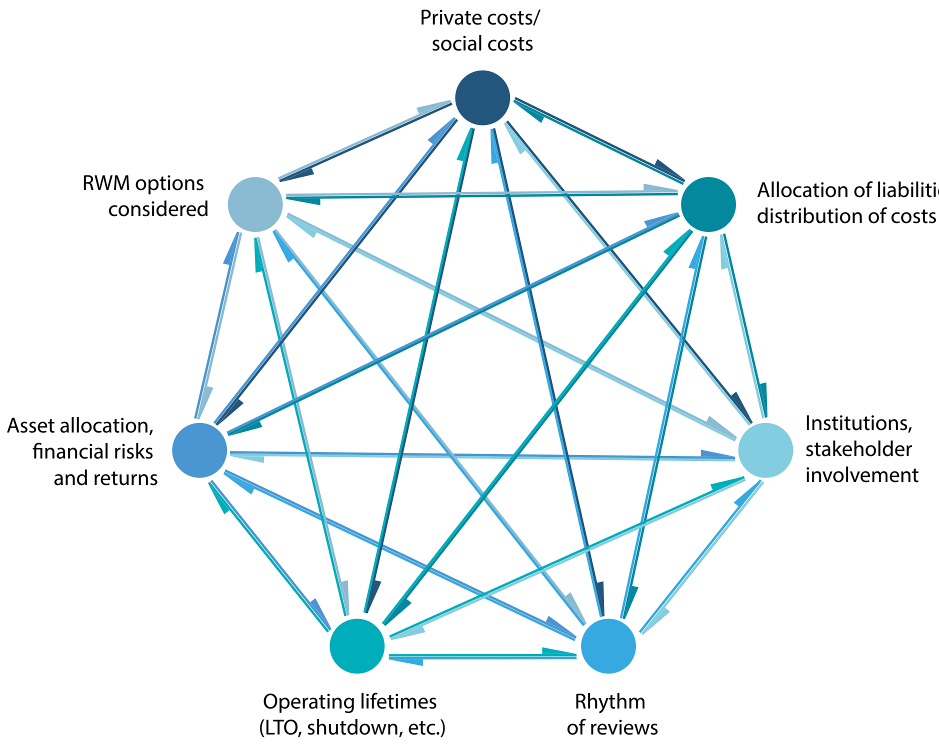
In the area of RWM, national governments seem to be the only credible actor capable of organising or overseeing the open-ended social processes leading up to the formulation of policies, which only over time will converge towards given technical solutions. In principle, if one day both social preferences, technical solutions and costs were sufficiently specified, different incentive structures could again be imagined. It is, however, difficult to conceive that the portion of RWM related to the treatment of high-level wastes and SNF could be fully extracted from the political realm.

From a linear to a circular approach in conceiving the adequacy of funding (including a special section on discounting)

Current approaches to the adequacy of funding for decommissioning and radioactive waste disposal typically use a simple linear decision-making framework based on the assumption that key parameters such as future costs, the discount rate, the return on capital or the operating lifetimes of nuclear power plants will remain stable for several decades. Frameworks that are more sophisticated will work with stochastic confidence intervals without abandoning the simple, one-directional logic of discounting assumed future costs to the present.

The present report instead proposes a circular decision-making framework, in which all elements of the system can vary, while continuing to feed into each other. Adequacy of funding is thus no longer defined by comparing estimated future costs, discounted by an assumed social discount rate, and accrued funds. Instead, the adequacy of funding is assessed by considering whether decision-making processes are capable of taking into account changes in key parameters in a manner that is sufficiently robust and sophisticated to align and realign them in different constellations. Such key parameters will include the envisioned technical solution and its costs, constituted assets and rates of return, as well as the lifetimes of nuclear power plants and evolving societal preferences (see Figure ES.1).

Figure ES.1:
A graphic representation of the circular framework



While the linear framework with its unidirectional causality from estimated costs to current assets is too simple, it remains, as long as stakeholders are aware of its limitations, a useful starting point. Its transparency and simplicity, even if to some extent fictitious, have been instrumental in setting up funding systems, informational infrastructures and legal obligations. However, it is also incomplete where there exists radical uncertainty.

The challenge is to maintain the robustness of funding systems at a moment where a number of framework conditions are changing significantly, including macroeconomic framework conditions, energy policy making, societal preferences or the structure of electricity markets. Such uncertainties are magnified by the context of funding for decommissioning and RWM: long delays between current decision-making and eventual implementation, a high level of residual uncertainty concerning technologies and costs as well as considerable political sensitivity. The circular approach is based on five principles:

1. *Interdependence and bi-directional causalities*: All elements are interconnected with all other elements of the funding systems; causalities are complex and bi-directional.
2. *Endogenous nature of cost estimates*: The costs of decommissioning or RWM are not an objective, exogenous number but depend on political, regulatory and technical choices and the redrawing of system boundaries.
3. *Adaptability*: All elements, including cost estimations, expected revenues and liability allocation must be able to adapt to endogenous (e.g. changes in societal preferences) and exogenous changes.
4. *Possibility of discontinuous changes*: Technological changes and political choices can introduce discontinuous change requiring radical adaptations outside initial assumptions.
5. *Regular revisions with stakeholder involvement*: Revisions must take place at regular intervals specified in advance, be legitimated by appropriate institutional processes and involve all stakeholders.

The essence of the circular approach is that a necessary evolution of the system can be triggered by any given element of the system. This could be a change in economic framework conditions, a political decision to shorten or extend the operating lifetimes of nuclear power plants, a new technological or legal option for RWM or new societal pressures to accelerate or delay the implementation of RWM solutions. By its very nature the circular approach is adaptive and iterative.

The circular approach considers in particular RWM a societal and political issue as much as an industrial and commercial issue. This does not imply freeing operators and their customers from their financial obligations, which are part of the original social contract under which nuclear power plants were constructed and operated. However, once they have paid their fair share – and fairness is here a political question to be decided at the national level – operators are unlikely to be best placed to assume the liability for decisions that affect issues outside their competence or even legitimacy. For instance, the timing or location of a DGR, both parameters highly relevant for costs, are not for an electricity company to decide. Even if it organised the process, this could, depending on circumstances, pose difficult legal and administrative questions.

One should also note that an adaptive or circular approach does not imply perennial uncertainty. Changes in key parameters or respective responsibilities will play out over time gradually and deliberately. The key point is to put in place the institutional processes to organise the adaptation of the funding system in function of changing circumstances as well as political decisions. Even more important than the specific financial assumptions are the processes, institutional settings and distributional arrangements in which such revisions take place. Ultimately, the financial sustainability of the funding systems also depends on the political sustainability of the overall framework and the perceived fairness of the decision-making process.

Special section on discount rates

Discount rates determine how future revenues and liabilities are taken into account in the present. They also determine the trade-off between the well-being of the present generation and that of future generations. Discount rates are thus a crucial element of the implicit social contract between generations on which the funding for decommissioning and RWM also relies. Depending on timing, the discount rate establishes how estimated future costs translate into required levels of assets today.

Traditionally, the social discount rates of the kind used in the calculation of the net present value (NPV) of public sector projects were *lower* than the private discount rates that correspond to the cost of capital in financial markets. There are good economic reasons for this. Governments should care for the welfare of future generations, especially if they subscribe to the *Intergenerational Equity Principle*. Large public sector projects frequently also have lower costs of capital due to explicit or implicit government guarantees. Governments can provide such guarantees at low costs because they can pool and spread risks over a large number of projects and individuals.

However, discussions about the appropriate setting of discount rates have been thrown into disarray due to the extremely low *market* interest rates, far lower than the 2% or 3% historically associated with social rates that also determined the level of required assets to finance future projects. In April 2021, the real return on US 20-year bonds stood at minus 0.2%. US Treasury bonds are a global benchmark and, because of their liquidity and the credit worthiness of the US government, define what is considered the risk-free rate of return.

The expansionary monetary policies referred to as "quantitative easing" that have been in place in all OECD countries since the economic crisis of 2008 make thus for very low returns on risk-free and low-risk assets such as government bonds. This does not necessarily mean that all funding systems for the back-end of the nuclear fuel cycle have had low financial returns these recent years. Those allowed to invest in equities and other riskier assets have done rather well from "asset price inflation", i.e. rising prices for certain financial assets. Despite the very modest returns on low-risk assets, there is no sign anywhere of a crisis in the funding of decommissioning and RWM liabilities.

Nevertheless, a number of developments merit attention. The discount rates used to establish funding requirements continue to differ strongly from country to country. Several countries have either reduced the discount rates for calculating required current assets, with significant impacts for liability holders, broadened the range to include riskier assets with higher returns, or both. Much of this is very sensible. Yet riskier investments imply a higher risk of shortfall at the time of disbursement. Hitting a precise level of funds at a given date in the future with reasonable certainty, something that was possible in the past, for instance, with indexed bonds, has become far more challenging. Recent events, such as the coronavirus crisis of 2020 and 2021 reinforces this point. Current macroeconomic circumstances constitute a further argument in favour of funding systems with high degrees of flexibility as well as an allocation of liability to the party that is capable of adjusting RWM solutions or of covering any potential shortfall by fiscal or monetary means.

Towards a broader interpretation of the Polluter Pays Principle (PPP)

The allocation of liability for decommission and RWM is based in the great majority of NEA countries on the PPP. Based on the work by Pigou on social costs, it was first set forth by the OECD in 1972 and subsequently spelled out and refined at regular intervals. The PPP aims at ensuring the full internalisation of environmental damages. As its title indicates, the key idea is that polluters should be liable for any social cost of the pollution they generate. This idea can be applied also to decommissioning and RWM, where it is understood to mean that operators of nuclear power plants are liable for the costs of decommissioning and RWM, which are then passed on to electricity customers. It translates, in particular, into the requirement to build up financial means to cover all decommissioning expenses and ensure safe and secure disposal of the waste (NEA, 2006: p. 33).

There is strong agreement that current generations should not leave unfunded liabilities for future generations. This conviction assumes special importance in the context of RWM, where financial commitments may last for many decades, a century or longer. It is also well known that ionising radiation from spent fuel and high-level radioactive wastes can continue for thousands of years. With good conditioning and appropriate storage or disposal solutions, the impact will be minimal. Nevertheless, the responsibility toward future generations requires that such solutions are convincingly conceived, implemented and properly funded.

As an entry into the discussion of funding decommissioning and RWM, the PPP has served the nuclear community well. It will continue to do so even though, as will be shown below, it needs to be approached in a somewhat broader perspective when applied to the area of managing high-level radioactive waste and spent nuclear fuels. It should be clear that such a broader interpretation would not revise the notion of fairness that is inherent in the PPP.

Indeed, the notion that polluters or users should be liable for the full costs of their activities and the economic efficiency principle of full internalisation of externalities coincide only under a number of assumptions, not all of which apply to RWM. The most important of these is that decisions take place in partial equilibrium frameworks with fixed parameters and that polluters have full control and, of course, knowledge of both their technical costs of abatement and the social costs associated with their activities. In the area of RWM, however, polluters, that is, the producers of radioactive waste, have little influence over their "private" costs of abatement, i.e. the cost of a DGR or an alternative solution. As mentioned previously, not only are these costs not under the control of the polluter, in the majority of cases they are also still largely unknown. In addition, the social costs, i.e. the costs to the public from radioactive wastes, are based on evolving societal perceptions. This does not make them any less real. However, it does make it impossible to apply the idea that an appropriate levy on each unit of waste would correspond to both the marginal costs of a future RWM solution and the marginal social costs.

The political nature of the choices, the long lag between the constitution of funds and their disbursement as well as the large uncertainties involved strongly limit the literal application of the PPP. The spirit of the PPP is to incentivise those who are responsible for social costs to minimise overall costs, i.e. the sum of private and social costs, to maximise welfare. The assumption is that the "polluter" knows and controls those costs. In the area of RWM, however, the nuclear operator as the generator of social costs does not hold sufficient information at the time of decision-making to allow for any form of welfare maximisation. In many cases, the original operators will not even be around anymore when implementation of the relevant RWM strategy takes place.

In the area of RWM, the choice of the appropriate solution, which will determine the technology, its location and timing, as well as both the industrial (private) and the social costs, lies with the government. Only the government has the legitimacy and ability to organise the trade-offs between industrial and social costs that, if done well, will ensure welfare maximisation. Given that the government sets all the parameters in the area of RWM, the most efficient solution in the spirit of the Law and Economics approach alluded to earlier would be to assume also the corresponding legal liability and financial responsibility.

If this seems to contradict the PPP's central tenet that the polluter should pay, it does so in appearance only. As pointed out already, any transfer of liability and financial responsibility must be accompanied by a transfer of the assets constituted for purposes of RWM. If need be, the transfer can be adjusted for any present or likely future shortfall. Transferring liabilities to the party that controls the costs and that is best placed to manage uncertainties is very much in keeping with the intent of the PPP. If done well – and there is no doubt that such transfers need to be carefully prepared and executed – transferring liabilities and constituted funds for managing high-level radioactive wastes and SNF will be the most economically efficient solution also in the sense of overall welfare optimisation. It is also fair, as the funding will rely primarily on the constituted funds by the operators through the surcharges billed to electricity customers. Broadening the narrow understanding of the PPP is thus necessary to remain coherent with its original spirit.

Forms of funding, investment strategies and cost estimation

The report also provides an overview of the principal funding arrangements and investment strategies for decommissioning and RWM in NEA countries. Like any other form of investment, funds for financing decommissioning and RWM need to make the appropriate trade-off between investment returns and risks. The protection and security of the funds are, of course, the highest priority. In most NEA countries, the funds for RWM were often statutorily managed in a low-risk manner, e.g. by depositing them in an escrow account at the finance ministry or by investing them in national government bonds. The country studies show that given the very low rates for such investments, several countries have now broadened the array of assets in which funds can be invested to include equity, real estate or, in some cases, even private equity.

A small number of countries are also considering using additional criteria in the management of their funds for decommissioning and RWM such as the performance of investments in terms of environmental and social impacts and corporate governance (ESG). While this is currently a big theme in the investment world at large, it is particularly relevant for public funds holding tens of billions of USD, possibly for decades. So far, the nuclear community has refrained from providing indications in this area. However, the issue of ESG criteria in investing the often considerable funds for financing decommissioning and RWM can no longer be ignored. It is particularly relevant for an investment activity that aims explicitly at ensuring the long-term sustainability of nuclear power systems by adequately financing the management of the often politically and socially sensitive back-end of the nuclear fuel cycle. Explicitly including ESG criteria into the investment objectives would constitute important support for sustainable investing in general and may even affect public perceptions of decommissioning and RWM and their financing.

NEA countries also address uncertainties in fund management and performance through a variety of strategies to mitigate risks associated with the decommissioning and RWM-related funding mechanisms. National systems of restrictions and reviews are in place to ensure the adequacy of funding under all but the most extreme circumstances, although the structure of these systems can vary substantially across NEA countries (NEA, 2016a: p. 128-9). The protection of funds can be advanced through several mechanisms, most notably the posting of guarantees and investment restrictions.

Funds are periodically reviewed and the country case studies provide a detailed picture of the changes enacted in recent years to preserve and improve the adequacy of funding. Given the long timeframes and the political nature of the issues involved, in particular with regard to RWM, the key issue is not to maintain a particularly high frequency of reviews but rather to adopt as broad a scope as possible. Transparency and stakeholder involvement are key elements.

As has been argued before, financial sustainability is ultimately based on the political sustainability of the vastly different options that can be adopted, in particular for high-level radioactive waste and SNF. Ensuring the adequacy of funding for decommissioning and RWM thus requires a broad set of technical, legal, economic and financial competences combined with a keen sense for political sensitivities.

Twelve case studies of the funding arrangements for decommissioning and radioactive waste management (RWM) in NEA countries

The twelve case studies of the funding arrangements for decommissioning and RWM in NEA countries provide the concrete experience and the empirical evidence to complement the considerations developed in the conceptual framework. Taken together, they convey a double message. First, national particularities are important. History, institutional arrangements, the size and role of the nuclear industry all matter in determining both the current and future forms of funding arrangements. Second, in almost all countries studied change is under way in different forms. The extent and the speed of the adaptations vary widely and can range from minor adaptations in the investable asset classes to comprehensive transfers of liabilities and assets. These changes are also introduced for different reasons. In some countries, they may reflect the new macroeconomic context or changes in electricity markets that affect nuclear operators. In others, they rather reflect an adaptation to broader considerations such as national nuclear strategy.

Yet despite these differences, in all cases countries are moving toward cautiously allowing for more flexibility when compared to the original blueprint of the linear approach. Today's funding systems increasingly go beyond the simple idea that it suffices to match the discounted future costs of a specific technical solution at a given point in the future with the steadily accruing assets of a utility with nuclear power generation invested in risk-free government bonds. The country studies, however, also show that these changes are taking place in an implicit, partial and ad hoc manner without reference to a coherent alternative framework. If a complete new framework still needs to be established, this report aims precisely at supplying a number of conceptual references and elements of language to allow a discussion of these changes to take place in a more explicit and systematic manner.

The different changes described in the twelve case studies nevertheless make for compelling reading and constitute a formidable resource for further reflections about the appropriate future funding arrangements for decommissioning and RWM. They also show how funding systems are not immune to broader policy developments that can require significant adjustments. Only the complete country study can convey a reliable picture of these interactions. The following paragraphs present a number of highlights that require contextualisation to be fully appreciated.

Belgium has decided to phase out nuclear energy by 2025, though nuclear energy currently still provides roughly half of its electricity. In this context, a number of adjustments were made to its funding system for decommissioning and RWM. The two most notable ones are the reduction of the discount rate used in the cost estimates for back-end solutions and the separation of the funds for decommissioning, which are held by the industry, from the funds for long-term RWM activities, which are held by a public entity. Belgium will also no longer permit a significant share of the constituted funds to be lent back to nuclear operators.

The funding scheme in **Canada** is characterised by the sharing of responsibilities between the national level, the provincial level and the license holders and relies primarily on a set of financial guarantees. The largest license holder, Ontario Power Generation (OPG), is wholly owned by the Province of Ontario with whom it has concluded the 1999 Ontario Nuclear Funds Agreement (ONFA) that is updated every five years. At the national level, Canada's approach of Adaptive Phased Management (APM) to a final repository strategy for radioactive waste allows for flexibility as social and technical conditions evolve.

Finland is a global leader in implementing solutions for the disposal of radioactive waste by building the world's first DGR, which is expected to be operational from 2025. Funding is organised through the State Nuclear Waste Management Fund, which ensures that the sum of constituted assets and securities provided by nuclear operators corresponds to liabilities. Nuclear operators and the Finnish state are both entitled to borrow up to 75% of their respective fund holding against the provision of securities. The adequacy of funding is reassessed every three years. Future liabilities are calculated without applying discount rates, which avoids a number of accounting issues, in particular in the context of an environment of low rates of return on assets.

In **France**, the discounted value of future decommissioning and RWM liabilities is held by the nuclear operator Electricité de France (EDF) in the form of inalienable dedicated assets. Funding adequacy is reviewed annually. A recent review decided on a significant upward revision of the expected costs of the Cigéo DGR project, for which an underground laboratory is currently under construction. A significant share of France's SNF is reprocessed, which leads to a relatively short-term liability. Reprocessing costs are indeed considered as operational costs and are paid as part of current expenditures during operations and there is no obligation to set aside dedicated funds. The French state owns 85% of EDF. This provides added security for the adequacy of funding in case of need, but also implies a special effort with regard to transparency and communication.

Following the 2011 decision to phase out nuclear power, the last commercial reactors in **Germany** will come off the grid at the end of 2022. In this context, the funding system for decommissioning and RWM was substantially revised. Decommissioning funding will remain the responsibility of the operators, while liabilities for RWM and constituted funds, augmented by a 35% surcharge to cover for uncertainties, were transferred to the state. In this manner, all financial, legal and administrative aspects of RWM are handled under the same roof, with a decision due by 2031 on a politically sustainable solution for long-term storage and disposal.

In **Japan**, the Fukushima Daiichi accident, the liberalisation of the electricity market as well as regulatory changes that have established the planned operational lifetimes of nuclear reactors at 40 years with a possible extension to 60 years, have led to a strengthening of the funding systems for decommissioning and RWM. Prudent management and realistic discount rates ensure that, in particular, the Final Disposal Fund for RWM ensures adequacy even in the current low interest rate environment. Funding adequacy is assessed annually. In addition to the funding systems for decommissioning, RWM and SNF reprocessing, a complementary arrangement dedicated to reactors affected by accidents was created. The Fukushima Daiichi accident underlined the importance of close public-private co-operation.

The adequacy of funding for decommissioning and RWM in **Korea** is overseen by the Korea Radioactive Waste Agency (KORAD), which manages, in particular, the Radioactive Waste Management Fund (RWMF), whose adequacy is assessed annually. A recent review of discount rates in line with expected returns led to an increase in the current assets required to match future RWM liabilities. The Korean system envisions RWM being undertaken by KORAD and decommissioning by the nuclear operator Korea Hydro & Nuclear Power (KHNP), which is majority-owned by the government. For the time being, however, radioactive waste is also still managed by KHNP. Differences in cost assumptions and discount rates between the two organisations are in the process of being reconciled but new policy intentions - such as the desire to not enact originally planned lifetime extensions - are likely to require further adaptability from all actors.

In **Spain**, decommissioning and RWM are considered essential public services under the responsibility of the state. They are thus both managed by state-owned Enresa. The management and financing of RWM and decommissioning under a single roof provides a good degree of clarity and foreseeability. At the same, this requires realistic estimates of future costs and contributions by license holders to avoid transferring residual financial responsibilities to the state and thus ultimately to the taxpayers. The latest adjustment of fees was enacted in 2020. The forthcoming 7th General Radioactive Waste Plan will further rebalance funding streams and provide both license holders and Enresa with additional certainty for the medium and long term.

The importance of ensuring the adequacy of funding for decommissioning and RWM in **Sweden** was highlighted by the 2015 decision of license holders to hold the operations of several nuclear power plants, two of which have since been shut down, due to a lack of profitability. The government has since transferred the responsibility for supervision of the Nuclear Waste Fund from SSM, the Safety Authority, to the Swedish National Debt Office (SNDO), while allowing at the same time for a broader set of asset classes to be considered for investment. Sweden operates a centralised storage scheme for nuclear waste and a DGR project is in its final stage of authorisation. Funding adequacy and cost estimates are reassessed on a three-year basis. In addition, elaborated risk assessments seek to ensure that the fees contributed by the four nuclear operators are in line with liabilities.

The system for funding decommissioning and RWM in **Switzerland** is based on two external funds whose assets are reviewed annually, while cost estimates are reconsidered every five years. Since 2015, its rules for calculating the adequacy of funding have undergone several rounds of carefully considered changes. The assumed rate of return on invested assets was thus reduced, while reference costs as well as potential inaccuracies and risks were reassessed. The new rules have entered into force in 2020. Switzerland has two further lines of defense should a funding shortfall occur. First, if any single nuclear operator were unable to assume its liabilities, all nuclear operators would become collectively financially responsible. Second, if all else should fail, the federal government could step in, albeit only if authorised by the federal assembly.

The funding system for decommissioning and RWM in the **United Kingdom** consists of three branches: one for reactors operated today by EDF Energy, one for legacy wastes, including the large Sellafield site, which is managed by the Nuclear Decommissioning Authority (NDA), and one for new power plants built after the 2008 Energy Act. The funding for decommissioning and RWM for the current reactor fleet as well as for reactors built after 2008 is ensured through dedicated funds. The latter have to adopt an investment strategy whose financial risks decrease as the end of a reactor's lifetime, and thus disbursement, approaches. This allows for riskier strategies at earlier stages. The management of legacy wastes with significant uncertainty in cost and schedule is instead financed through the budget of the central government. Use of market-based interest rates to estimate the NDA's liabilities recently translated into negative rates and highlights current challenges when accounting for decommissioning and RWM liabilities.

In the **United States**, liabilities for decommissioning and for low-level and intermediate-level radioactive waste (LLW and ILW) are allocated to the industry. The liability for managing SNF was transferred to the federal government in exchange for a fee paid into the Nuclear Waste Fund that is integrated into the national budget. However, the absence of a DGR due to a complex interplay of political forces has delayed the government's ability to accept SNF. Consequently, utilities are storing SNF on site in a decentralised fashion for longer than expected, the nuclear waste fee was set to zero in 2014 and several lawsuits for compensation were successful. The US experience shows how even well-conceived and well-funded systems can be unsettled by political decisions that invalidate underlying assumptions. In the absence of a DGR, a comprehensive scheme for interim storage is one of the options being studied. For the time being, government contributions provide a form of funding of last resort and allow day-to-day operations to continue. Advancing towards a long-term solution for RWM will likely include a careful and systematic effort at the institutional level to bring together major stakeholders in an effort to achieve political sustainability, which can then be translated also into the full financial sustainability of the funding system.

Elements of good policy practice

This report sets out the theory and, in many cases, the practice of modern, future-oriented policies to ensure the adequacy of financing for decommissioning and RWM. Such policies move away from comparing estimations of current assets with highly uncertain future liabilities that are discounted by social discount rates that have little grounding in either economic conditions or a coherent conceptual framework. Such policies will also be mindful that liabilities of such orders of magnitude will ultimately need to be borne by the parties that are best placed to manage the specific risks associated with funding decommissioning and RWM.

Instead of linearly discounting hypothetical costs with hypothetical discount rates, sustainable funding frameworks should explicitly be conceived in a manner that enables them to react flexibly as key elements of the system change. Changes, particularly with regard to potential RWM solutions, their timing, location and costs, but also with regard to the financial return on assets, the lifetime of operators, the emergence of new stakeholders and institutions and so forth, would thus each time require adjustments in all the other parameters of the system.

Such a circular and adaptive approach recognises the interdependence of all elements. Future costs are not an exogenous, objective data point but the endogenous result of policy decisions taken and adapted in function of new incoming information concerning available technologies, their costs, public preferences and social choices. The possibility of discontinuous changes in any of these parameters, including the allocation of liability for residual risk, for which neither expected values nor probabilities can be assigned, is fully acknowledged.

Ultimately, such an adaptive approach will also include a broader interpretation of the PPP. In the context of decommissioning and RWM, the latter is commonly understood to imply that costs should be borne by electric utilities and their customers. However, the limited lifetimes of utilities, the uncertain outlook in fast-moving electricity markets and the inability to influence decisive cost parameters such as timing or choice of RWM technology does not allow for a straightforward application of the original reading of the PPP. At the same time, there is continuing agreement that electric utilities and their customers need to honour their original financing commitments. While situations differ from country to country, in many instances, the transfer of both constituted assets and liabilities to public or quasi-public institutions with the ability to carry the multiple dimensions of residual risks provides a promising perspective for improving the adequacy of financing in the area of RWM.

Such a perspective does not imply a radical change from established practice. For obvious reasons, governments and legislators have closely regulated and overseen funding arrangements since their very beginning. Implicit forms of public-private sharing of funding and its risks can also be identified in many countries. However explicitly adopting a circular approach would allow such risk-sharing and, where appropriate, transfers of liabilities and assets, to proceed in a more systematic and transparent fashion.

The situation in the area of decommissioning is slightly different as the timeframes are shorter, the technologies are better established, and objectives are well-defined, meaning incalculable residual risks can overall be expected to be of lesser importance. This makes a literal interpretation of the PPP far more pertinent. Nuclear operators are indeed much better placed to assume the responsibility for both the funding and the operational implementation of decommissioning than for RWM solutions. The emergence of a secondary market for the transfer of decommissioning liabilities on a commercial basis in some countries shows the high degree of industrial maturity and codification that has been achieved in this area. While there remains, of course, a need to manage the interface of decommissioning and RWM carefully, overall the results of this report suggest somewhat different approaches to ensuring the adequacy of funding for decommissioning and RWM.

Finally, over the years, work on the adequacy of funding by independent research institutions and inter-governmental organisations such as the NEA has also generated a wealth of information on specific forms of funding, investment strategies and cost estimations. Experiences with many of these can be found in the twelve country case studies.

The combination of conceptual considerations and practical experiences leads to 15 "Elements of good policy practice" that would need to be part of approaches to ensure the long-term adequacy of funding arrangements for decommissioning and RWM. They are indicated at the end of this report. While the ideas behind these elements are general, their concrete implementation will need to take account of the differences between NEA countries with regard to the structure of the electricity and the nuclear industries, the timing of RWM solutions, institutional arrangements as well as political commitments and social preferences.

Once it is understood that sustainable funding arrangements for decommissioning and RWM need to correspond to the specific situation of each NEA country, the following guiding thoughts apply. The long-term nature of decommissioning and RWM and the uncertainties surrounding the technical solutions concerning the latter require a *circular approach*, in which all key elements of the funding system are adapted at regular intervals in function of major changes in any one element. This has an impact on optimal liability allocation. Even the best designed funding system will have to deal over time with uncertainties, including political and societal changes, which private actors, including large well-funded utilities, will not be able to hedge against. In such cases, governments or public bodies might well be the party best equipped to handle them. Any transfer of liabilities will then, of course, need to be accompanied by a transfer of constituted funds and, where appropriate, complementary burden sharing arrangements that are perceived as fair. In summary, transitioning from a linear to a circular approach would recognise that ensuring the adequacy of funding for decommissioning and RWM is not akin to traditional project finance, but a dynamic societal process requiring multiple adjustments along the way.

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PART I

A conceptual framework for financially and politically sustainable financing arrangements for the back-end of the nuclear fuel cycle

Chapter 1

Introduction: A new look at ensuring the adequacy of financing

The back-end of the nuclear fuel cycle increasingly commands the attention of decision-makers in industry, finance and, in particular, politics. This is largely a natural development as the nuclear reactor fleet in OECD Nuclear Energy Agency (NEA) member countries is ageing and large amounts of radioactive waste have already been produced or continue to be produced.[1] Despite vigorous initiatives in various countries to enable the safe and profitable long-term operation (LTO) of existing reactors, a growing share will reach the end of their operating lifetimes in the years to come and will need to be decommissioned. Today, according to the IAEA's Power Reactor Information System (PRIS) database, more than 190 of the world's nuclear power reactors have been permanently shut down and are either awaiting decommissioning or are in various stages of the decommissioning process.

The management of nuclear waste presents an ever-present policy challenge partly because of the radioactive waste and spent nuclear fuel (SNF) stemming from decommissioned reactors but also due to the increase in SNF from operating reactors. There are material constraints such as reaching capacity limits for the on-site storage of spent nuclear fuels in several countries and a shortage of interim storage solutions. There are also social and political pressures that demand the implementation of definite solutions for managing SNF and high-level radioactive wastes (HLW) or, at the very least, their preparation in the framework of credible long-term strategies.

Both decommissioning and radioactive waste management (RWM) can be technically complex and politically sensitive. They also constitute highly capital-intensive, long-term endeavours, RWM even more so than decommissioning as it requires the provision of large amounts of funds in advance. This is the topic of this report by the NEA. The NEA, of course, regularly provides information and policy advice to its member countries on technical, legal and social issues related to decommissioning and RWM. It has also repeatedly dealt with the financing of those activities (see, for instance, NEA, 1996, 2003a, 2003b, 2005, 2006 and 2016b). In recent years, it has particularly focused on the estimation of decommissioning costs (see 2010, 2015, 2016a and 2017).

This report builds on these earlier studies. However, its objective is not to provide additional advice on particular technical issues, funding schemes or cost estimates but rather to provide elements and a coherent framework for a broader discussion on the adequacy of funding for decommissioning and RWM. This framework is ultimately informed by economic theory, in particular a branch of economics called Law and Economics, but does not aim to make precise prescriptions about particular funding levels, assumptions about discount rates, asset allocation or similar issues usually associated with economic analysis.

1. In the following, this report will refer to *radioactive waste* as a short for spent nuclear fuel (SNF) and high-level radioactive waste. Only when necessary, for instance when referring to countries practicing reprocessing, will it distinguish specifically between the two materials. In referring to radioactive waste management (RWM), the report does not make any judgement with respect to particular strategies, solutions and technologies. While national deep geological repositories (DGR) are considered the appropriate solution in many NEA member countries, other solutions such as extended interim storage, reprocessing, releasing or participation in multilateral repositories are also considered part of RWM.

The “circular approach” to the adequacy of funding for decommissioning and RWM rather reflects the broader fact that multiple changes in different dimensions will play out between today’s decisions and future funding needs, many of which will only fall due many decades from now. Both activities, RWM more so than decommissioning, are characterised by three factors that require complementing traditional economic analysis with a systematic understanding of the boundary conditions, the objectives, responsibilities and capabilities of different stakeholders as well as the incentive structures that are at play. The first factor concerns the uncertainties that exist both on the funding side as well as on the side of the cost estimations for decommissioning and RWM. On the asset side, the low or zero returns on the risk-free or low-risk assets, notably government bonds that were traditionally favoured by regulators, are likely to persist for a long time. The absence of diversification into riskier asset classes, an increasingly used option in many funding systems, can compensate this effect to some extent. Nevertheless, the declining importance of assets with predictable real returns over the long run questions some of the assumptions behind existing models of constituting funds for disbursement in the far-away future through the mechanical accrual of predictable compound interest. On the cost side, in particular for RWM, the funds required for different technological options or different time horizons can differ by up to an order of magnitude.

The second, related, factor concerns the very long timeframes between decision-making and implementation that still prevail in most counties in the area of RWM and to a lesser extent in the area of decommissioning. Timeframes for building, loading and closing DGRs can span from several decades to a century or more. Other infrastructure assets, say a road or a bridge, are also conceived for long timeframes. However, their technical specifications are well-defined and they do not face the same hiatus between decision-making and implementation, nor the same level of political uncertainties. The lack of codification of a solution that depends on social preferences and political decisions that are still evolving in the great majority of NEA member countries thus contributes over time to the uncertainties. The length of the timeframe and the nature of the potential modifications change the nature of the uncertainty. In particular, RWM no longer takes place in a sphere of risk that can be expressed in terms of a known probability function and that can be insured against in financial markets but in a sphere, in the term introduced by Frank Knight, of *uncertainty*, i.e. radical undiversifiable residual risk (see Box 1.1 below).

Box 1.1:

“Risk” and “uncertainty” or the different roles of markets and governments

Frank Knight (1885-1972), one of the founders of the Chicago School of economics, developed the important distinction between diversifiable risk and non-diversifiable uncertainty in his classic 1921 book Risk, Uncertainty and Profit. In essence, risks, which are supposed to have a known probability function, can be handled very well by private actors in competitive markets. Uncertainty instead, for which no known probability function exists, cannot be handled by markets. Uncertainty refers to an incompressible and non-insurable residual risk, which is also referred to as “tail risk” in financial markets. It requires structures other than markets to manage it.

Knight thought in particular of the vertical structure of the firm with an entrepreneur on top who will engage in a particular risk-sharing agreement with his employees. The entrepreneur will take on the residual economic uncertainty and will in return receive any residual profits once the workers have received their stable salary. In public policy settings, it is instead the vertical structure of government that needs to assume any uninsurable risks or uncertainties. Uncertainty always arises when markets are unable to trade, diversify and insure risks. This may be due to the non-linear or irreversible nature of certain risks, which makes them no longer substitutable at the margin. Discontinuous changes in preferences or in framework conditions have comparable effects. In the present context, the appropriate structure for ensuring the funding of decommissioning and RWM is one that holds private actors liable for issues dominated by insurable risks and that holds public actors liable for issues dominated by uninsurable uncertainty.

Beyond investment risk or the uncertainty around the costs and benefits of different technological options, this regards the social and political preferences that govern RWM and that are bound to evolve over such long timeframes. The length of these timeframes introduces uncertainty regarding the continued existence of the actors supposed to carry the principal responsibility for funding RWM.

This concerns, in particular, electric utilities, which are exposed to multiple stresses even in regulated markets as the electricity industry is undergoing massive structural change. Their risk of bankruptcy before funds are fully accrued is not just a distant possibility.

Finally, decommissioning and RWM as well as their respective funding arrangements are characterised by high political visibility and sensitivity. This is one area of public policymaking where maintaining transparency and trust both with the larger public and political decision-makers is vitally important. RWM is possibly the one area in the nuclear field where the gap between perceptions and realities on the ground is greatest. Such disparity can easily breed distrust.[2] At the same time, it constitutes the rare opportunity of a challenge where all stakeholders, whatever their view on nuclear power, agree that the issue needs to be addressed head-on to find a long-term solution.

There is also strong agreement that current generations should not leave unfunded liabilities for future generations. This conviction assumes special importance in the context of RWM, where financial commitments may stretch over decades. It is also well known that ionising radiation from spent fuel and HLW continues even for thousands of years. With good conditioning and appropriate storage or disposal solutions any impact on future generations is highly likely to be minimal. Nevertheless, the responsibility before future generations requires that such solutions are properly conceived, implemented and funded.

Uncertainty, long timeframes and political sensitivity make decommissioning and RWM unique challenges requiring specific frameworks and appropriate solutions. In order to realise the opportunity contained in this challenge, it must not be approached in a purely technocratic manner that seeks justification in the various technical, legal and administrative complexities. On the contrary, while these complexities require careful attention, their management must be informed at all times by a clear strategic view of the objectives that decommissioning and RWM are meant to achieve. In a very general sense, these objectives could be indicated as returning the sites of former nuclear power plants to their previous state in the case of decommissioning and the long-term isolation of HLW from the environment in the case of RWM. Of course, the challenge is to translate such high-level objectives into concrete industrial solutions commanding broad stakeholder support at reasonable costs. This includes an understanding of how an approach that promises to be both economically efficient and socially sustainable can ensure any given solution. Subsequent discussions will emphasise how economic efficiency and social and political sustainability go hand in hand.

Guiding principles and the Law and Economics approach

Financially, socially and politically sustainable funding arrangements will need to be built on two fundamental guiding thoughts that determine their structure and nature:

1. The parties that are best capable of managing the costs and risks related to decommissioning and RWM should ultimately be the ones to have responsibility for funding.[3] This includes the ability to choose between different available options and to determine technological choices. This is also the most efficient manner to ensure that assets and liabilities remain aligned over the longer term. While this may imply in specific circumstances a broader reading of the Polluter Pays Principle (PPP), it does in no way imply that the original creators of decommissioning and waste liabilities, primarily electric utilities and their customers, are released from their obligations. Any transfer of responsibilities will need to be accompanied by concomitant transfers of accrued funds and the rights to future revenue streams as well as by appropriate additional payments.

2. For example, during discussions in the run-up to the adoption of the taxonomy on sustainable investment adopted by the European Union the absence of definite solutions in RWM loomed large. See European Commission (2019), *Sustainable finance: Commission welcomes deal on an EU-wide classification system for sustainable investments* (Taxonomy) https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6793.

3. Pure economic theory would hold that the incidence of liability has no impact on overall efficiency as liabilities can be traded and would thus automatically end up at the party having the lowest cost to handle them. However, this assumes the absence of transaction costs. In the real world, and a fortiori in a nuclear sector with numerous asymmetries of information and broader social issues, transaction costs can be high. Assigning or re-assigning liabilities is thus a complex process, which requires thorough preparation, broad-based stakeholder involvement and careful implementation.

Such an alignment of responsibilities with the ability to manage costs and risks may well result in different institutional set-ups and constellations in the areas of decommissioning and RWM.

2. The decommissioning of the current and future reactors of NEA countries and even more so RWM concern commitments that stretch out decades into the future, possibly a century or more. It is obvious that economic, political and technical framework conditions both on the asset and on the cost side will change over these periods. As long as commitments for disbursement are far away, maintaining a narrative of stable parameters can be a useful intermediate step to set up funding systems. However, as soon as real disbursements loom, the accuracy of estimates can no longer be taken for granted. In other words, funding frameworks will increasingly need to integrate the conscious and explicit management of change in a sustainable rhythm. This is the essence of the switch from the current linear frameworks to the circular frameworks discussed in Chapter 2 of this framework (see below). The key question is thus no longer "are my current assets A and my future expected revenues B adequate to finance my best estimate of costs C?" but rather "what is the sustainable process involving all stakeholders to adjust A and B when C changes?" or even, under exceptional circumstances, "A and B have changed, are there any options available to bring C in line?".

Many existing frameworks in NEA member countries already respect these two guiding principles to varying degrees. The adequacy of financing for decommissioning and RWM is a major issue that receives high policy attention. Systems are in place and much good work is under way, although frequently in an eclectic and implicit manner, rather than in a systematic and explicit one. Elaborate systems have been put in place and it would be wrong to imply that there exists an immediate need for drastic change across a wide range of countries. The different principles to guide policy action that are listed in the NEA status report on *Decommissioning Funding: Ethics, Implementation, Uncertainties* of 2006 remain valid and are fully compatible with the approach indicated above which aims to complement them rather than substitute them.[4]

The two fundamental guiding thoughts proposed above aim to strengthen the resilience of funding arrangements for the back-end of the nuclear fuel cycle. The first principle, to allocate responsibility for financing to the party best equipped to determine or manage costs, is in reality an efficiency criterion that stems from the economics of tort litigation. It is part of a branch of economics referred to as Law and Economics. A good starting point to familiarise oneself with this literature is the article by Calabresi (1961), which has spawned a large amount of secondary literature. His principal idea is precisely that legal obligations are most efficiently handled by those who have the best control over the level of liabilities and the general context in which they are likely to arise.[5]

4. In accordance with the propositions of the US Academy of Public Administration (1997), the 2006 NEA study lists the Trustee Principle, the Sustainability Principle, the Chain of Obligation Principle and the Precautionary Principle, which affirm the responsibility of the present generation for the consequences of its actions and the well-being of future generations (NEA, 2006: pp. 17-18). It also introduces the Polluter Pays Principle (PPP) in the following manner:

> "The Polluter-Pays Principle… means that the polluter should bear the expenses of carrying out the pollution prevention and control measures introduced by public authorities in Member countries, to ensure that the environment is in an acceptable state (ibid., pp. 21-22)."

Additional criteria for the establishment of adequate funds for decommissioning and RWM mentioned in previous NEA reports are sufficiency, availability and transparency (NEA, 2013: p. 31 and 147; NEA, 2016: p. 40). To which the German Wuppertal Institute adds the criterion of independence, i.e. that any funds for decommissioning and RWM should not be used for other purposes (Wuppertal Institute, 2007, p. XIV). These are of course all eminently sensible, if general, principles that remain valid in the context of the approach proposed in this report.

5. In the context of tort litigation for workplace accidents, Calabresi writes:

> "Proper resources allocation… militates for allocating to an enterprise all costs that are within the scope of that enterprise. 'The enterprise is held liable for the injuries even though no fault on its part can be shown' (Calabresi, 1961: p. 514)."

Such allocation of liability would be independent of causal responsibility as traditionally understood, e.g. in the context of the Polluter Pays Principle. One might think of a worker who injured himself by making a mistake. However, holding the enterprise liable for worker safety also in this case makes sense, as it is best placed to select responsible workers, train them according to the requirements of the task and put appropriate internal incentive measures in place (e.g. a bonus for incident-free work). Making workers responsible for their own safety might have local advantages, e.g. other things equal companies could pay them higher salaries. However, overall economic efficiency would decline as workers were mismatched with their jobs (or the matching process would be costly and cumbersome) and the overall rate of workplace accidents was likely to increase.

This is a highly important notion, particularly in the context of RWM, where currently liabilities routinely lie with parties who have little control over either their level or their context. The nuclear operators and electric utilities that primarily bear funding liabilities, for instance, have little control over the cost side.

First, in most countries they will not implement themselves any of the technical options for radioactive waste disposal but rely on specialised providers, which can raise issues of incentive compatibility.[6]

Second, in many countries, operators are only marginally involved in the processes leading up to the social and political decisions that will determine the technical solutions to be implemented and hence the resulting costs. Of course, large differences exist between countries according to the structure of the electricity sector and whether utilities are owned privately or publicly. In many countries, nuclear operators also have extensive experience in the interim handling of radioactive waste and even in the financial management of their funds. However, structural decisions regarding the back-end of the nuclear fuel cycle, such as whether to engage in reprocessing or the timing and location of a DGR facility, inevitably belong to the realm of politics. These are however the most decisive parameters determining funding needs.

For example, in no NEA member country do nuclear operators control the timing of RWM solutions, which is, of course, a crucial parameter in determining the adequacy of financing. Political decisions to phase out nuclear power also affect the lifetimes of nuclear power plants and hence the years of revenue collection for funding programmes. Existing estimates of funding arrangements are thus rendered obsolete as the future costs of decommissioning and RWM now need to be spread over a reduced amount of nuclear electricity production. In some cases, such as Switzerland, the obligations of nuclear power plant operators are restricted to their ability to pay without the notion being entirely defined, which introduces further uncertainty. Such political decisions obviously diminish the ability of operators to decide autonomously about timing, funding choices and technical solutions.

This dichotomy between funding responsibilities on the one hand and, due to the importance of social and political processes playing out in parallel, control over costs and in some cases funding itself on the other is largely unique to the nuclear sector and in particular to RWM.

The main function of the second guiding principle – to maintain flexibility in the system – is to support the previous one by better preparing systems to absorb new information and to be more flexible in order to function in a way that is manageable for operators and various stakeholders.

Allocating responsibilities to the party most likely to control the process and the outcome of any definite solution may lead to very different solutions in the areas of decommissioning and in RWM. While operators of nuclear facilities are currently responsible in most NEA countries for securing funding in both areas, the actors charged with the management of the constituted funds differ widely. In the area of decommissioning, the required skill set, the profile of potential risks and the timeframe usually match quite well the competencies and risk management abilities of operators as well as the time horizons of their shareholders.[7] Methodologies are being codified, including at the NEA, experience is increasingly gained and benchmarks exist. Due to such codification and the maturing of the industry, transaction costs decrease and the alignment of private and social welfare becomes easier.

6. In some countries, the organisation ultimately overseeing and implementing a final RWM option such as building a DGR is a spun-off of the previous nuclear power plant operator liable for ensuring adequate funding.

7. At the face of it, the Safstor concept would contradict this statement. Safstor was developed by the US Nuclear Regulatory Committee (NRC) and allows a nuclear plant once it is shut down and defueled to be monitored for up to 60 years before actual decommissioning takes place. Concrete entombment is a third option. Safstor and entombment lengthen timeframes also for decommissioning and while framework conditions in terms of regulation, technology and knowledge are likely to change less than with RWM, some changes will take place. Nevertheless, these changes are of a nature that can be handled by nuclear power plant operators and their shareholders in the same manner as they handle other economic and commercial uncertainties. Decommissioning is thus dealt with in a framework of habitual economic decision-making with three technical options. The nascent secondary market for decommissioning liabilities in the United States is proof that the three options are sufficiently codified to allow commercial trading. They thus do not require reintegration into the realm of political decision-making beyond standard regulatory oversight.

This is, however, much less the case in the area of RWM. On average, time horizons are far longer and more uncertain. Technological choices are also far more varied. While deep geological repositories (DGR) are identified as a final endpoint of RWM in many countries, their form, size and cost may differ widely, just as the interim solutions adopted in the meantime. In the area of RWM, national governments seem to be the only credible actor capable of either organising themselves or overseeing the open-ended social processes leading up to the formulation of policies, which only over time will converge towards a given technical solution.

Whether such an allocation of responsibilities is compatible with the PPP in a broad sense is a matter of interpretation. Chapter 3 will show, however, how a narrow interpretation of PPP, based on assumptions such as parameter stability and simple causal relationships, is not applicable to RWM. The obligation of the operators of nuclear facilities and their customers to assume the funding for decommissioning and radioactive waste disposal as agreed in the originally formulated social contract must, of course, be respected, and is limited only by their actual ability to pay. At some point, however, it needs to be recognised, that the realised level of the accrued funds depends only in a notional manner on the actual funding requirements for long-term RWM, which will depend on many factors, including social and political developments, regulatory requirements, and technological changes. Divergence is equally likely in either direction, overprovision or under-provision, depending on the decisions made over time concerning the concrete solutions.

In order to consider these topics, the general approach rather than the specific findings of the literature referred to as Law and Economics can be helpful. It is a branch of applied economics concerned with the working of the real world at the interface of economics, established practice and the law. It allows bringing together a number of notions such as transaction costs, informational asymmetries or agency problems, of which an awareness exists also in the nuclear sector though they are not always discussed explicitly.

The field of Law and Economics attempts to link the general economic notions of efficiency and cost minimisation in a flexible and non-dogmatic manner to the working of institutions, including the working of the justice system, and the allocation of legal responsibilities. Frequently it is concerned with (1) the optimal allocation of responsibilities, (2) the alignment of incentives, (3) risk management, (4) the reduction of transaction costs and (5) the overcoming of informational asymmetries.[8] The overall objective remains economic optimisation, i.e. cost minimisation in the pursuit of a given objective, in environments characterised by complexity, asymmetries of information and risk. The Law and Economics approach does take its overall normative references of cost efficiency and welfare maximisation from standard economics. However, it applies them not to a conceptual world of perfect information and absence of transaction costs but to the reality of current institutions, historic liabilities and the specific resources and incentives of individual stakeholders. Concrete institutional circumstances, the specificities of member countries and the evolution of decision-making processes through time all play an important role here. Important sets of questions that can be usefully pursued under this approach are, for instance:

1. What are the current processes to realign funding requirements and costs to ensure robust adequacy over the long run as new information becomes available to different parties?
2. How are different risk dimensions dealt with, in particular non-diversifiable residual risk? What are the respective roles of operators, funding institutions and governments when operators change ownership or go bankrupt?
3. What are the incentives for cost minimisation? Do they differ between private and public actors? Are new technological and socially acceptable options regularly assessed? How can designing solution towards available assets be avoided? Should it be avoided?

8. Informational asymmetries lead to so-called agency problems that lead to economically inefficient arrangements between different parties. The literature usually distinguishes between moral hazard (where agents act unilaterally and sub-optimally on a variable that is difficult to verify and that they control, typically effort) and adverse selection (where agents act unilaterally and sub-optimally on a variable that is difficult to verify and that they do not control, such as the quality of good). Of course, the two go together. Due to its complexity, the nuclear industry offers many occasions for moral hazard or adverse selection. Vertical integration, which may have other disadvantages, is one commonly proposed remedy for some issues of moral hazard and adverse selection.

4. Is a narrow interpretation of the Polluter Pays Principle ("operators are liable for all costs") the appropriate one in light of the timeframes and the necessary social and political dimension of decision-making processes the appropriate one? What should be the specific responsibility of operators and their customers in a somewhat wider interpretation?

These are clearly just some examples; several of them are discussed at greater length in the following chapter. However, this report does not pretend to do a systematic treatment of all aspects of the funding of decommissioning and RWM but sees its role primarily in proposing a more comprehensive approach to the issue. In paraphrasing the title of a well-known article by Calabresi and Melamed (1972) on liability allocation that refers to Monet's extensive series of paintings of the Cathedral of Rouen, the present report aims to provide "another view of the cathedral".

Why reconsider funding systems now?

This is a good moment to take a step back and consider the funding of decommissioning and radioactive waste disposal in a broader perspective. For several reasons, NEA countries are approaching an inflection point in the public debate on funding decommissioning and radioactive waste disposal. As the world moves from a state in which disbursements for decommissioning and waste management projects are no longer a vague future possibility but a current reality, existing systems will be exposed to new stresses and closer scrutiny than in the past. It is well known, and the country studies in Part II corroborate this, that the relevant funding requirements for decommissioning and, in particular, RWM amount at the country-level to many billions, sometimes several tens of billions of USD. Of course, such estimates vary dramatically with the technical solution chosen, the degree of international co-operation or the amount of economies of scale. In any case, the funding requirements of NEA countries need to be explicitly and systematically articulated, discussed and justified. The resulting arrangements corresponding to the political consensus will need to be formalised in institutions that are sufficiently stable to reassure all stakeholders that their concerns have been taken into account and sufficiently flexible to allow changes to be reflected at a socially and politically sustainable pace.

Such articulation, justification and institutional adaptation is required to enhance social and political acceptability and to help decision-makers identify margins for improvements that enhance efficiency. This is not to imply that current institutions are wholly unsuited to the challenges at hand. On the contrary, funding systems in NEA countries are largely in good shape, supported by stable legal frameworks and competent administrators. However, especially in the area of RWM, most systems are only beginning to be exposed to the industrial reality of proceeding towards financing concrete medium- or long-term solutions. Finland, Sweden and France are the only countries where actual construction work on DGRs is ongoing. Quite obviously, their experiences are closely watched by the international community. While it is too early to say what precisely will be the impact of an operational DGR coming into existence on the debate over the funding of the back-end of the nuclear fuel cycle, it is likely to be significant.

The purpose of this report is to provide elements that can assist in the process of better articulating, justifying and improving current funding arrangements. The responsibilities and operating philosophies of current institutions are not always articulated in a manner that would allow engaging a sceptical public. Priority is often given to presenting key notions such as future costs in a language of rationality and certainty rather than to outlining possible pathways that present different options at defined bifurcations. The framework is one of static optimisation rather than of continuous dynamic adjustment. This report thus aims to contribute to the development of more comprehensive and more flexible discourses in NEA countries regarding the financing of the back-end of the nuclear fuel cycle to ensure its financial, social and political sustainability.

The time to consider such changes is now. The nuclear power reactor fleet is ageing, with many units approaching the end of their original operating licenses in the years to come and with prospects for their long-term operation (LTO) varying widely across NEA countries. Nuclear decommissioning and waste management are therefore expected to grow significantly in importance, considering the increases in both the inherited and future volumes of radioactive waste that shall need to be disposed of. These industrial challenges are complicated by the magnitude of the timescales involved, which can last up to several decades or even more than a century. This requires careful management to ensure the availability of adequate funds for the continued fulfilment of responsibilities and the proper and timely discharge of all activities (IAEA, 2007: p. 3; IAEA, 2009: p. 19; NEA, 2013: p. 33).

The need to advance from abstract visions of future frameworks for decommissioning and nuclear waste management is also heightened by industrial realities. Decommissioning is fast becoming a scalable industrial activity. By April 2020, 187 nuclear reactors had been shut down, many of which are at different stages of decommissioning. The largest number of shut down commercial reactors are found in the United States, the United Kingdom and Germany. Decommissioning has been fully concluded for 16 reactors, 13 in the United States and 3 in Germany (NEA, 2016a: pp. 25-27). A number of experimental and research reactors as well as fuel cycle facilities have also been fully decommissioned.

The long-term management and disposal of radioactive waste is also moving in several countries towards a more operational phase. Finland is furthest down the road by actually having begun construction of a DGR for the long-term storage of high-level nuclear waste at its Onkalo site. Sweden and France have selected sites and have for several years been testing conditions in underground laboratories. While these projects certainly add urgency to the global discussion on the frameworks and financing of long-term radioactive waste disposal, many other NEA countries are still far from operational stages and will still need to select the appropriate sites and the ultimately employed technologies. The existence of an operational DGR may also change the terms of the debate. On current planning, in many countries, however the actual loading of repositories will not happen before the middle of the century. This makes extended interim storage an ever more pressing issue, in particular for countries that have decided not to reprocess spent nuclear fuel. While it is not the primary focus of this report, clearly the development, communication and financing of comprehensive interim storage solutions for the next few decades need to be part of any coherent RWM strategy.

There are three additional reasons why this is a particularly appropriate moment to reflect on the adequacy of current funding arrangements. The first is that change is happening in NEA countries. A striking example is Germany, where in 2017 the liabilities for funding the long-term management of HLW were transferred from the operators of nuclear power plants to the Nuclear Waste Disposal Fund overseen by the federal government. In return, operators transferred all constituted assets plus a 30% surcharge to the Fund. However, also in Belgium, Spain, Sweden and Switzerland discussions about the appropriate sharing of responsibilities are under way and funding systems are evolving. These issues are echoed in international fora such as the NEA, IAEA and European Union, where questions about the adequacy of funding systems are discussed with a renewed interest in sharing national experiences and mutual learning.

The second reason is the continuing importance of nuclear waste management in general policy debates. While the potential role of nuclear power as a source of dispatchable low carbon electricity in greenhouse gas emission reductions is undisputed, it is still held back by doubts about its long-term sustainability. This is currently visible in the current discussions about a European *Taxonomy* for financial investments aspiring to be labelled as sustainable, notably so-called “green bonds”. The debate is also important as some countries are considering reinvesting part of their funding portfolio in projects that satisfy certain sustainability criteria. While investments in nuclear energy are currently not included in the *Taxonomy*, reflecting the current stalemate of nuclear policy at the European level, the key argument of those advocating an exclusion of nuclear investments is the long-term nature of nuclear waste (EU, 2019: pp. 234-5). Whatever the scarcity of sound information about the realities of nuclear waste management in EU policy debates, it is evident that developing long-term frameworks for nuclear waste management that are *politically* sustainable is imperative in order to enable the inclusion of nuclear energy in broader policy debates. A pertinent and generally accepted financing framework, capable of financing the first concrete steps of the process towards convincing long-term solutions is indispensable in this context. This holds also for countries that have decided to phase out nuclear energy and where there is strong demand for solutions that convey the idea that all relevant issues have been comprehensively dealt with.

The third reason that militates in favour of rethinking the funding of decommissioning and RWM is a macroeconomic environment that seriously challenges the central assumptions that underlie the current financing system. Since more than a decade, the returns on many financial assets, in particular risk-free or low-risk assets, have been considerably lower than previously. This holds, in particular, for government bonds, which in many countries traditionally made up a large share of the low-risk assets used by the managers of the portfolios of the funds for financing decommissioning and long-term RWM. Some funding systems also required to hold a minimum share of bonds, although there is a broad tendency among OECD countries to relax such constraints. Nevertheless, it continues to constitute a challenge for many funding systems to operate in an environment, in which in 2019 USD 15 trillion worth of government bonds, roughly one-quarter of the total market yielded *negative* returns in nominal terms, which translates in the great majority of cases in negative real returns. For macroeconomic policymakers and central bankers, the pervasiveness of financial assets with zero or negative yields is a concern that goes far beyond the adequacy of financing for decommissioning and RWM. However, there is also widespread consensus that chances are slim that yields on government bonds will ever return to historic levels. Yields on long-dated bonds over 20 and 30 years barely exceed those of short-dated ones.

This invalidates simple assumptions about the compounding of stable positive returns over many decades and funding adequacy understood as commensurability between assets and liabilities. Negative returns on investments would require today's constituted assets to be *higher* in nominal terms than future liabilities. This is far from fanciful as the case study of the United Kingdom shows. Adjustments following lower projected returns in other countries such as Switzerland also begin to feed through. Together with the uncertainties about the projected lifetimes of nuclear power plants, due to either long-term operation or politically decided early shutdowns, this raises a number of new questions about the adequacy of constituted funds.

None of this implies that the funding of the liabilities connected with the back-end of the nuclear fuel cycle is in disarray. Aware of the muted outlook for returns on low-risk assets, many funding systems have recently relaxed restrictions on the composition of their portfolios and now allow for assets such as equities, real estate or even private equity. Indeed, as low interest rates have inflated the prices of several asset classes, some funds for decommissioning and RWM have seen very healthy returns on their investments in recent years. However, this implies that the uncertainties about the level of available funds at the moment of disbursement are now larger than what could be reasonably assumed in the past. This is unlikely to be a passing phenomenon. The very low long-term interest rates on risk-free assets such as government bonds reflect, among other things, muted expectations for profitable investment opportunities and global growth. Either the returns on the assets of existing funds will remain durably lower than expected or their managers will need to diversify into riskier assets. A growing number of funds for the financing of the back-end of the nuclear fuel cycle are choosing this option. While this is entirely justifiable for well-diversified portfolios without immediate disbursement needs, NEA countries need to prepare themselves and their stakeholders for higher levels of uncertainty. Ideally, the changes in investment culture under way would take place in an explicit and systematic manner, as part of a common framework to discuss the changes under way and the most appropriate responses. This report aims to indicate a number of topics that would need to be addressed in such a future framework and be elaborated in the appropriate international and inter-governmental fora.

Differences between decommissioning and RWM

While the funding for decommissioning and the funding for nuclear waste disposal display a number of common elements, not least high levels of public scrutiny and low returns on risk-free and low-risk investments, a closer look will reveal that timeframes, the level of uncertainty regarding costs as well as the level of industrial maturity are quite distinct. These divergences warrant, in the majority of cases, somewhat different approaches and might lead to different conclusions concerning the path of future evolutions of the respective funding systems.

In the area of decommissioning, while national circumstances remain diverse and limit the scope for technical and financial economies of scale, international experience is being gained with ever more mature methodologies for cost estimation, impact assessment and technical feasibility. The challenge is now to allow competitive decommissioning markets to emerge through technical and organisational standardisation.

In the area of RWM and, in particular, final disposal, challenges for financing do not only relate to technology and industrial readiness but also possess a strong political dimension. If funding for decommissioning can progressively be handled convincingly by accounting conventions for large industrial enterprises, this is not yet the case for disposal of HLW and spent nuclear fuel. There is a strong scientific consensus regarding the feasibility of DGRs, but this category represents a broad range of actual solutions, which only in rare cases correspond to a technically and financially fully characterised industrial project. The final costs depend on technical and locational choices that have yet to be formulated and may vary by up to an order of magnitude. Frameworks for decision-making are evolving according to the social and political processes appropriate for each member country.

Today, decommissioning can be considered in most NEA countries as a mature industrial activity comparable to other large-scale industrial projects inside or outside the nuclear sector. To date, 16 reactors have been fully decommissioned (mostly in the United States) and a number of others (mainly in Europe) are currently evolving through the late stages of the process. Added experience has been gained with the decommissioning of fuel cycle facilities and research reactors. The United States are also seeing the emergence of a secondary market, where decommissioning liabilities are traded among industrial partners. In these cases, the market mechanism can already be relied on to minimise private and social costs. Information on decommissioning costs is widely available, see the recent NEA study on the *Costs of Decommissioning Power Plants* (NEA, 2016: pp. 28-9, 136), although, like in other industries, commercial confidentiality clauses can limit the publication of some data, and costs are not necessarily easily comparable across countries and projects.

During the past two decades, a substantial number of reports published in international fora have helped fill previous gaps in knowledge (see, for instance, IAEA, 2005a, 2005b; NEA, 2003b, 2010, 2015, 2016a, 2017). A number of institutional initiatives on these topics are also advancing the issue. These include the joint IAEA/EC/NEA project on the International Structure for Decommissioning Costing for Nuclear Installations (ISDC), the IAEA's DRiMa project on decommissioning risk management, the activities under the NEA's WPDD-Decommissioning Cost Estimation Group and Expert Group on Costs of Decommissioning as well as the European Commission's Decommissioning Funding Group (EC, 2013) under the Nuclear Illustrative Programme (PINC) (EC, 2017a, 2017b, 2017c). There are expectations that such mutual learning from decommissioning activities is likely to continue and will drive both the further codification of industrial standards and processes as well as a continuing decline in the overall costs of decommissioning.

Due to the long lead times and uncertainties associated with the planning and implementation of different RWM options, both in the medium and the long term, the literature on the costs and funding mechanisms for radioactive waste disposal is far narrower. Among the few available cross-country syntheses must be cited IAEA (2007) and (2009), EC (2013) and NEA (1999, 2013). Most of the available information is restricted to the national level and hard cost figures, as opposed to conceptually defined liabilities, are not always available. Primarily, this state of affairs is not due to any lack of transparency but stems rather from the particular nature of the information pertaining to RWM projects:

1. There is legal, regulatory and, for solutions envisaged for a far-away future, technological uncertainty concerning the options for RWM at the time of implementation. This regards, obviously, solutions for long-term disposal but also interim solutions such as long-term storage.
2. There is uncertainty about the costs even where technological options are well characterised and regulatory frameworks are stable. These are industrial constellations of bilateral monopoly or oligopoly (one customer and one or a small number of suppliers) with few pricing benchmarks. Many funding systems thus account for nuclear-specific inflation, i.e. cost increases specific to the nuclear industry. However, the samples for assessing such cost evolutions, even where they exist, are necessarily too small and too heterogeneous to allow reliable conclusions on future cost evolution.
3. Finally, there is uncertainty about the social preferences that will prevail during the run-up to and at the time of decision-making. The majority of NEA countries thus has not yet decided on a definite site for the final disposal of its spent fuel and radioactive waste. It is obvious that the choice of site and, even more so, the choice of options (size, packaging, retrievability, etc.) will have a significant impact on costs.

In most NEA countries, Finland, France and Sweden being notable exceptions, it is today still too soon to even provide reliable estimates for the costs of the options for interim storage and final waste disposal. However, this does not imply that all decision-making on appropriate funding systems needs to be put on hold. It is, for instance, quite possible also in the absence of firm costs figures to establish a societal consensus on certain magnitudes of constituted funds that will need to be attained at given points in the future. Ensuring the adequacy of funding, even in an environment characterised by strong *endogenous*, i.e. internally generated, uncertainties does require the firm definition of headline figures for liabilities so as to structure the debate. Adequacy of funding requires that such liabilities are matched by the sum of existing assets, future revenues from any levies on electricity consumption as well as any investment returns on the sum of the former two. The case studies in Part II of this report provide the most up-to-date overview of the liabilities for RWM in the NEA countries with the largest nuclear reactor fleets.

In the context of this report, however, it is important to understand the difference between liabilities and costs. The former are reference points defined by social and political processes. The latter are the private and social resources employed to realise certain technical solutions. The distinction is particularly important to avoid that future solutions are not "designed to cost", i.e. "designed to available funds", when they need to be designed to serve a given purpose at the lowest possible cost. Incentive compatibility is key in this context. It implies that each stakeholder (operator, vendors, regulators and governments) contributes to the common objective of efficiently realising a politically defined objective, while maximising its own legitimate individual objectives, be this profit maximisation, regulatory reach, re-election or other.

For instance, the fact that the cost of solutions for decommissioning and RWM solutions has consistently outpaced broader inflation measures could be an indicator of "moral hazard", i.e. the misalignment of incentives between different actors. It is important to understand that cost escalation is not an exogenous parameter but the result of a given incentive structure that impacts both operators (as the initially responsible party for ensuring adequate funding) and vendors on the one hand and regulators and governments on the other (see below).

A given amount of funds that has been constituted in function of an only vaguely defined technical objective will inevitably call forward solutions that will consider those funds as the lower bound of their future costs. One incentive-compatible solution would be to make the party that is responsible for the implementation of a given technical solution, typically the operator or the vendor, the beneficiary of any costs savings and the claimant of any unused funds. Effective oversight would need to ensure that all specifications and milestones are fully met.

This points towards a fundamental difference between optimal incentives in the case of decommissioning and in RWM. As far as decommissioning is concerned, where technical solutions are usually well-defined, and all sides have a clear understanding of the tasks, the incentive structure indicated above is largely implemented. Many decommissioning projects are terminated in a relatively short time, i.e. a decade or less. It benefits from increasingly experienced solution providers and an established global supply chain. In this situation, the operator constitutes the necessary funds, implements a specific solution, pays the vendor(s) for the required products and services, and gets to keep any residual surplus funds. His own objective of profit maximisation will ensure cost minimisation and thus social welfare maximisation. Vertical integration, supply chain consolidation and the emergence of a secondary market for decommissioning liabilities involving specialised enterprises can further enhance efficiency.

Things are very different in the case of RWM, where solutions can be far out in the future or subject to evolving political and social preferences. Typically, they are also adapted to the specific situation and requirements of a given country. Projects themselves take a long time. In such a situation, there exist large uncertainties and massive informational asymmetries. Each party involved has its own, necessarily partial and incomplete assessment of the situation. In the absence of codified solutions or benchmarks, each provider will enter even preliminary discussions with the top-of-the-line product with a hefty surplus to ensure himself against any uncertainties. Uncertainties on the side of regulators and governments will also push towards ever more sophisticated solutions. Political pressures will also skew discussions toward solutions that are perceived as the safest and most definite, which in the absence of other pertinent information may be the most expensive.

In such a situation of imperfect information and yet-to-be-defined solutions, making a private party the claimant of the residual of any constituted funds, which is appropriate in a situation of full information, will only provide incentives for rent-seeking. A considerable amount of resources will also evaporate due to transaction costs – eternal discussions back and forth, legal fees, recourses, re-designs, legal and political challenges and so forth. In such a situation, economic theory would suggest that one turns in the opposite direction, namely the integration of the definition of final objectives, technical solutions, funding and possibly even implementation under the responsibility one single actor. Given the necessarily political nature of the definition of final objectives, this actor can only be a national government.

As long as any solutions are still endogenous to complex, evolving decision-making processes such integration is preferable. That said, such a judgement applies in a given context of yet-to-be-fully defined solutions and a lack of fully codified technical solutions. In principle, if one day both social preferences and technical solutions were fully specified, different incentive structures could again be imagined. It is, however, difficult to conceive that the portion of RWM related to the treatment of high-level waste and SNF could be fully removed from the political realm. For the time being, the theory of incentives would suggest for RWM to also regroup funding and implementation under institutions maintaining a direct link with regulators and policy making. This would include, of course, also the transfer of accrued funds and future revenue streams to these entities.

On the nature of this report

This report aims to tackle these and a number of related issues in a three-pronged approach. Part I lays out the conceptual framework and the arguments in favour of shifting towards an approach that allows addressing long-term change in financing systems for decommissioning and RWM in a systematic manner. Part II will present twelve country studies of the funding systems for decommissioning and RWM in NEA countries, highlighting the key issues that need to be addressed to ensure long-term adequacy. Part III concludes with *Guidelines for Good Policy Practice* based on the conceptual framework, the country case studies and the feedback from member countries.

This report focuses on the adequacy and long-term economic sustainability of existing funding arrangements for decommissioning and RWM relating to commercial nuclear power plants. The objective is to identify areas where current economic, financial and institutional arrangements might be susceptible to improvement in the light of changing circumstances and social preferences. This includes a broader discussion of what applying the PPP in a sensible manner means in a context of very long timeframes and high uncertainty on both the cost and the asset side in different countries. The report thus does not focus on the technical validity of cost estimates or financial provisions per se but looks at the institutional, regulatory and financial mechanisms through which cost estimates and funding arrangements are determined, endorsed, communicated, implemented and revised. Key questions structuring this approach are:

- What are the current funding mechanisms and fund management models in place or under consideration for nuclear power plant decommissioning and RWM? How are cost estimates and associated risks and uncertainties integrated in the working of the funds?
- Do recent evolutions in the funding arrangements retained by NEA countries present discernible trends; can they provide evidence for general, concrete analyses on international good practice?

The present report deliberately avoids second-guessing existing cost estimates or the adequacy of constituted assets in a narrow sense. It proceeds on the quite reasonable assumption that existing estimates of both assets and liabilities have been prepared competently according to best available information. Its objective is rather to highlight the potential pitfalls of building financing systems exclusively around fixed point estimates. The emphasis is thus on institutional processes, best practice and, in particular, the management of residual, unquantifiable risks. By definition, such unknown unknowns cannot be included in any quantified assessments but will inevitably arise during the complex long-term path towards the final disposal of HLW. Yet funding arrangements will need to be robust and flexible enough to deal with them, preferably with the help of routines that have been announced and validated in advance.

One thing that does not change in this report compared to earlier studies or reports is an emphasis on the importance of country specificities in the design of sustainable funding systems. If, of course, common challenges and approaches can be identified, ultimately funding systems for decommissioning and radioactive waste disposal depend on the political legitimacy that can only be ensured at the level of the individual country. Highlighting the importance of country specificities does not diminish the value of international co-operation in fora such as the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) of the OECD Nuclear Energy Agency, which supervised this study. During the preparation of this report, regular exchanges were also held with the NEA Committee on Radioactive Waste Management (RWMC), the NEA Committee for Decommissioning and Legacy Management (CDLM), the IAEA and the Decommissioning Funding Group (DFG) of the European Commission.

Preparation of this report has been greatly facilitated by prior work as well as the fact that in all NEA countries, mechanisms for providing funding for decommissioning and RWM are in place and based on national law or regulation. However, they differ in the way the funds are accumulated, the oversight, and even in the scope of funding according to different national legislation and practices. In the area of decommissioning, the variability of strategies between countries, utilities and power plant characteristics leads to differences in cost estimates and, ultimately, in funding schemes (NEA, 2003b: p. 10). Because financing programmes are also based in many different regulatory and legal systems, it remains very complex to define international standards or universal best approaches to ensuring the availability of decommissioning funds (NEA, 2016b: p. 8).

Likewise, appropriate national arrangements for RWM are well established in most countries with advanced nuclear power in compliance with the internationally acknowledged principles and requirements that are to be transposed into national legislations. However, the definition of the policies for RWM (and especially for SNF/HLW management) remains influenced by a wide range of country-specific factors and sovereign choices. Regarding SNF management, there has been a clear divide between countries that have adopted reprocessing and those who have not. Additionally, a number of countries such as the Netherlands, Spain or Korea have been holding off from developing a single strategy for the disposal of HLW and instead retained a number of options (NEA, 2013: pp. 32-6).

This report thus greatly benefits from previous studies on decommissioning and RWM at the NEA and elsewhere in general and on previous work on their financing and costs in particular. The primary objective of this report is to enlarge the conceptual framework in which these issues are approached in order to render current approaches and discourses less schematic, more flexible and, hopefully, more pertinent to the specificities of a policy challenge that is unlike any other. In addition, it provides an updated overview of the arrangements for the funding of the back-end of the nuclear fuel cycle in all major NEA countries as well as the policy dynamics that pertain to it. By looking at these arrangements in a broad, long-term perspective, its aim is to illustrate both where necessary evolutions are under way already and where adopting the proposed framework could suggest new options in the future. This is at the same time a very modest and a highly ambitious objective. It is modest in terms of providing definite policy prescriptions; it is ambitious in terms of adjusting the conceptual framework in which these policy prescriptions are being developed. The Recommendations for Best Practice in Part III reflect this nature of the report.

Chapter 2

From a linear to a circular approach in conceiving the adequacy of funding[1]

Current approaches to the adequacy of funding for decommissioning and radioactive waste disposal typically use a simple linear decision-making framework relying on the assumption that key parameters such as future costs, the discount rate, the return on capital or the operating lifetimes of nuclear power plants will remain stable for several decades. More sophisticated frameworks include assumptions about cost changes or work with stochastic confidence intervals without abandoning the linear logic.

The present report is instead proposing a *circular* decision-making framework, in which all elements of the system can vary, while continuing to feed into each other. Adequacy of funding is thus not defined by comparing two numbers with a considerable degree of uncertainty, typically the discounted amount of future assumed costs and accrued funds, but by the manner in which changes in key parameters such as costs, discount rates and rates of return as well as operating lifetimes and assumed revenues influence all other elements of the funding system.

The starting point of a linear approach in the area of RWM is a cost estimate for a future waste management solution, typically a DGR, at a given point in time in the future, say, 2070. This cost estimate, either based on current or assumed future technologies, is then discounted at an institutionally defined social discount to the present, which defines the amount of funding that needs to have been constituted at this moment. This amount will then determine the defined contributions that nuclear operators need to include in cost estimates and pricing formulas based on expected load factors and lifetimes. In a case where the rate of return on accrued funds corresponds to the social discount rate, the funds constituted by the defined contributions and compounded by their annual returns will precisely correspond to the financing needs at the time of implementing the chosen RWM solution. While this framework to ensure the adequacy of funding of RWM is conceptually coherent, it is also sustained only by several unproven and largely unprovable assumptions.

In principle, the same linear framework applies to ensuring the adequacy of funding of decommissioning obligations. Nevertheless, there are a number of important differences between RWM and decommissioning. The first one is that the ultimate objective, return to greenfield, is well-defined and unlikely to change. In addition, the technical solutions to arrive there are based on technologies that exist today. The latter are largely well known by nuclear operators and their subcontractors and can thus be assessed, both technically and financially, in terms of reasonable expected values of known probability distributions. In addition, the timeframes are usually shorter, which reduces uncertainties on the funding side. To the extent that decommissioning solutions are implemented by private actors according to well-codified legal obligations, the market rate for long-term investment provides the appropriate parameter for ensuring the adequacy of funding for decommissioning liabilities.

None of this means that the linear frameworks applied implicitly or explicitly by NEA countries, even when assessing the funding needs for RWM solutions, were either based on false premises or useless. Far from it. Many countries have also very sensibly adapted elements of the system in an implicit manner while continuing to refer to a linear approach in principle. The particularity of

1. Including a special section on discounting.

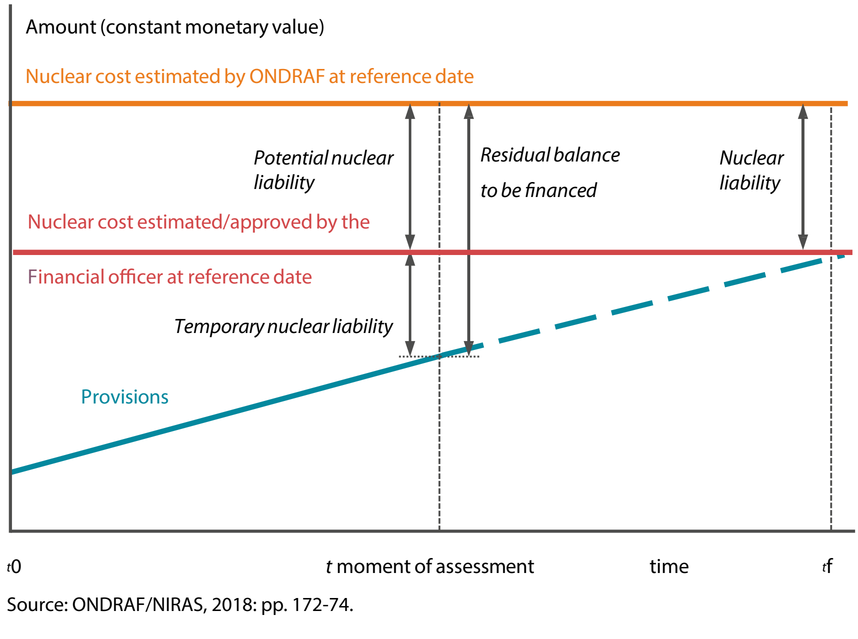
constituting financing frameworks for liabilities that will often fall due only many decades in the future is that whichever assumptions are made regarding key parameters, they can only provide limited guidance for assessing the adequacy of funding. Even sophisticated stochastic frameworks (see for instance the case study of the United States) are of limited predictive power if assumptions of key parameters, e.g. the availability of certain political or technical options, change.

At the same time, pursuing the notion of a given technological solution with a reliable cost estimate and the predictability of rates of return and lifetimes has allowed NEA countries to set up funding systems for decommissioning and radioactive waste disposal that provide a solid starting point. Overall, the current funding for the back-end of the nuclear fuel cycle, which in most NEA countries is based on segregated funds with substantial endowments, provides a robust base for any adjustments that may become necessary in the future. However, to strengthen the adequacy of funding further in an environment characterised by great long-term uncertainties, it is important that such adjustments be made in a framework that recognises that equating costs and available assets may require a readjustment of existing structural parameters as well as detailed liability arrangements.

Assessing the adequacy of funding of these systems in terms of a simple comparison of current assets compounded with hypothetical rates of return over several decades with future liabilities based on current technologies and assumptions requires several large leaps of faith. In addition, as pointed out in the preceding chapter, the limited lifetime of many nuclear operators, a trend toward long-term operation of nuclear power plants, new options such as extended interim storage and lower long-term expectations for returns on risk-free or low-risk investments are forcing changes to existing systems that cannot be accommodated by the existing linear approaches. The level of liabilities for decommissioning and RWM will also depend on changes in regulation or policy. Consequently, funding plans need to be more flexible than for plans designed for the retirement of conventional assets (Laraia et al., 2012: p. 32).

A typical figure exemplifying the linear approach to the adequacy of funding is provided by the Belgian organisation tasked with the management of liabilities for RWM, the ONDRAF/NIRAS. The proposed approach allows, in principle, a straightforward manner of estimating adequacy and identifying potential funding gaps. The funding mechanism needs to cover the anticipated costs at time tf. This allows calculating the annual contribution (*provisions*) to the fund. At any time t, one can identify a temporary funding gap, the difference between the originally estimated costs and the constituted provisions. One may also identify potential additional funding gaps in case cost estimations by ONDRAF/NIRAS exceed the original estimate based on which the annual provisions have been calculated.

Figure 2.1:
Simplified representation of the funding assessment system in Belgium

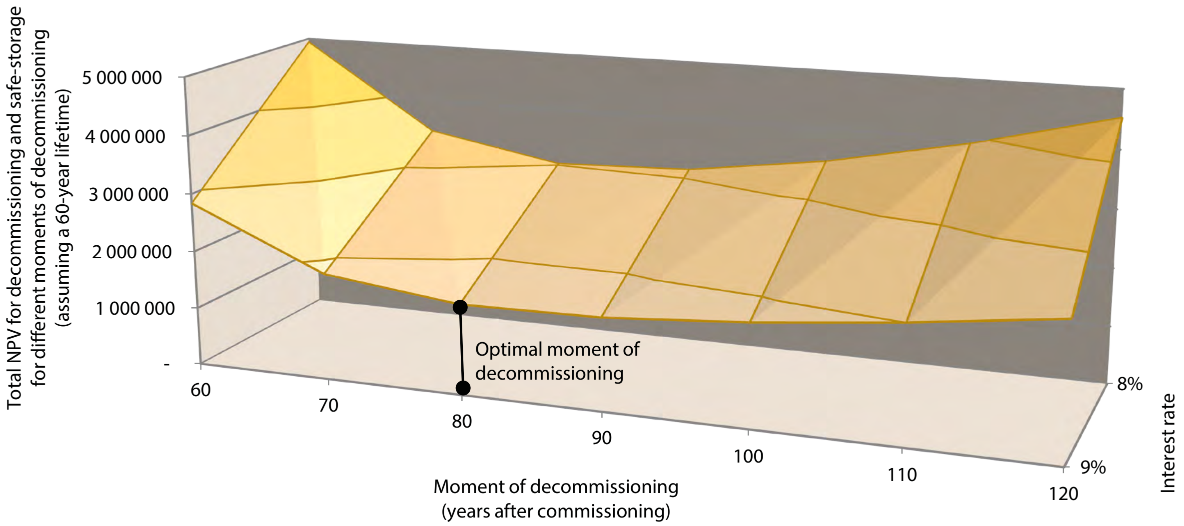


Source: ONDRAF/NIRAS, 2018: pp. 172-74.

Of course, the linear approach can be rendered more sophisticated in a great number of ways. Countries such as the United States or Sweden have worked with Monte Carlo simulations using probability distributions over costs and returns. Other approaches aim at optimally timing either decommissioning or the disposal of radioactive waste. Of course, the optimal timing will be a function of discount rate but also of any nuclear-specific cost inflation, the rate of radioactive decay or the speed of obsolescence of accumulated knowledge (see Figure 2.2 below). The latter is of concern primarily in decommissioning as staff familiar with the specific outlay of a reactor retires between the halt of operations and the beginning of decommissioning.

Such approaches allow varying degrees of precision in arbitraging between different key parameters. Independent of their relative sophistication, their usefulness depends entirely on the stability of those parameters. In some cases, it is not even sure whether the sign of such changes is positive or negative. Several countries expect both decommissioning and RWM to be subject to cost increases that are specific to the nuclear industry, partly due to heightened safety concerns and increasing regulatory stringency, partly due to the difficulties of aligning incentives due to informational asymmetries. At the same time, great hope is stored in the cost decreases due to technological progress over time. Such questions do not arise only on the cost side. As has already been pointed out, the level of contributions, the length of time of accrual, depending on the lifetimes of both operators and plants, as well as the return on capital, are all subjected to high levels of uncertainty.

Figure 2.2:
The net present value in function of timing and discount rate



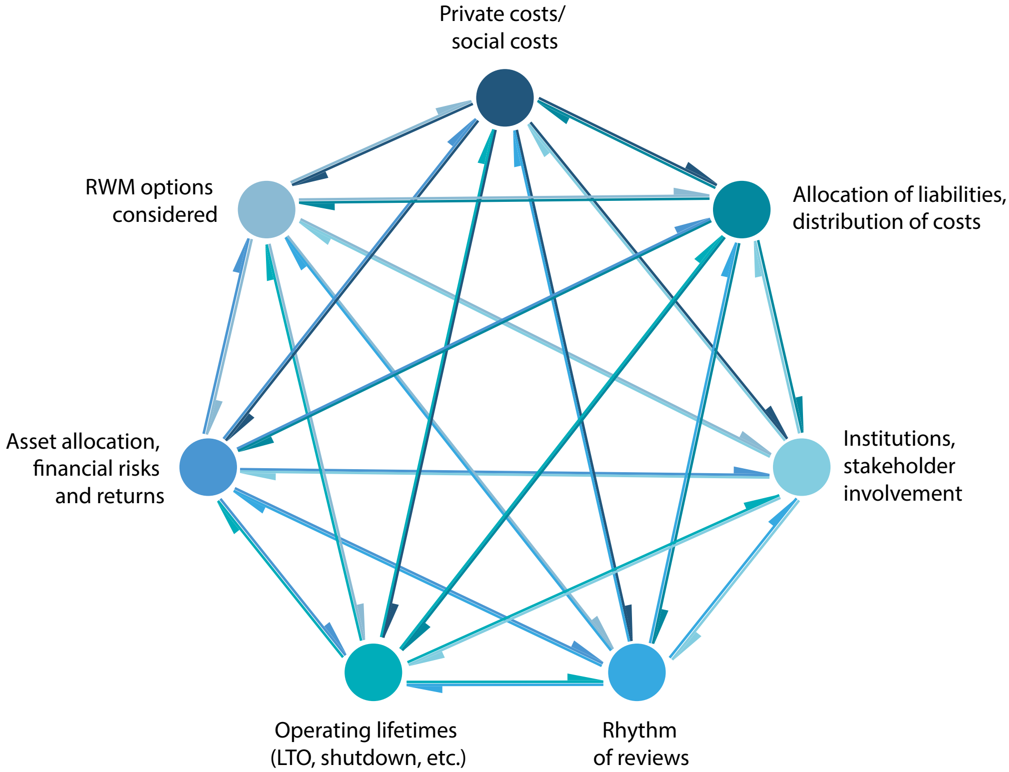
Source: Keppler and Rothwell, 2016: p. 13.

Of course, as long as the realised parameters can be expected to be part of a probability distribution with a defined expected value, such calculations make good sense. This is why this linear approach of discounting future expenditures, suitably adapted by expected rates of change, has been adopted widely, implicitly or explicitly, among NEA countries. As has been argued in Chapter 1, it is incomplete if there is a significant risk of large discontinuous changes, e.g. due to political, technological or economic ruptures. The challenge is to maintain the robustness of funding systems in the presence of such radical uncertainty at a moment where a number of framework conditions are also changing significantly. The latter include both energy policy making, the structure of electricity markets as well as the workings of the financial system. Ensuring robustness is even more necessary as NEA countries are moving from a phase of setting up and putting money into their funding systems to a phase of beginning to pay out and finance actual projects in decommissioning and RWM.

Ensuring robustness is precisely what motivates the conceptualisation of a circular approach for funding systems for decommissioning and RWM that correspond to the unique context, in which they take place: long delays between current decision-making and eventual implementation, a high level of residual uncertainty concerning technologies and costs as well as considerable political sensitivity. This circular approach is based on five principles:

1. *Interdependence and bi-directional causalities*: All elements are interconnected with all other elements of the funding systems; a change in one parameter might require an adaptation of all other parameters. Causalities are complex and bi-directional.
2. *Endogenous nature of cost estimates*: the costs of decommissioning or RWM are not an objective, exogenous number but depend on political, regulatory and technical choices. This holds even if there exists a stable consensus for a given category of solution, such as DGRs.
3. *Adaptability*: All elements, including cost estimations, expected revenues and the allocation of liability between different stakeholders must be able to adapt to endogenous changes (e.g. changes in political and social preferences) and exogenous ones (e.g. changes in economic framework conditions or the return on assets).
4. *Possibility of discontinuous changes*: Technological changes and political choices can introduce discontinuous change requiring radical adaptations outside initial assumptions.
5. *Regular revisions with stakeholder involvement*: Revisions must take place at regular intervals that are specified in advance, legitimated by appropriate democratic and institutional processes and involve all stakeholders.

Figure 2.3:
A circular framework



While quite distinct from the assumptions that underlie existing approaches to ensuring the adequacy of funding, these five principles should not be read as so many criticisms of linear approaches with their unidirectional causality from assumed costs to estimated assets. While the linear framework is too simple, it remains an obvious and, as long as all stakeholders are aware of its limitations, useful starting point. As mentioned, the transparency and simplicity of the linear approach, even if to some extent fictitious, have been instrumental in setting up and getting broad approval for funding systems. The conventional linear approach has also allowed establishing an informational infrastructure and clear legal obligations (see, for instance, NEA, 2003a: p. 4; NEA, 2006: pp. 27-8). Liabilities may not be allocated in an economically efficient manner; yet at least they are clearly indicated. Nuclear installations and sites that contain radioactive material are clearly identified and cost estimations, however uncertain, are established. Moreover, whatever information becomes available is updated regularly.

In addition, the linear approach is grounded, at least in principle, in economic theory, in particular Cost-Benefit Analysis (CBA), which is also the basis for the PPP. Of course, both approaches depend on the availability of reasonably reliable data about costs and benefits. Their role in providing building blocks of welfare optimisation is suspended as soon as such data is no longer available.

The link between the circular approach to ensuring the adequacy of funding for decommissioning and RWM and a normative framework of welfare optimisation is more roundabout. Economic theory is never comfortable with the dynamic adaptation of parameters. The dynamic approach thus picks up where the standard framework has shown to be no longer adequate, as many of its key assumptions can no longer be considered stable. Ultimately, of course, the circular framework is also committed to welfare maximisation and social cost minimisation. However, it can achieve these objectives only in an implicit manner, precisely because the very notions of cost, benefits and welfare are not unequivocally defined in a process that spans over several decades and involves multiple societal stakeholders. In other words, adequacy of funding of the back-end of the nuclear fuel cycle is very much a moving target and should be approached as such.

The essence of the circular approach is that a necessary evolution of the system can be triggered by any given element of the system. This could be a change in economic framework conditions, a political decision to shorten or extend the operating lifetimes of nuclear power plants, a new technological or legal option for RWM (e.g. the possibility to export high-level wastes or participation in a multilateral repository), or new societal pressures to accelerate or delay the implementation of RWM solutions. Causalities are also not considered as being one-directional but bi-directional. Changes in one element would imply, in due time and after careful consideration and consultation, adaptations in all other elements. As an example, take lower-than-expected assets at a given point in time due to adverse macroeconomic framework conditions. The only solution implied by the linear approach to rebalance the system is an increase in the decommissioning or RWM fee included in electricity tariffs in order to reach the defined future target. In a circular approach, this remains an option. However, an alternative option might be intensifying the search for different and less costly technical solutions. Yet another one would be to diversify investments into riskier but higher-yielding assets coupled with a government guarantee to make up for any shortfall if it should still materialise at the time of disbursement.

The circular approach considers in particular RWM a societal and political issue as much as an industrial and commercial issue. This does not imply freeing operators and their customers from their financial obligations, which are part of the original social contract under which nuclear power plants were constructed and operated. However, once they have paid their fair share – and fairness is here a political question to be decided at the national level – operators and their customers are probably not the party best placed to assume long-term residual risks, most of which arise in areas outside their competence or even legitimacy. The choice of location of a DGR, a parameter highly relevant for costs, is not for an electricity company to decide. Even if it organised the process, this could, depending on circumstances, pose difficult legal and administrative questions.

Some countries have chosen to reprocess radioactive waste streams, completely or partially, aiming for the closure of the nuclear fuel cycle and a reduction of the needs for final disposal capacity. In such cases, circularity needs to be considered in an even broader sense, where financial decisions affecting the funding of RWM are interlocked in a circular way with those affecting energy and waste streams. All three dimensions, finance, energy and materials, will then need to be approached in a way that foresees continuous adjustments to each of them to ensure the optimal interrelation of the technical and material system with the economic and financial system in order to determine funding needs and their appropriate financing.

The longer the timeframes and the less codified the solutions, the more malleable the different parts of the system inevitably become. This is where the alignment of private and social incentives, which works so well in a pure market economy with fully codified goods, can no longer be taken for granted. Whatever the final financial liability arrangements, and different countries will choose different solutions, governments will need to take responsibility for a dynamic process that is likely to reveal challenges and potential solutions many of which are unknown today. As has been said before, in many cases such dynamic adaptations are already taking place in an entirely sensible manner. A linear funding system with a sufficient number of regular revisions, stakeholder involvement and feedback loops between different parameters is nearing a circular approach. However, the overall conceptual framework in which funding systems are presented to policymakers and the wider public is still very much couched in the terms of a linear approach. This can limit the search for a broader set of options in terms of technology or timing or necessary adaptations to bring all parameters into line.

The circular approach to ensuring the adequacy of funding for decommissioning and RWM thus also aims at optimising long-term economic welfare, including all social benefits and costs, mindful that it is operating inevitably in a dynamic context shaped by changing societal preferences, policy decisions and technologies. This offers also greater flexibility in distributional issues. One of the potentially problematic issues in the linear approach is, for instance, that concrete technical solutions are not designed to correspond to social preferences and political objectives in a least-cost fashion but rather to exhaust available funds. In other words, there is a risk that technology providers in the fields of decommissioning and RWM will extract rents by ensuring that the ultimate costs of any potential solution correspond precisely to available funds. The risk is particularly high as informational asymmetries are large and most back-end solutions will be bespoke, i.e. few international benchmarks exists, and there exist few alternative uses for the available funds. This is why it is important to have provisions that allow returning or otherwise employing any unused funds, once agreed policy objectives have been attained.

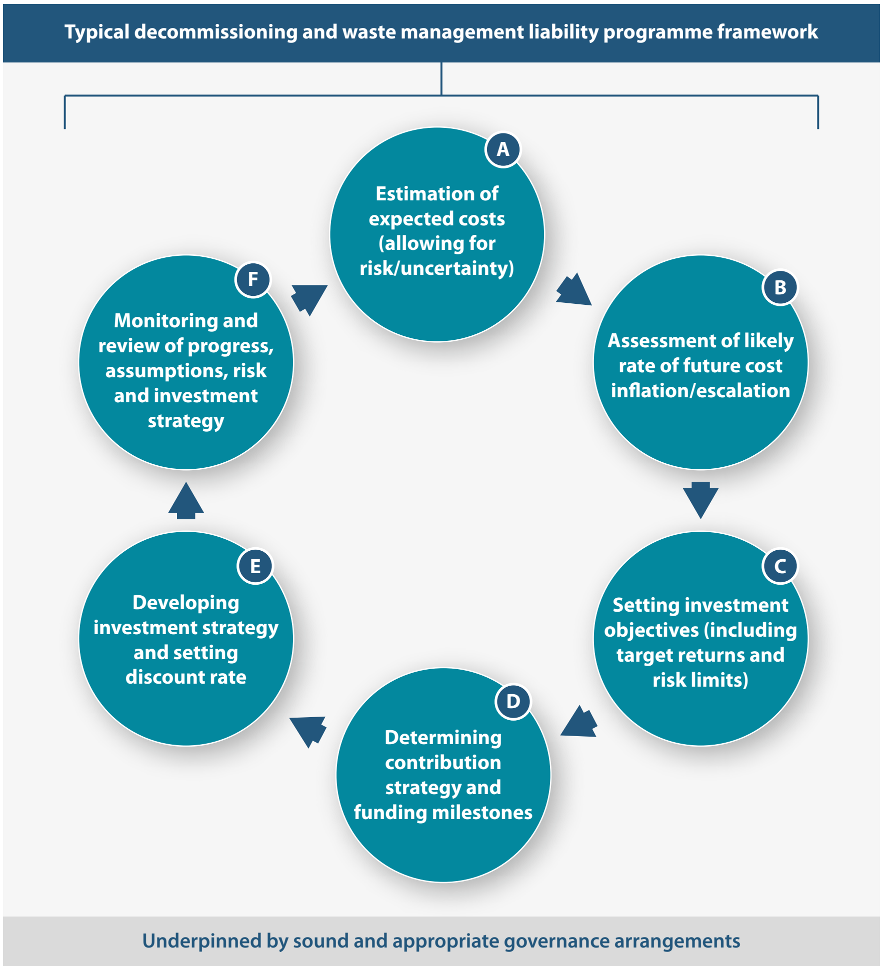
However, one should note that adaptive or circular approaches do not imply perennial uncertainty. Changes in key parameters or respective responsibilities will play out over time gradually and deliberately. Timeframes will be measured in years or even decades. A key point is to put into place institutional processes that can organise the adaptation of the funding system in function of changing circumstances as well as political decisions on particular funding options. Several NEA countries, for instance, have revised or are considering revising both the expected rates on returns of the already constituted assets and the composition of the portfolios of their funds for financing decommissioning and RWM. Given changes in economic framework conditions, this is a rational and even necessary process. However, even more important than the specific assumptions concerning rates of return are the processes, institutional settings and distributional arrangements in which such revisions take place. Ultimately, the financial sustainability of the funding systems depends on the political sustainability of their overall framework, the perceived fairness of their decision-making processes and the set of technological options they consider.

Of course, the graphic representation provides only a general indication as to which causal relationships might exist. In addition, there is necessarily a cyclical component in the sense that the circular motion needs to be completed at regular well-defined intervals. Regular reviews are practised in some NEA countries but are usually limited to adjusting defined contributions if expected rates of return differ from original assumptions.

A hybrid between a linear and a circular approach was sketched in the so-called *Risk Study* of the European Commission, European Commission (2018). While it suggests cyclicality, the process is driven in each round by an "Estimation of expected costs" (A) from which all other elements of the system will be derived in a one-directional causality (see Figure 2.4).

Finally, one needs to keep in mind that circular approaches are already implicitly being practised at several levels in many NEA countries. This however is taking place in an implicit rather than an explicit manner, as policies are still couched in terms of a linear approach of mechanically discounting hypothetical future costs and integrating those into electricity prices. In this perspective, the present report primarily aims at providing the building blocks for a more coherent and systematic conversation on the changes that, under the pressure of necessity, are already taking place in many countries.

Figure 2.4:



Source: EC, 2018.

Special section: Discount rates

Discounting converts expected future costs for decommissioning and RWM into the net present value (NPV) of liabilities, which needs to be matched by currently constituted funds.[2] In principle, the discount rate should match the long-term expected rate of return on those funds. If the rate of return corresponds to the discount rate, available funds will correspond precisely to expected costs once decommissioning and disposal get under way. As long as the discount rate is positive, an assumption that was unchallenged for the longest of time but can no longer be taken for granted (see below), the holder of the liability needs to set aside only a fraction of the estimated costs, the remaining fraction being raised through the process of capital accumulation. Obviously, the validity of this approach depends entirely on the correctness of the assumptions on the discount rate, rate of return on capital, the timing of liabilities and the expense schedule, assumptions that usually remain unchanged over long periods.

2. In order to keep the argument simple, we abstract in the following of this section from any future expected payments by electricity consumers such as waste or decommissioning fees included in electricity tariffs that would still need to accrue. In other words, nuclear plants have been or are about to be decommissioned. We also assume that RWM consists of a combination of interim storage at very low costs over a defined period and disposal by way of a deep geological repository at the end of this timeframe. Of course, reality is more complex. This is also reflected in the work prepared in the framework of the linear approach. The point has never been that the linear approach lacks sophistication. The point is that it considers key parameters such as the discount rate in isolation. This deprives decision-makers of necessary degrees of freedom once assumptions turn out to be erroneous.

While the rate of return on existing funds is determined by capital markets, discount rates are set by the managers of decommissioning and waste disposal funds and their political taskmasters. While returns on capital accrue in the future over the coming decades and are thus unknown, discount rates have to be defined ex ante. Ideally, they would be defined based on an estimate of future long-term returns on capital. In practice, it is hard to reconcile some of the assumptions being used for discount rates in NEA countries with information stemming from capital markets. At the end of March 2020, the real return on inflation-protected US 30-year bonds (Treasury Inflation-Protected securities or TIPS) stood at -0.08%. US Treasury bonds are a global benchmark and, because of their liquidity and the credit worthiness of the US government, define what is considered the risk-free rate of return. Countries such as France, Germany, Japan or the United Kingdom operate in very similar conditions and offer nominal rates between -0.04% (Germany) and 0.9% (UK) on long-dated bonds, which, when inflation is taken into account, also amounts to real returns very close to or below zero. This means that current funds, for the portion they hold in bonds, would essentially already now need to cover future liabilities fully, if they wanted to avoid any of the risks associated with higher average returns.

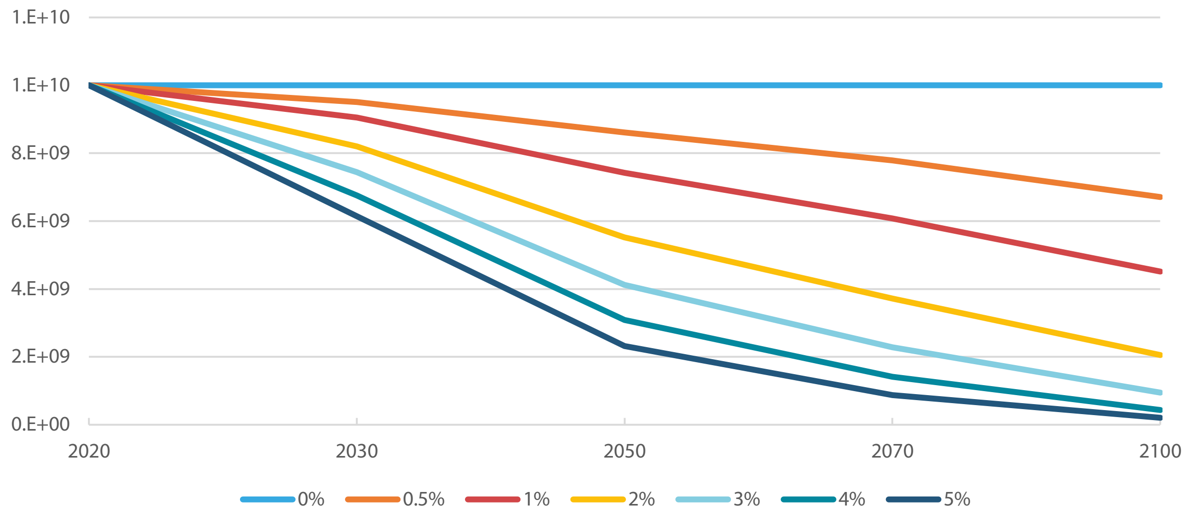
Of course, not all the assets of the funds for financing decommissioning and RWM consist of governments bonds and the tendency is rather towards reducing the latter's share primarily for the reason mentioned. The question is then to which extent branching out into assets that promise higher returns such as shares, real estate, infrastructure hedge funds or private equity translates into higher financial risks. In recent years, such higher-risk assets have consistently outperformed low-risk assets such as cash or bonds with little evidence of sudden downward shifts. They have been supported in this by very expansionary monetary policies often practicing what is referred to as "quantitative easing", i.e. buying bonds to inject a constant flow of new liquidity into markets. Expansionary monetary policy has been in place in all OECD countries since the economic crisis of 2008 and has led to what some observers refer to as "asset price inflation", continuing high and rising prices for all financial assets. Indeed, many investors as well as several funding systems for the back-end of the nuclear fuel cycle have benefitted handsomely from this state of affairs. One can state with some confidence that despite the low returns on low-risk assets and even under a large array of assumptions there are no signs anywhere of a crisis in the funding of decommissioning and RWM liabilities.

Nevertheless, despite the historically unprecedented monetary conditions, the shortage of low-risk assets with reasonable returns pushes investors into higher-risk assets. As long as investors are risk averse, and for obvious reasons funding systems for politically sensitive long-term projects should be particularly risk averse, there is a trade-off between rewards and risks. Bluntly, riskier investment strategies imply a higher risk of shortfall at the time of disbursement. To some extent, such risks can be managed through standard investment strategies such as diversification and hedging. To another extent, risks can be tailored to the specific needs of funding systems, e.g. they must decrease as firm financing commitments approach. None of this does away with the fact that in current macroeconomic and monetary conditions, it has become more challenging than ever to hit a precise level of funds at a given date in the future with reasonable certainty, something that was possible in the past, for instance, with indexed bonds. Building added flexibility in terms of timing, technology, location, holders of residual risk, etc., into the funding system is thus a particularly appropriate strategy under current circumstances. A particular question in this context is to which extent the remaining risks can be adequately handled by individual market actors such as electric utilities and to which extent government, capable of covering any shortfalls either by fiscal or monetary means, would be better placed.

In practice, the detailed methods for calculating and reporting liabilities differ between countries and sometimes between operators. In many cases, the discount rate and hence the present value of the assumed future liability is adjusted periodically as the cost estimates evolve owing to technology progress, regulatory changes and inflation (NEA, 2003b: pp. 49-50; NEA, 2005: p. 56; Laraia et al., 2012: pp. 72-3). Switzerland provides a recent example. However, in many countries such changes take place in an ad hoc manner rather than systematically at pre-defined intervals with broad stakeholder involvement. It is safe to say that the great majority of countries have not yet adapted their funding systems to the environment of very low or zero long-term rates of return that has evolved in the wake of the 2008 financial crisis and the unorthodox monetary policies that followed. The coronavirus crisis of spring 2020 only reinforces this point.

Just how crucial assumptions about discount rates are is highlighted by the examples in Figure 2.5. The NPV of a future liability of USD 10 billion at the time of disbursement corresponds to the amount that the holder of the liability, which today in most countries is still the operator of the nuclear power plants, need to holds in terms of constituted funds today in 2020. The further out in the future the funds for financing radioactive waste disposal will have to be disbursed, the more important assumptions about discount rates become.

Figure 2.5:
Net present value in 2020 of a USD 10 billion liability in 2030, 2050, 2070 or 2100 at different discount rates



If discount rates are zero for the foreseeable future, then currently available funds will, of course, also need to correspond to USD 10 billion regardless at which point in time disbursement takes place. The picture changes dramatically with positive discount rates. Taking a 3% discount rate and a time lag of 50 years between decommissioning and the disbursement of funds for, say, building a DGR, which are entirely reasonable assumptions used by several countries. The funds constituted today would only need to be USD 2.2 billion or 78% less. Higher discount rates and longer time lags would reduce the amount of required funds even further. Waiting until the end of the century, which is not an absurd proposition for radioactive waste disposal, and assuming a discount rate of 5% would oblige the holder of the liability to hold in 2020 only 2% of the final amount. The implications for power plant operators are obvious.

Table 2.1:
Annuity required to finance a USD 10 billion liability in 2030, 2050, 2070 or 2100 at different discount rates starting in 2020

Discount rate	2030	2050	2070	2100
0%	1 000 000 000	333 333 333	200 000 000	125 000 000
0.5%	977 705 727	309 789 184	176 537 580	101 970 359
1%	955 820 766	287 481 132	155 127 309	82 188 501
2%	913 265 279	246 499 223	118 232 097	51 607 055
3%	872 305 066	210 192 593	88 654 944	31 117 457
4%	832 909 443	178 300 991	65 502 004	18 140 755
5%	795 045 750	150 514 351	47 767 355	10 296 235

The same issue can be looked at through the lens of ratepayers, i.e. the annual amount that ratepayers would need to generate in order to finance the USD 10 billion project at the stipulated time. The orders of magnitude are comparable, but the timing of the project and the period during which the payment accrues are now even more important. Building the DGR after ten years at zero discount rates would require an annual contribution of USD 1 billion. In comparison, a 50-year delay at 3% would reduce this amount by more than 90% to USD 87 million. Finally, at a discount rate of 5% and a delay until 2100 (assuming that payments would be smoothed over the whole period), annual contributions would need to be only in the order of USD 10 million.

Quite obviously, setting discount rates is a key element, perhaps together with the allocation of liabilities the key element in any effort to ensure the adequacy of funding arrangements. This is not only a technical question. Discount rates determine the rate at which future revenues and liabilities are taken into account in present economic decisions. They thus determine the trade-off between the well-being of the present generation and that of future generations. They are a crucial element in the social contract that underpins a society.

Discount rates also reflect the fundamental risk surrounding future projects. This may concern their construction and cost risk, their future benefits or simply the fear of not being around anymore in order to benefit from them, which in economic terms is the basis for the time preference of consumption. Traditionally, social discount rates of the kind used in the calculation of the net present value of public sector projects were *lower* than private discount rates that corresponded to the costs of capital, typically the rate banks would pay on deposits or ask for loans. Since the discount rates for decommissioning and radioactive waste disposal are set by regulators and governments, it makes sense to consider projects in this area under the same angle as public sector projects.

There were good economic reasons for assuming that public discount rates should be lower than private discount rates. Governments should care for the welfare of future generations and thus discount their utility less than private individuals would. This is, in particular the case if countries subscribe to the *Intergenerational Equity Principle*. This stipulates that each generation benefitting from nuclear power should deal with its radioactive waste in a manner that protects human health and the environment, now and in the future, without imposing undue burdens on future generations.

Large public sector entities frequently also have lower costs of capital due to implicit or explicit government guarantees. Governments can provide such guarantees at low or even zero costs because their own risks from these projects are very small due to two separate effects. First, governments can reduce their overall risks by pooling a large number of projects whose individual risks offset each other (risk pooling). The Arrow-Lind theorem by economists Kenneth Arrow and Robert Lind even holds that the social costs of the risk related to public sector projects would go close to zero as the government can spread the risks of any single project over a very large number of tax payers, on whom the ultimate success or failure of the project would only have a negligible impact (risk spreading). Of course, all of these considerations depend on a number of assumptions. However, most of them are reasonable and for decades there has been a stable consensus that social discount rates set by governments should be lower than private discount rates.

However, the ability of governments to borrow at costs lower than any private party must be balanced against considerations of efficiency and distributional fairness. Just because governments are capable of borrowing at lower rates, this does not imply that they are automatically best placed to take on the tasks of decommissioning and RWM. The previous chapter already mentioned the principle that responsibilities for risky endeavours should be allocated to the party that is most likely capable to have an influence on the level of the risk. In the case of decommissioning, an industrial activity, this is unlikely to be the government. Its ability to drive technological progress would also favour the private sector. In the case of RWM instead, which frequently involves arbitraging between strongly held social preferences and making political choices, governments may indeed be better placed than private actors to identify cost-effective solutions in the broadest possible sense. Legal obligations, for instance the obligation to dispose of radioactive wastes inside national borders, may further limit the applicability of economic principles. There thus exists a trade-off between technical efficiency and, for want of a better word, regulatory or political efficiency. Both are important, their relative importance, however, is likely to be different in the context of decommissioning and RWM.

The discussion whether the private or the public sector is better placed to resort to low-cost financing in order to minimise the costs of decommissioning and RWM has been thrown into disarray due to extremely low private interest rates, far lower than the 2% or 3% historically associated with social rates. As mentioned earlier, the latter are now close and in some countries below zero. The implications for funding systems are clear. To the extent that the rates indicated by bond markets are anything to go by, NEA countries will need to adjust significantly the cost assumptions, the defined contributions or both in order to ensure the long-term adequacy of their funding systems.

Currently, the assumptions of NEA countries regarding discount rates, both real and nominal, and inflation vary widely, even between countries of the European Union (see Table 2.2 below showing values drawn from the 2016 *Risk Study* of the European Commission). Germany uses the highest nominal discount rate with 4.6%, whereas the Slovak Republic uses a discount rate of only 1.1%. This is related to the fact that the coverage ratio, i.e. the ratio of assets over liabilities is 173% in Germany and only 11% in the Slovak Republic. Inflation rates (which are the sum of general inflation and nuclear-specific cost inflation) range between 4% in the UK and 1.6% in France.

In real terms, rates vary from 2.6% in France and -0.8% and -0.9% in the UK and in the Slovak Republic. In other terms, in the latter two countries current funds will have to exceed the real value of future liabilities. This is a rather counter-intuitive proposition, which in the case of the UK can be partly explained by the fact that future liabilities are not equated with future assets but with claims against the government, which will provide financing from annual government budgets.

Table 2.2:
Discount rate assumptions of several European countries

Country	France	UK	Germany	Spain	Slovak Republic	Hungary	Sweden
Nominal discount rate	4.2%	3.2%	4.6%	3.5%	1.1%	4.4%	3.5%
Inflation rate	1.6%	4.0%	3.6%	2.0%	2.0%	2.0%	1.8%
Real discount rate	2.6%	-0.8%	1.0%	1.5%	-0.9%	2.5%	1.7%

Source: Adapted from EC, 2016: p. 39.

Despite its general interest, there are few specific lessons to be drawn from this information on discount rates used by different countries to calculate the required level of current assets in the light of future liabilities contained in EC (2018). The discount rates used, for all their importance in structuring funding systems, do not follow a discernible trend and seem to some degree quite arbitrary. Work by Van Marcke (2018) at the IAEA confirms the wide dispersion of discount rate assumptions even among countries with comparable long-term macroeconomic outlooks. The EC *Risk Study* itself does not focus primarily on the general dispersion of rate assumptions but concentrates on the countries with the highest rates:

> "The discount rates adopted by several Member States do not appear to be consistent with the future investment returns that might reasonably be expected from their investment portfolios. Use of a discount rate higher than a realistic estimate of future investment returns… is likely to understate liabilities for future decommissioning and waste management and the corresponding amount of funding required (EC, 2016: p. 54)."

This is undoubtedly true. Currently, the discount rate assumptions used in many NEA countries are on the high side and where revisions have been made since 2016, they have all been downward (see the country studies in Part II). However, one should be warned against concluding that "finding the right discount rate" on its own could solve the issue of ensuring the adequacy of funding systems. Indeed, in its Executive Summary the EC *Risk Study* adopts a more emollient tone.

> "A discount rate (or target level of return over inflation) should be derived that is realistic in light of prevailing market conditions and intended investment strategy… A regular… monitoring and reporting regime, which requires consideration of how the

> level of funding and exposure to risk have developed relative to expectations and in light of changing market conditions should be required. Results should be made publicly available to the extent possible. The methodology and assumptions used as well as the results obtained should be clearly set out and provided to relevant oversight bodies (EC, 2016: p. 13)."

This is very much in the spirit of the circular approach of continuous adaptation described in the first part of this chapter. At the same time, all stakeholders must be aware that because of the decisive nature of discount rates, such reviews can lead to painful adjustments for the holders of the liabilities, in most countries still the operators of nuclear power plants. Both Belgium and Switzerland went through such exercises in recent years resulting in the requirement for their nuclear utilities to secure billions of euros of new provisions.

The very low, zero or even negative interest rates on risk-free or low-risk assets such as government bonds play an important role in motivating such adjustments. Under current market conditions, such assets are likely to have rates of return that are lower than the discount rates currently adopted by most NEA countries. In the absence of adjustments or the reallocation of residual risk for funding shortfalls for riskier portfolios, this can pose long-term issues for the equilibrium between current assets and future expected costs. At the same time, changes in the discount rates decided by regulators can be extremely painful for the operators that need to implement them at the costs of billions of dollars. If the funding system is in equilibrium, the discount rate will correspond to the assumed of rate of return on the constituted assets. What was shown in Figure 2.5 for discount rates thus also applies to rates of return: the lower the assumed rates of return, the higher current assets need to be under an assumption of constant costs.

Regular adjustments of discount rates in the light of the long-term market outlook are undoubtedly a good idea and indeed part of both a linear and a circular approach. It is also clear that current macroeconomic circumstances imply downward rather than upward revisions. However, the spirit of the circular approach to the adequacy of funding does not suggest making the search for "the right discount rate" the centrepiece of the sustainability of any funding system. Even the most precise and realistic estimate of future discount rates and returns on capital will not be able to ensure the adequacy of funding on its own. Other major sources of uncertainty, most notably the level of future liabilities in function of political choices and available technologies, which will affect cost inflation, will require regular adjustments of a more systemic nature.

The circular approach thus suggests rather infrequent adjustments, say every five years, depending on the policy context of the country. Such adjustments should be made based on broad reviews of the funding system in its entirety involving all major stakeholders. It should, of course, align current assets, discount rates and future liabilities in a robust and realistic manner. However, just as important is the review of the allocation of liabilities and timeframes as well as the extent to which options alternative to DGRs such as extended interim storage, regional solutions for long-term nuclear waste disposal, long-term back-leasing of nuclear waste, etc. may be considered. Given the uncertainty surrounding the level of future liabilities, in particular if they are supposed to take place many decades from now, one might even consider defining and submitting to the validation of stakeholders easily recognisable milestones, say USD 10 billion of assets in 2030, USD 20 billion of assets in 2040 and so forth rather than trying to tie the funding system to the results of a discounting exercise intrinsically fraught with uncertainties.

Finally, the importance of pursuing a holistic approach to funding systems rather than focussing on "getting right" individual elements of the system such as discount rates is further underlined by the fact that the latter may not be entirely exogenous. In particular, government fiscal policy and central bank decisions have some control over the return on capital. Even if their power to influence discount rates is not complete, involving such actors at every level of planning and adjusting funding systems is indispensable.

Chapter 3

Liability allocation and the polluter pays principle

Ensuring the adequacy of financing for decommissioning and radioactive waste is a legal obligation. The IAEA's Safety Standards, for instance, state that:

> "Responsibilities in respect of financial provisions for decommissioning shall be set out in national legislation. These provisions shall include establishing a mechanism to provide adequate financial resources and to ensure that they are available when necessary, for ensuring safe decommissioning… It shall be ensured that adequate financial resources to cover the costs associated with safe decommissioning, including management of the resulting waste, are available when necessary' (IAEA, 2014: p. 13)."

In the majority of NEA countries, there are typically three parties involved in the funding of decommissioning and RWM: (1) operators of nuclear power plants, also referred to as the licensee, that produce the waste, (2) regulatory authorities who oversee the operators and (3) national governments who formulate the legal framework and set the ultimate objectives to be attained. A fourth party involved in RWM in some NEA countries are dedicated nuclear waste management organisations (WMOs) – which can be state-owned, utility-owned or private companies – responsible for dealing with long-term radioactive waste. The scope of responsibilities, technical capabilities, and autonomy in the build-up and management of funds for RWM that are attributed to WMOs varies according to the national institutional framework in place (NEA, 2013: p. 33).

The licensee is responsible for all aspects of the safe decommissioning and RWM, but may contract out some tasks to other organisations. In some countries, such as the United States, the legal responsibility for nuclear power plant decommissioning and related RWM can also be transferred to a dedicated organisation after the plant shutdown, an instance in which this dedicated organisation becomes the new licensee of the now to be decommissioned plant (Laraia et al., 2012: p. 22). In addition, legal ownership of the SNF or radioactive waste might change during the process of implementation of a country's national strategy. The responsibility of operators for the radioactive wastes may end at the time of disposal, cease before, or it may extend beyond (e.g. after closure of the permanent disposal site), depending on the interface between the waste generators and the WMO (NEA, 2013: p. 34). Such transfers of responsibilities are always delicate processes that require a consensus on the distribution of costs and liabilities as well as some form of transfer of the assets that have been constituted to fund the management of radioactive wastes.

If the ownership of waste is unknown or unspecified (orphan wastes) or when the owner no longer exists (legacy wastes), the financial responsibility for RWM usually falls to the state, which then in turn can delegate these RWM tasks to a WMO (IAEA, 2007: p. 10). The state is always the ultimately responsible party for any residual RWM-related liabilities, notably in case of bankruptcy of the operator (NEA, 2013: p. 52 and 58).

The responsibilities of the operator or licensee usually include (IAEA, 2006: pp. 7-8 and 2014: pp. 9-10):

- Selecting a decommissioning strategy as the basis for preparing and maintaining the decommissioning plans throughout the lifetime of the facility;

- Estimating the cost of decommissioning actions and ensuring the adequacy of funding to finance decommissioning and the management of radioactive wastes;
- Submitting a final decommissioning plan and supporting documents for review and approval by the regulatory body, in accordance with national regulations;
- Managing the remaining operational waste from the facility and all waste from decommissioning;
- Performing safety assessments and environmental impact assessments in support of decommissioning actions.

In the case where a WMO exists, its responsibilities are closely intertwined with those of the licensee and include in some cases taking over the decommissioning of nuclear facilities, providing facilities for treatment, conditioning, storage and transportation of radioactive waste as well as developing waste disposal facilities, including organising the relevant R&D, siting, construction, operation, repository closure and post-closure monitoring (IAEA, 2007: p. 11). The relationship between the WMO, the licensee and eventual subcontractors can be complex as legal obligations and financial liabilities become interlinked with technical responsibilities. In these cases, efficiency gains due to outsourcing must be weighed against the added transaction costs of formulating, supervising and enforcing complicated contracts.

In some cases, re-verticalisation has taken place. The UK Nuclear Decommissioning Authority (NDA), for instance, has in recent years repatriated a number of contracts that had been previously outsourced. Such cases show that questions of economic efficiency can be more intricate than usually assumed. Issues can become even more complicated if the transfer of ownership and responsibilities is substituted by long-term fuel leasing arrangements, which may include long-term releasing to the original provider country as well as reprocessing, and which may run over several decades. NEA (2015) provides an overview of the theories of Ronald Coase and Oliver Williamson that offers a useful framework for discussing questions of the optimal economic organisation of highly complex industrial and legal challenges.

One or more regulatory bodies may exist to supervise decommissioning and RWM, whether undertaken by the licensee or a WMO. They are invested with the legal authority for conducting the regulatory process, including issuing authorisations by national governments (IAEA, 2007: p. 10). Regulatory authorities assess the proposals of operators or the WMO for decommissioning or RWM and monitor their implementation with special attention to the safety of site personnel and the public, and environmental radiation protection (Laraia et al., 2012: p. 22). The main responsibilities of the regulatory authority include establishing the criteria and timeframes for decommissioning and RWM, overseeing the running of radiological surveys and, critically, ensuring that adequate resources will be available when necessary for the safe decommissioning and RWM. Once decommissioning or radioactive waste disposal get under way, they will need to enforce compliance with safety requirements and the national legal and regulatory framework (IAEA, 2006: p. 7 and 2014: pp. 8-9).

Finally, national governments need to develop and enforce the legislation governing all aspects of decommissioning and RWM, including radioactive waste generated during decommissioning, thus ensuring safety and environmental protection at all times (IAEA, 2006: p. 6 and 2014: pp. 7-8). Governments are thus called upon to:

> "Establish and maintain a governmental, legal and regulatory framework that shall include a clear allocation of responsibilities, provision of independent regulatory functions, and requirements in respect of financial assurance for decommissioning and the management of radioactive waste (IAEA, 2014: p. 7 and NEA, 1996: p. 27)."

Governments will also oversee the process of selecting the technology and, if applicable, site for the final disposal of radioactive waste. This includes specifying the legal, technical and financial responsibilities for the organisations involved and for the management of the resulting radioactive waste by a WMO.

In this context, the legislative framework governing the collection of fees and the establishment of adequate funds for future decommissioning and RWM is, of course, crucial (Laraia et al., 2012: p. 22).

Governments are the ultimate guarantors of the availability of adequate financial resources for safe decommissioning and for the management of the resulting radioactive waste. This can include taking over part or all of the operators' liabilities for either decommissioning or RWM if so required (see Wuppertal Institute et al., 2007: pp. 13-14, as well as the country case studies of Spain, Italy, Germany and the Slovak Republic).

The Polluter Pays Principle (PPP): The need for a broader view

The allocation of liability for decommissioning and nuclear waste management is based in the great majority of NEA countries on the PPP. It was first set forth by the OECD in 1972 and subsequently spelled out and refined at regular intervals. Based on the writing of A. C. Pigou and R. H. Coase, the PPP aims at ensuring the full internalisation of environmental damages. As its title says, its key idea is that polluters should be liable for any social cost of the pollution they produce. This idea can be made to apply also to decommissioning and nuclear waste management. Here it is understood to mean that operators of nuclear power plants are liable for the costs of decommissioning and RWM, which are then passed on to electricity customers. It translates, in particular, into the requirement to build up financial means that cover all decommissioning expenses and ensure safe and secure disposal of the waste (NEA, 2006: p. 33).

The PPP is a framework that enjoys general acceptance as it corresponds to the intuitive notion that those who have generated waste should be responsible for its management and disposal and hence bear the costs. It is also a framework that is easily communicated to a wider public. Implicit in the PPP is the conviction that past and present generations should not leave unfunded liabilities resulting from their economic activities to future generations. The electricity generation that lights homes, cools offices or powers industry, is also responsible for old plants that need to be decommissioned and radioactive waste that needs to be disposed of. The price of current generation should reflect its full costs, including those that will fall due in the future. These are eminently important and widely accepted ethical principles. Naturally, both experts and policymakers, including at the NEA, IAEA and the European Commission, habitually conduct their discussions with reference to the framework of the PPP.

In order to ensure the PPP is fully applied, the funding set aside for future liabilities should be adequate, readily available and transparently managed (IAEA, 2005a: p. 3). As an entry into the discussion of funding decommissioning and RWM, the PPP has served the nuclear community well. It will continue to do so even though, as will be shown below, it requires to be approached in a somewhat broader perspective when applied to the area of managing HLW and SNF.

If the PPP continues to enjoy widespread support, in general as well as in the nuclear sector, some of the elements of the conceptual framework that underpin it require broader discussion. This relates, in particular, to the fact that the PPP assumes that the cost of environmental damage is fully known and the "polluter" has full control over them. The fact that several countries, including Finland, Sweden or France, are moving towards operating DGRs for HLW increases the timeliness of such a discussion. The normative objective of the creators of the PPP was social welfare optimisation including all welfare-relevant arguments, in particular, clearly identified environmental externalities.

As such, this does not pose a particular issue. Social welfare optimisation including all welfare-relevant arguments seems a perfectly appropriate policy objective also for the 21st century. However, the methodological framework in which such welfare optimisation is to take place in the context of the PPP is not entirely applicable when managing HLW. The PPP has its origins in the work of A.C. Pigou on social welfare optimisation. This work is couched in what is referred to as a "partial equilibrium framework with static optimisation". Such frameworks presuppose certainty, (or at least known probability function allowing for the calculation of expected values), perfect knowledge, the stability of structural parameters as well as the ability of the polluter to assess all costs and benefits and to adjust output levels optimally. Crucially, partial equilibrium frameworks rely on stable parameters and one-directional causalities. The "linear approach" to the assessment of the adequacy of funding that was discussed in the previous chapter also takes place in a partial equilibrium framework.

Contrary to standard partial equilibrium analysis, e.g. supply and demand in a single industry, the PPP introduces the additional assumption that “social costs”, such as environmental quality or public health, which are not valued by private markets, can be measured, monetised and internalised through appropriate incentive measures. This would then allow their integration into the private profit-maximising behaviour of the polluter and the smooth substitutability of private costs and social costs. Of course, in practice such substitutability will always only be achieved in approximation. However, it presupposes that changes can be made at the margin. In other words, no expenditure item is so uncertain or so large as to affect a company’s overall viability. This can be a potential issue with ensuring the adequacy of funding for decommissioning and RWM, in particular during a period where electricity markets are undergoing rapid change. To the extent that the constituted assets approach the same order of magnitude as the residual value of the operator, the risk is increasingly that assets are managed in a corporate finance logic to support solvency and viability rather than in the original PPP logic of social welfare optimisation. The ring-fencing of funds for decommissioning and RWM at the accounting level will provide only limited protection as long as the liabilities remain part of the same corporate entity.

Partial equilibrium frameworks with autonomous, profit-maximising agents that, based on known information, react to the incentives formulated by perfectly informed governments are closely aligned with the “linear approach” presented in the previous chapter. As such, they are distinct from the “circular approach” that was presented in the same chapter as the appropriate manner to deal, in particular, with long-term issues surrounding the management of HLW and SNF. The latter require a broader perspective than the one provided by the default assumption that the operator, i.e. electricity customers, will take care of decommissioning and RWM in autonomy. In economic modelling terms, the general approach would correspond to a general equilibrium framework, in which all variables and parameters are constantly adjusted in function of each other.

The framework of static optimisation that underlies the PPP depends on the stability of all relevant parameters. For decommissioning and RWM, this would imply that relevant parameters such as costs, technical choices, available technologies and timing were known in advance or at least part of well-known probability distributions. The responsible party, i.e. the “polluter”, can then optimise by equating at the margin the economic benefits of pollution, i.e. electricity production with its costs. The latter would need, of course, to include the costs of decommissioning and RWM. The purpose of the PPP is precisely to incentivise the polluter to adopt such optimising behaviour.

Of course, the assumption of parameter stability always needs to be looked at in a differentiated manner. In some sense, the future is always unwritten. Economic optimisation must also be approached in a roundabout manner. Industrial reality rarely conforms to the smooth, continuously differentiable, curves of the textbooks. Optimisation here means choosing the most advantageous cost-benefit trade-off choosing among different distinct options rather than striving for perfect equality at the margin. Thus, when considering decommissioning or LLW, the assumption that costs and technological choices are, in an order of magnitude way, known in advance is not absurd. It may need to be adapted, allowances might need to be made for different contingencies etc. but the PPP can function as a useful starting point.

However, the assumption of parameter stability is far less applicable in the areas of the disposal of HLW and SNF. This is because radically different technical options (DGRs in different geological environments, extended interim storage, retrievability, leasing, reprocessing, etc.) are available and unknown ex ante. Moreover, these choices are not incumbent on the “polluter”, i.e. the operator of a nuclear plant and producer of HLW, but on government and relevant regulatory bodies. In other words, the polluter has little or no influence over the choice of the technological solutions and thus the costs of RWM. The very concept of running operations according to a logic of economic welfare optimisation is thus no longer applicable. It also clashes with the principle of the Law and Economics literature, presented in Chapter 1, that liability should be allocated to the party that is best equipped to control the overall costs.

In the case of decommissioning and RWM, the “polluter”, or more precisely, the utility that has produced radioactive waste in the service of its customers, has employed well-specified industrial processes with full regulatory compliance. In other words, as long as the regulation was adequate then all impacts were fully internalised and no "pollution" in the sense of un-internalised externalities exists. If regulation was inadequate and un-internalised externalities arise then changes in social costs are hardly the responsibility of the electric utility. Non-compliance with adequate regulation would instead fully engage its responsibility.

Pointing out such limits to the PPP, of course, does not imply that nuclear operators should be able to pass on part of the costs of nuclear power production to third parties, i.e. government, taxpayers and the public. This applies to the financial obligations regarding the funding of decommissioning and RWM as well as to the potential social costs they generate in terms of environmental damage or public health risks.

Of course, operators should be held liable for paying their fair share also in the future. However, the fact that they hold little or no control over the future costs of high-level RWM prevents a simplistic application of the PPP. The possibility that political decisions may limit their lifetimes and the period over which revenues towards funding the financing of RWM solutions further strengthens that point. At the very least, continuous reciprocal feedback between operators and government is required, as the latter chooses the modalities and costs of RWM, while the former determine the level of output and mode of operations and collect the funds. In practice there will be, of course, major differences in the precise division of labour between operators and governments, depending on the organisation of the electricity sector, historical precedent, institutional arrangements and so forth.

However, independent of country specifics, as operators neither determine the RWM solution, nor its timing or cost, the idea of equalisation at the margin, even in an approximate manner, gets lost. Funds are accumulated with reference to hypothetical costs that will accrue in a far-flung future and that, given the political and technological uncertainties, may or may not correspond to available funds. Countries where concrete projects for DGR are already under way are not facing an altogether different situation. Operations during the past few decades could not have possibly taken the shape and cost of today's projects into account, even where adjustments have taken place over time. This does not only regard the constitution of assets to finance liabilities for decommissioning and RWM, but also the level of output and the mode of operation, e.g. the level of burn-up, the intervals of refuelling or even the choice of reactor technology. All of them have significant impacts on the amount and toxicity of HLW as well as on the economic conditions of electricity generation.

The political nature of the choices, the long lag between the constitution of funds and their disbursement as well as the large uncertainties involved strongly limits the literal application of the PPP to the extent that it is based on the idea of welfare maximisation in the partial equilibrium framework. The spirit of the PPP is that decisions should be made by those who are responsible for the costs. The implicit assumption is that "polluter" know and control those costs. In the area of RWM, however, the polluter, i.e. the nuclear operator just does not hold sufficient information at the time of decision-making in order to allow for any form of welfare maximisation.

There exists even an added risk that has the potential to push the situation even further from any form of optimality. Given that constituted funds are known and future technological choices are unknown, the risk is that solutions are designed to correspond to available funds rather than the other way around.

There is thus a case for adapting the PPP to the specificities of ensuring adequacy of funding for the back-end of the fuel cycle and, in particular the management of HLW and SNF. The latter includes very long timeframes, the importance of social and political decision-making processes that can make for discontinuous changes on both the asset and the liability side, the uncertain length of operating lifetimes and radically different technical options between DGR, extended interim storage, take-back or reprocessing. As spelled out in the previous chapter, a long-term economic context with ultra-low returns for low-risk assets expected to meet certain objectives with high probability further complicates matters, especially if social discount rates and funding levels remain at their originally predicated levels. There thus exists a large amount of "residual risk" that cannot be expressed in terms of probabilities with known magnitudes over a set of clearly defined events. Managing such residual risk in the economically least-cost manner requires careful interpretation and adaptation of the PPP. As mentioned, things are different in the areas of decommissioning and low- and medium-level radioactive waste, which are well-codified industrial activities, where private enterprise can usefully employ its strengths in achieving cost reductions and efficiency gains.

One of the key aspects of the PPP is to assign the responsibility for the social costs of an industrial activity to the party that best controls those costs. In the case of nuclear power generation, this means that decisions on the level of output, the amount of fuels used as well as on the relevant technologies and their operations should, in the framework established by the relevant legal obligations, indeed be left to the operators. However, when it comes to the management of HLW, there is very little that the operator of a nuclear power plant controls. The choice of the relevant strategic option, which determines the technology as well as both the industrial (private) and the social costs, lies with government. In many cases, the original operator will not even be around anymore at the moment of implementation of the relevant waste management strategy. Only government has the legitimacy and ability to organise the trade-offs between industrial and social costs that, if done well, will ensure welfare maximisation.

Theoretically, constant iteration between all parties, in particular government and the successive holders of the operator's liability and constituted assets, could achieve an equivalent outcome. However, there is a transaction cost argument here. Given that government sets all the parameters of RWM, the most efficient solution would be for it to assume also the corresponding legal liability and financial responsibility.

If this looks like a direct contradiction of the PPP's central tenet that the polluter should pay, it does so in appearance only. As pointed out above, any transfer of liability and financial responsibility must be accompanied with a transfer of all constituted assets for this purpose. If need be the transfer can be adjusted for any present or likely future shortfall. In Germany, for instance, the nuclear operators had to pay into the newly constituted public Fund for the Financing of Nuclear Waste Disposal (KENFO) the internal provisions for RWM accrued by the companies as well as a 35% surcharge in order to cover for any uncertainties on the cost side (WNA, 2017). Ultimately, government, taxpayers and the public will thus be liable only for the residual financial risks introduced by any decisions made after the moment of transfer. There is no denying that such risks may be significant, as might also be the potential gains due to technological progress, for instance. However, only government will be able to organise the trade-offs in an appropriate and efficient manner. This refers to the proper taking into account of the long term, including the interest and rights of future generations, of any strategic considerations including the security of supply and, most importantly, of the social preferences concerning the management of HLW and SNF. Technological choices in this area are inevitable political choices.

Transferring liabilities to the party that controls cost and is best placed to manage the risks is very much in keeping with the intent of the PPP. Broadening too narrow a literal reading of the PPP is thus necessary to remain coherent with its original spirit. Done well, and there is no doubt that such transfers need to be carefully prepared and executed, transferring liabilities and constituted funds for managing HLW and SNF will be the economically most efficient solution also in the broad sense of social welfare optimisation. It is also fair, as the funding will rely primarily on the constituted funds by the operators through the surcharges billed to electricity customers. By ensuring efficiency and fairness, such transfers can constitute long-term sustainable solutions that are fully consistent with the original objectives of the PPP.

Chapter 4

Forms of funding, investment strategies and cost estimation

The international community has long recognised the importance of establishing funds to prepare for the eventual permanent shutdown of nuclear facilities and to provide for the long-term management of their radioactive waste, especially of HLW and SNF. Funds to cover decommissioning and RWM are set aside in most NEA countries with nuclear power programmes, as early reviews by the NEA indicate. Funding adequacy is considered essential to guarantee the safe performance of the relevant tasks and the completion of the work without risk to the public, worker health and safety, and the environment (NEA, 1996 and 2006: p. 34).

National legislation in all NEA countries defines the responsibilities and legal ownerships for the management of HLW and SNF. These legal and institutional frameworks also specify the conditions for establishing the necessary funds, the safeguards against mishandling, inappropriate claims or use, their adequate administration, and, in case of shortfalls, the provision of financial guarantees (NEA 2013: p. 32 and p. 47). National legislation is of central importance in the determination of the costs, funding and timing of operations. See, for instance, the contrasting definitions and options in the area of decommissioning and RWM in different countries (NEA, 2003b: p. 22, 2013: p. 34 and Laraia et al., 2012: p. 30).

While full harmonisation in this area is not feasible and perhaps not even desirable (see below), exchange of information and reciprocal learning is essential and a number of international legal instruments set broad minimum requirements in this area. The IAEA Joint Convention on Safety of Spent Fuel Management and Safety of Radioactive Waste Management (1997) that came into force on 18 June 2001 thus encourages in its Article 22 Contracting Parties to:

> "Take the appropriate steps to ensure that (…) adequate financial resources are available to support the safety of facilities for spent fuel management and radioactive waste management during their operating lifetime and for decommissioning [and that] financial provision is made which will enable the appropriate institutional controls and monitoring arrangements to be continued for the period deemed necessary following the closure of a facility (IAEA, 2007: p. 9, NEA, 2016a: pp. 40-1)."

Within the European Union, a legally binding framework for the responsible and safe management of spent fuel and radioactive waste is provided through the Council Directive 2011/70/Euratom, following a 2006 recommendation and a guide on the management of financial resources for the decommissioning of nuclear installations and the handling of SNF and radioactive waste. According to the 2011 Directive, all EU countries are to ensure that funding resources are available for waste management (NEA, 2013: p. 32 and NEA, 2016a: p. 41). Legal and regulatory frameworks have thus been put in place in all NEA countries to regulate the creation of decommissioning and RWM funds. These funds need to meet the following criteria (IAEA, 2005a: p. 18 and NEA, 2016a: pp. 119-20):

- Contributions to the fund are to be made by facilities using radioactive material during their operation to ensure sufficient funds are available at the time of final shutdown to cover all decommissioning and waste management expenses.

- Contributions are to be in line with the estimated service life, defined time schedule, and chosen strategy to cover (1) decommissioning of the facility, (2) long-term management of conventional and radioactive wastes, and spent fuel and wastes from reprocessing operations not already fully covered in legal requirements or as operational costs.
- The funds are to be managed and reviewed periodically in a manner ensuring liquidity compatible with the timetable for the decommissioning obligations and their costs.

The first three chapters of this conceptual framework have developed the general approach to questions of funding the decommissioning of nuclear power plants and RWM in a perspective provided by the branches of economic theory that are Law and Economics and environmental economics for the PPP. The present chapter will proceed with a number of more practical considerations that regard the concrete set-up of funding mechanisms, the choice of investment strategies and the measures in place to deal with uncertainty.

Forms of funding decommissioning and RWM activities

The funding of decommissioning and RWM-related operations does not always cover the same costs and activities in all countries. A first categorisation distinguishes between *joint funds*, which cover the financing of the costs of both decommissioning and RWM, and *segregated funds*, which only cover one or the other (NEA, 2016a: p. 120). There is currently no harmonised, global approach adopted across the OECD to establishing funds. In many countries, segregated funds are often administered by a qualified third party. Together with effective ring-fencing of the funds, this approach is considered to favour transparency and confidence (NEA, 2013: pp. 47-8).

Most existing funds are established at the level of an operator's fleet. However, in some cases the collection of funds may be organised on a site-wide basis (NEA, 2016a: p. 120). In general, the mechanisms adopted for the accrual of funds are of two kinds (IAEA, 2005a: pp. 20-1; NEA, 2005, pp. 57-58 and 2016a: p. 120):

- Collection from electricity customers through a fee included in *electricity rates*, in which funds are set aside from the revenue obtained from each MWh of electricity. Consistent with the PPP, decommissioning and RWM costs are thus integrated into the overall costs of nuclear-generated electricity. This can also take the form of a *levy on revenues* from electricity sales or on the profits made by an operator.
- Direct financing through *state budgets* due to a lack of dedicated resources, financing schemes, or because of a sooner than anticipated phase-out of nuclear energy. Such public financing can take the form of an *endowment* for the provision of a WMO's initial capital, through a lump sum payment. Governments may also provide the WMOs with *guarantees* that may allow the latter to take out bank loans or to resort to other similar financial instruments (IAEA, 2007, pp. 26-30). Currently, direct state funding applies primarily to legacy waste, fuel cycle facilities and research reactors. As discussed earlier, there are good reasons to anticipate some form of public involvement for RWM solutions also for existing nuclear power plants.

As regards RWM, in particular HLW and SNF management, the most common mechanisms for collecting funds in NEA countries remains a *levy on electricity* (NEA, 2013: p. 47). However, for decommissioning a recent review of funds accrual practices evidenced that no specific funding mechanism is distinctly preferred. In some countries, also more than one approach is being used (NEA, 2016a: p. 121). In some cases, the national regulation on decommissioning funds collection will also require operators to provide adequate financial guarantees in order to cover for instances such as earlier than anticipated shutdown or a shortfall of funds due to unanticipated economic changes (NEA, 2005: pp. 57-8; IAEA, 2007: p. 30). A closer look reveals that preparations for such cases can be patchy. A review of the different ways in which EU countries address financial uncertainties related to the special cases of early shutdown, unexpected decommissioning cost increases or transfer of nuclear power plant ownership shows that in most countries, no special provisions exist and resulting liabilities would fall on taxpayers (see Wuppertal Institute et al., 2007: pp. 57-60).

The ownership and organisation management of the funds vary across countries. Among the many specific forms being employed in different countries, two major categories can be identified (IAEA, 2005a: pp. 21-3, 2007: p. 30; NEA, 2005: pp. 58-60, 2016a: p. 124; Wuppertal Institute et al., 2007: pp. 37-8, 2013: p. 33; Laraia, 2012: pp. 73-5):

- *Internal management* ("accruals"): in this case, the licensees, operators or WMOs are responsible for collecting and managing the funds and are appointed as being directly responsible for carrying out the decommissioning work and incur any relevant expenditures. The contributions are held within the licensees' accounts in the form of reserves. In some countries, there are separate funds for decommissioning and RWM. There can also be further differentiation between the management of low-level radioactive waste (LLW) and intermediate-level waste (ILW), HLW and SNF. Funds for decommissioning and RWM need to be separated at the accounting level from other income and expenditures.
- *External management* ("trusts"): here funds are collected by operators from consumers but are held in a trust managed by an external organisation. These funds can be held either in a commercial bank account or in a dedicated treasury account, subject to specific rules protecting it from misuse and financial risk; or it can be managed by a legally established body that is completely independent from the operator. External management can be centralised or decentralised. In the latter case, there is an operator for every fund. In the former, there is a unique national fund for all nuclear operators, each one of which has its own account, while the state authorities regularly establish the required balance of each account. Should an operator no longer be able to take care of its obligation for financial provisions, the state can take over the account and the associated securities to guarantee that the appropriate funds are available.

Release of any funds may depend on the operator or the regulatory body in function of designated project milestones or authorisations of expenditure. The legal and regulatory framework must also address any measures necessary to protect against the risk of future fund loss due, for instance, to bankruptcy of the owner of the facility. In some countries, the operators contributing to the fund can borrow back a certain percentage of the funds capital against full securities and at a defined interest rate. In others, the government can borrow from the capital of the fund.

Laraia et al. (2012: p. 76) state that external trusts are generally considered more reliable from a standpoint of financial security and are thus the preferred option for establishing decommissioning funds in Canada, the United States and Europe. The argument goes that external funds are better at avoiding inconsistent incentives and moral hazard. The EC *Risk Study* elaborates on this point:

> "Where the fund is not external to the operator… [t]his introduces the potential for conflicts of interest and moral hazard. For example:
>
> - If an operator were to get into serious financial difficulty, it may be keen to adopt a higher-risk investment strategy with a higher level of expected investment return and associated lower cash funding requirements.
> - However, it is arguable that in these circumstances the fund should instead be looking to reduce its exposure to investment related risks since the operator may no longer be able to underwrite or correct for these risks in future.
>
> Establishing a fund that is legally independent of the operator also provides additional comfort that any accumulated financial resources will continue to be available for future decommissioning and waste management purposes following a corporate transaction involving the operator or if the operator were to become insolvent (EC, 2016, p. 48)."

One of the risk of internal funds is that in the absence of sufficiently stringent supervision, operators might consider internal funds as a low-cost source of funding and adopt investment criteria other than ensuring long-term adequacy. This danger was particularly high in those cases where operators were authorised to invest a share of the decommissioning and waste management funds into their own industrial activities. It is a sign of distinct progress in the adequacy of funding that the provisions that allowed for such internal investment of funds dedicated to the financing decommissioning and RWM have now been discontinued in all NEA countries concerned.

It should also be stressed that there is no unanimity concerning the superiority of external funds as the appropriateness of funding arrangements depends on the strongly differing institutional set-ups in different countries. An important role is played here by the nature of the relationship between operators and central government. In practice, all countries have some form of governmental supervision in order to ensure that funding keeps pace with inflation, technological changes, regulatory requirements and environmental commitments, independent of the fact whether the management of funds is nominally internal or external. Ultimately, the question is not whether a fund is internal or external but whether operators have the means for professional management of the sometimes very large amounts of assets that have been constituted and government oversight is sufficiently effective.

The specific fund management models in NEA countries differ mainly with respect to the distribution of responsibilities for the collection, management and monitoring of funds (NEA, 2005: p. 62, NEA, 2016: pp. 124-5). One can thus distinguish:

- *Internal non-segregated ("own assets") model*: funds are collected and managed by the operators as internally held reserves. Monitoring is carried out ex post by regulators, which can create risks regarding the adequacy, availability and transparency of the funds. While nearly half of NEA countries employed this model in the early 2000s, it is now becoming less widespread.
- *Internal segregated ("separate account") model*: the collection of funds and monitoring activities are organised the same fashion as in the internal non-segregated model. The funds are still managed internally by the operating organisation, but are either accounted for separately from other assets and liabilities or held in an escrow account by an external body (commercial bank, treasury account or other). This limits access to the funds, facilitates oversight and ensures that they are used only for the agreed upon purposes.
- *External segregated model*: as mentioned, funds are collected and held by an independent body and managed by either public or private independent finance professionals. Monitoring the funds is the responsibility of a specialised regulator that influences ex ante the investment choices of fund manager and evaluates these choices ex post. Other things equal, this option allows for increased transparency, enhanced insolvency protection and improved public confidence.
- *Government-funded model*: here the national government assumes the ultimate responsibility for funding decommissioning and RWM liabilities. This may involve a prior transfer of previously constituted funds from operators or dedicated special-purpose vehicles. This is rare in the case of decommissioning funding. It is of interest primarily in those areas where historical liabilities are difficult to establish or solutions are complex, long-term and policy-dependent. This may include older generations of nuclear power plants, legacy radioactive waste or spent fuel management.

In all of these cases, the appropriate institutional set-up needs to be part of a decision-making framework in which changes in key parameters are systematically communicated and adapted throughout the decision-making framework. Regular publication of key variables, wide consultation, clarification of timeframes and decision-making processes, and designation of liabilities for residual risk due to unforeseen circumstances are just some of the elements of an improvement in the overall institutional set-up to further the long-term adequacy of funding. The EU Risk Study points out in this context that in general a good understanding of financial risks and their management remains to be proven:

> "Having defined clear investment objectives, the next step is usually to consider what constitutes an acceptable level of investment risk to take to achieve this objective. This could, for example, be expressed as the maximum level of loss that could be tolerated over a given time frame (i.e. a VaR measure) or as a tracking error relative to the performance/ growth in liabilities… An important consideration in determining an acceptable level of risk is the financial strength of the operator … Profitability, cashflow generation, credit rating, the size of the balance sheet and a range of other metrics can all be used to form a view on the financial strength of the operator.

> There is no evidence to suggest that any of the EU Member States have attempted to specify some form of risk limit or that the resulting investment portfolios have been designed with this in mind (EC, 2016: pp. 55-56)."

The country studies in the second part of this publication do not entirely corroborate this point of view. On the contrary, in many NEA countries, European and other, the formal understanding of the different dimensions of financial risks and the possibility of a gap between constituted assets and funding requirements is quite well-developed. However, it remains exceedingly difficult to assess adequacy, as *residual risks* are very large. The issue is not the sophistication of the financial risk metrics applied but the fact that it is intrinsically difficult to assess funding requirements in a meaningful way many years, sometimes decades into the future, when they depend on changes in long-term economic framework conditions, social preferences, political decisions and technologies.

The *EU Risk Study*, which is overall a useful reference document, errs to the extent that it considers a more sophisticated understanding of financial risk metrics could resolve an issue of non-quantifiable residual risk with its inherent political dimension. In the vast majority of countries, if not in all, the ultimate adequacy of funding depends on an explicit or implicit government guarantee. One of the important questions in this context is precisely the extent to which such de facto guarantees can gradually be integrated into the conceptual frameworks in which the adequacy of funding is discussed at both the international and the national level.

At the same time, the authors of the *Risk Study* are right to point out that boosting returns in the current low interest rate environment does mechanically come with added risks:

> "At present, investing in "risk-free" assets would not be expected to provide sufficient returns to allow a fund to outperform the expected inflation of the decommissioning and waste management cost […] Pursuit of investment returns in excess of a risk-free rate requires taking risk and taking risk implies that it is possible for investment returns to be lower than expected (EC, 2016: p. 8)."

As pointed out above, certain forms of calculated risk-taking by professional investment managers in order to aim for higher average returns can make sense in particular for large, diversified funds who will not be called upon for many years or even several decades. However, the structure of such risks needs to be managed carefully over time, i.e. risks should reduce as disbursement approaches, and needs to be explained, understood and validated by relevant stakeholders.

Investment strategies for funding the back-end of the nuclear fuel cycle

Like any other form of investment, funds for financing decommissioning and RWM need to make the appropriate trade-off between investment returns and risks. The protection and security of the funds are, of course, of the highest priority. In most NEA countries, the funds for RWM were often statutorily managed in a low-risk manner, e.g. by depositing them in an escrow account at the finance Ministry or by investing them in national government bonds (NEA, 2013: p. 47 and pp. 53-4). Traditionally, the overseers of funds for financing decommissioning and RWM liabilities preferred investments in national or international government bonds, equities and real estate (IAEA, 2005a: p. 23; NEA, 2006: p. 37).

Partly due to the zero returns on long-term risk-free deposits, a broad trend is currently underway to allow a greater diversification of investments. Holdings in real estate, private equity vehicles and hedge funds are today part of the portfolios of a growing number of funds. Of course, it is imperative that political decision-makers fully understand the benefits and risks of such diversification and combine it appropriately with broader liability arrangements. This underlines once more the necessity to focus on "residual risk".

The stronger is the impetus of moving towards riskier assets, the higher is the probability of a shortfall. This puts the spotlight once more on the question of which party is best placed to assume such residual risk in case a call on funds is imminent and a shortfall materialises. While answers may differ, in many countries governments will need to be prepared to assume such residual risks once fair and politically sustainable cost-sharing arrangements have been put in place. For instance, riskier, but on average more profitable, investment strategies can make sense if governments are ready to step in if, on the day the funds are needed, their size should be smaller than originally assumed. Put differently, the lower the returns on low-risk assets, the higher the probability that ceteris paribus governments will be requested to step in at one moment or other. The ceteris paribus clause refers here to the expected costs of long-term RWM solutions and assumptions about social discount rates.

Given the different timeframes and risk profiles involved, investment strategies may differ for decommissioning funds and funds for RWM. Other things equal, the latter could engage in somewhat riskier investments with, on average, higher returns. Such a risk-reward relationship is more likely to play out in the long term rather than in the short run. Slightly higher investment risks could also be justified if governments commit to funding any potential shortfalls with ultimately retained RWM solutions.

Environmental, social and governance (ESG) criteria for investing funds for decommissioning and RWM

A small number of countries such as Germany are also exploring additional criteria in the management of their funds for decommissioning and RWM, such as the performance of investments in terms of environmental and social impacts and corporate governance (ESG). This is, of course, currently a broad theme in the investment world. Nevertheless, it is of particular salience to public funds, or private funds pursuing ultimately public aims, holding USD tens of billions possibly for decades. So far, the nuclear community has refrained from providing even general indications in this area. However, the issue of ESG criteria in investing the often sizeable funds for financing decommissioning and RWM can no longer be ignored. It is particularly relevant for an investment activity that aims explicitly at ensuring the long-term sustainability of nuclear power systems by adequately financing the management of the often politically and socially sensitive back-end of the nuclear fuel cycle.

Explicitly including ESG criteria into the investment objectives can constitute an important support for sustainable investing in general. It may also be a significant element in shifting public perceptions of decommissioning and RWM and their financing. Clearly, such considerations tie the question of ensuring the adequacy of funding even more to the realm of political decision-making and the realisation of broader societal objectives.

Dealing with uncertainty in fund management

In addition to classic investment risks such as market risk, risks of inflation (which diminishes existing assets) or deflation (which increases the present value of future liabilities), credit, liquidity or currency risks, funds for decommissioning and RWM are subject to added uncertainties. The latter may include the premature shutdown of the operations that support the collection of funds or bankruptcy of the operating company or, conversely, LTO for an additional 10 or 30 years compared to the initial design licenses. Even if arrangements for decommissioning funds are well established, it is not always clear how well funds are protected against such unknowns. When funds rely on a fee per unit of electricity, contributions are also a function of electricity demand (NEA, 2016a: pp. 127-8).

Of course, NEA countries are aware of this and are thus attempting a variety of strategies to mitigate risks associated with the decommissioning and RWM-related funding mechanisms, responsibilities for the funding, and with the fund performance (NEA, 2013: p. 59 and 2016b: p. 16). National legislative and regulatory frameworks have established rules to control the access to decommissioning funds and the timing as to when they could be withdrawn. These rules typically define the types of expenditures that may be made at different stages during the phased approach to decommissioning project management.

Moreover, national systems of restrictions and reviews are in place to ensure the adequacy of funding under all but the most extreme circumstances, although the structure of these systems can vary substantially across NEA countries (NEA, 2016a: pp. 128-9). The protection of funds can be advanced through several mechanisms, most notably the posting of guarantees and investment restrictions. This practice is often referred to as “restricted fund management”.

Posting guarantees implies that a private operator pledges high-quality securities to the fund or to the government in case of an inadequate amount of assets in the fund itself at the time of disbursement. In case of public ownership, such guarantees are often assumed to be implicitly provided by the government. Only specific types of securities are acceptable in this context. They will be vetted by a regulatory body or are subject to requirements set out in the legislation or regulations governing the financing of decommissioning and RWM activities (IAEA, 2005a: p. 25; NEA, 2016a: pp. 129-30).

Asset investment guidelines are used by many NEA countries to control the composition of investment portfolios and ensure diversification. An early template was provided by the IAEA, which insisted on the use of only low-risk investments and the interdiction of investments related to the activities of the operator or its holding company (IAEA, 2005a: p. 23). However, such guidelines only have a limited validity. For instance, governments bonds were traditionally regarded as safe assets. Yet, even if one is willing to accept the very low, zero or negative rates of return on government bonds, this would not necessarily protect the value of the invested funds. EC (2013), written at the time of the Greek debt crisis, notes:

> "Recent events in the financial markets have put serious doubts on the general safety of all types of government bonds. It may be advisable to revisit the implicit assumptions underlying the existing legislation in this respect, and take into account the risk of state bankruptcies (EC, 2013: p. 63)."

In other words, the question of what constitutes "safe" asset allocation in the long run needs to be approached in a broader perspective. This has indeed been a general trend in NEA countries as governments and regulators are allowing ever-greater degrees of diversification into new asset classes such as real estate, private equity, hedge funds and real estate. Given that, on average and in the long run, such more volatile assets produce higher returns, this might indeed improve the overall adequacy of funding. This would require three conditions though to maintain a given level of risk:

(1) Portfolios must be well-diversified to continue controlling risks;

(2) Governments must be prepared to fill any funding gaps that might arise, and;

(3) Portfolios must dynamically restructure towards lower-risk assets as the moment of disbursement approaches.

Given that volatile short-term performance tends to return to the mean only over long time periods, funds for RWM, other things equal, can be allowed to engage in somewhat riskier investment strategies than funds for decommissioning. The latter face indeed much closer dates of disbursement and, as has been argued above, due to the industrial nature of decommissioning should benefit from government guarantees only under the most exceptional circumstances.

One important point is that also with respect to investment strategies, a fully standardised approach would not be optimal. The specific profile of the risk exposure chosen by a given country needs to match its social and political preferences. For instance, funds in countries that accept government to cover a potential funding shortfall in the future, can, other things equal, engage in riskier, and thus on average more profitable, investment strategies than funds in countries where this is not the case.

The fact that investment strategies of funds for decommissioning and RWM still display large dissimilarities across NEA countries thus does not constitute a particular problem. However, there is little evidence that the different investment strategies in place are the result of broad societal discussions concerning the optimal risk profile. Some countries still do not even make their investment rules explicit (NEA, 2016a: pp. 132-3; and EC, 2017c: pp. 37-8), which cannot be a benchmark for good policy practice. While the harmonisation of the investment strategies of national funds for decommissioning and RWM is not a desirable objective as such, one needs to ensure that the risk profiles of the funds correspond to the timeframes under consideration, the risk preferences of stakeholders and the institutional arrangements governing the funding of decommissioning and RWM. Making investment strategies explicit and transparent is thus always a superior strategy in view of ensuring the adequacy of funding, as it allows the regular adjustment of all contingent parts of the system in order to ensure long-term financial and political sustainability.

Review funding to ensure adequacy

A final issue concerning fund management concerns the need for adequate human capital at the different institutions that are involved in fund management: investment managers, operators, regulators and governments. In all countries under review, the day-to-day management of funds is ensured by professional asset managers. Key tasks on the side of regulators and governments in this context are the accurate calculation of decommissioning and RWM-related costs, the need to monitor and control the latter while the activities are carried out and to ensure that funds are adequate and available on time (NEA, 2017: p. 39; Wuppertal Institute et al., 2007: p. IX; Laraia et al., 2012: p. 25). All three interrelated dimensions evolve over time, which makes it necessary to periodically plan for the reassessment and update of cost estimation models and funding schemes with empirical (operational) data (NEA, 2016b: p. 39). This is, of course, the essence of the circular approach presented above.

It is important that the fund be periodically reviewed and updated to respond to any changes as they occur. This monitoring principle is adopted in most NEA countries, with the periodical conduct of reviews of funds, inflows of contributions, together with those of cost estimates (NEA, 2016a: p.133). In addition, ad hoc reviews can also be conducted as necessary if a new situation occurs or if a significant modification of costs is to be expected due to unforeseen circumstances. The annual contributions to the fund can also change if, as a result of developments in the financial markets, the accumulated capital deviates from the target level within a certain bandwidth (IAEA, 2005a: p. 24). The identification of a shortfall between the value of the fund and the liabilities for decommissioning and RWM should immediately give way to corrective measures. However, the timing required to implement such corrective measures and the period during which they are required to be effective in addressing shortfalls varies considerably across NEA countries (NEA, 2016a: p. 134).

A recent survey shows that the frequency of fund reviews varies between NEA countries, ranging from “annually” to “every six years”, with “only when and if it is required” being also represented. In most countries, the review of funding mechanisms is conducted at the same frequency as the review of cost estimates, although in some countries the time intervals can be shorter (NEA, 2016a: p. 122 and, 2016b: p. 14). Such reviews of funds, contributions and cost estimates are key to ensuring the adequacy of financing arrangements and financial resources in comparison to the assessed liabilities, be it for decommissioning or RWM-related funds (NEA, 2005: pp. 60-1 and 2013: p. 52, p. 59).

Given the long timeframes and the political nature of the issues involved, in particular with regard to RWM, the key issue is not to maintain a particularly high frequency of reviews but rather to adopt as broad a scope as possible. Transparency and stakeholder involvement are key elements. As has been argued before, financial sustainability is ultimately based on the political sustainability of the widely differing options that can be adopted, in particular for HLW and SNF. Ensuring the adequacy of funding for decommissioning and RWM thus requires a broad set of technical, legal, economic and financial competences combined with a keen sense for political sensitivities. The understanding of financial risks, while indispensable, is only part of the required skill set. Decision-makers need to ensure that the appropriate groups of experts are employed and made to collaborate along long-term sustainable solution paths that are politically defined.

Cost estimation for decommissioning and RWM

The performance of funds for decommissioning or RWM is regularly assessed against defined milestones. As part of the linear model presented in Chapter 2, the most important reference point is the future financial liability of covering the costs of exogenously defined technical solutions for decommissioning or RWM. In the latter case, these costs are frequently related to the construction and operation of a DGR for HLW. While the circular model would allow for a definition of milestones other than the assumed future costs of a yet-to-be-defined technical solution, it is clear that such cost estimations are an important part of the overall context, in which funding activities take place.

In the area of decommissioning, a considerable amount of systematic work on cost estimates is being produced. Methodologies are firming up rapidly and an increasing amount of concrete industrial experiences are becoming available for benchmarking. A number of recent publications

(NEA, 2015, 2016a, 2016b and 2017) attest to the fact that the NEA is an important participant in the international discussion. The NEA Working Group on Decommissioning Costs (COSTDEC) is also following developments. Such codification of practices and costs also allows the organisation of the funding according to market-driven and industrial criteria. Of course, uncertainties relating to politics, economics or new technologies have not disappeared. One only need to consider instances of earlier than expected phase-outs of nuclear power generation or LTO. An important source of uncertainty relates also to the nexus between decommissioning and RWM. What happens with locally stored wastes, once a plant has been fully decommissioned? Who is responsible for it and pays for its transport and central interim storage. Obviously, these are crucial questions that need to be addressed by policymakers setting the frameworks for decommissioning in different countries. However, these are, to a considerable extent at least, "known unknowns", i.e. calculable risks. Maintaining original arrangements and fully leaving funding obligations for decommissioning with industrial operators and their investors is thus indeed the appropriate solution.

Things are different in the area of RWM, where cost estimates can be more complex due to very long lead times, new technical solutions that may arise between the moment when the waste is generated and its final disposal, as well as the different forms of interim storage and cycles of reprocessing. When considering reprocessing, not only the costs but also the different economic values of the waste streams need to be included. In the case of reprocessing, circularity not only refers to funding decisions but also to certain material flows. This re-enforces, of course the point that the interaction of the technical and the financial system needs to be carefully calibrated through dynamic adaptations on both sides. An exclusive focus on DGRs may initially facilitate communications, but will only capture a limited segment of the true range of possible future costs. Even in the area of DGRs, options with radically different cost profiles exist depending on location, geology and design. The costs of a national solution and a multinational repository (MNR) may differ by an order of magnitude. Some countries ban the exports of nuclear wastes and, in principle, thus limit the number of available options. However, economic realities can still drive creative solutions for alternative solutions, such as near-permanent releasing of SNF, even in the presence of such obstacles. In other words, while current cost estimates are an indispensable input into ensuring the adequacy of funding, all stakeholders need to understand their preliminary character.

Uncertainty reduces, of course, when the actual implementation of a specific technical solution approaches. The more concrete it becomes, the more important the precise assessment of costs against accumulated assets becomes (NEA, 2016a: p. 57). Even then, however, the underlying assumptions of cost estimations and resulting uncertainties need to be well understood. Generally accepted cost accounting standards do not exist for decommissioning or RWM. Even within single countries where there are several owners of facilities, different methodologies for calculating and reviewing cost estimates can be found (NEA, 2016a: p. 58 and 2017: p. 11). The main cost drivers in decommissioning projects have been identified as (adapted from NEA, 2017: pp. 9-10):

- National policy and technical options chosen for the decommissioning strategy;
- Assumed duration of the dismantling and clean-up activities;
- Delay between end of operations and beginning of decommissioning;
- Regulatory requirements, including details of reporting and clearance levels;
- Inventory of the physical, radiological and hazardous materials;
- Provisions for waste storage and management, availability of final disposal facilities and obligations pertaining to SNF;
- Availability of experienced personnel with knowledge of the plant.

Cost estimates in the field of RWM are even more challenging, as they must deal with long timescales and take into account the development of new technologies. In some cases, such timeframes may extend to over a century for DGRs. In addition, comparable projects do not exist as benchmarks. Recent experience remains narrow due to the scarcity of planned or implemented repository projects (IAEA, 2005a: pp. 18-19; Seidel and Wealer, 2016: p. 20). Nonetheless, most countries attempt to calculate the back-end costs as a basis for the assessment of funding needs (NEA, 2013:

p. 48). While one can list also a number of general cost drivers for RWM, projects depend strongly on factors that are country- or even site-specific (IAEA, 2007: p. 16; NEA, 2007: p. 22 and NEA, 2013: p. 48):

- Scope of national policy and legal frameworks (radioactive waste classification, cost estimation rules and nomenclatures, environmental impact assessment, socio-political factors);
- Options retained for RWM: waste volumes, types and characteristics, packaging requirements;
- Technological choices for final disposal of SNF/HLW;
- Availability of infrastructure and of designated sites as well as the geological features of the latter;
- Disposal concept and plan, notably co-location with other nuclear facilities, monitoring and retrievability options, security requirements.

Given these framework conditions, different cost estimation methodologies with different data requirements can be used. Their accuracy will depend on the availability and applicability of reliable data and the extent of the analysis conducted (NEA, 2016a: p. 58). Cost data may come from recorded experience from other projects (where available), estimating handbooks, or even equipment catalogues (Laraia et al., 2012: p. 60). Relevant, if not necessarily systematic, information on decommissioning costs is publicly available and continues to be produced in international fora such as the NEA Working Group on Decommissioning Costs (COSTDEC). Since empirical sources for RWM are rare, one may cautiously assume that some similarities exist with respect to broad cost categories such as heavy machinery, materials, personnel and sub-contracting, regulation, R&D and contingencies (IAEA, 2007: pp. 19-21).

While such categorisations inevitably are somewhat arbitrary, the IAEA (2005a) distinguishes between *order of magnitude estimates* before the full definition of the scope of the project, Budgetary estimates when the scope has been defined but the detailed engineering has not been performed, and *Definitive estimate* on the basis of detailed engineering data, diagrams and structural drawings (IAEA, 2005a: p. 13). In this context, the international discussion currently recognises five estimating techniques (IAEA, 2005a: pp. 13-14; NEA, 2006: p. 32 and 2015: pp. 12-13):

- Bottom-up estimate: the project is broken down into its smallest work components or tasks with estimations of the amount of labour and materials required.
- Specific analogy estimate: uses costs from prior estimates and projects allowing for adjustments regarding size, complexity, labour costs, inflation, escalation, and regulation.
- Parametric estimate: statistical method that uses historical databases of similar systems to identify links between cost drivers and project parameters such as units of inventory or square metres.
- Cost review and update: examines previous estimates for internal logic, completeness of scope, assumptions and estimating methodology; it usually updates a previous estimate.
- Expert opinion (Delphi method): used when other techniques or data are not available; it relies on the consultation of specialists to form a consensus cost estimate.

A major factor affecting costs estimates for both decommissioning and RWM projects is the variability between different estimates. Such variability is due to a variety of reasons. They include differences in the scope of work, labour costs, inflation, the costs of oversight and management, the specificities of the radioactive contamination, waste type and streams or the costs of environmental compliance. However, differences in methodologies, assumptions and conventions also play a role.

Ideally, cost estimates should be done on a detailed site-specific basis (IAEA, 2005a: p. 12). In the absence of project-specific estimates, only the costs of specific activities should be benchmarked rather than those of entire projects, since boundary conditions, assumptions as well as risks and uncertainties will differ (NEA, 2015: p. 11). There are three major issues that have a significant influence on the variability of cost estimates in the field of decommissioning that apply mutatis mutandis also to RWM (Wuppertal Institute et al., 2007: pp. 19-24; Laraia et al., 2012: p. 70):

(1) *Scope and precision of boundary assumptions*: whether the cost estimates include SNF removal and reprocessing, transition from operation to decommissioning, characterisation and inventory, maintenance, surveillance and security of the site, as well as the final state of the latter (greenfield or brownfield for decommissioning; type of repository for RWM).

(2) *Waste management costs*: the costs of waste disposal to be included in decommissioning estimates depends on critical RWM-related factors such as: options for recycling, repositories, or interim storage, the unit costs for each type of disposal, the kind of repository chosen, and the clearance levels to release materials; finally, the features of waste packaging and transportation (capacity, design life, limitations) need to be taken into account.

(3) *Information available*: cost estimation methods and their results are still suffering from heterogeneity. As highlighted by the NEA Working Group on Decommissioning Costs (COSTDEC), cost estimations are affected by large uncertainties even between facilities of the same type, with considerable variability in the format, content, practice of cost estimates. Methodological and quantitative information by NEA countries is difficult to reconcile, unless reprocessed through common nomenclatures such as ISDC (NEA, 2016a: p. 28, p. 47 and p. 156).

It can be safely assumed that the variability of estimates for the economic costs of RWM projects is far greater still. This is due (a) to an even greater lack of existing projects even for the most prudent forms of benchmarking, (b) the choice of options available (extended interim storage, DGR, reprocessing, back-leasing etc.) whose costs may differ by an order of magnitude or more and (c) the far longer timeframes under considerations. In its latest *Illustrative Nuclear Programme*, the European Commission States with respect to the cost estimation of national RWM programmes in Europe:

> "Although most Member States have estimated the global costs of the actions that are included in their national programmes, in the majority of cases this information is not sufficient to conclude on the completeness and accuracy of the figures reported (EC, 2017b: p. 15)."

This situation calls for a two-pronged approach. First, it requires concentrated work and international co-operation on methodological conventions and data requirement for RWM projects in order to narrow the variability of estimates and increase their pertinence. In many cases, the issue is not the availability of data as such, but the absence of international comparability and a lack of transparency. The latter can be due to a desire to create asymmetries of information in a context of misaligned incentives. Second, it requires an understanding of the strategic implications of such variability, which comes back to the necessity of adopting, implicitly or explicitly, a circular approach to the adequacy of funding RWM projects. Accrued funds, available technological options and evolving social and political preferences will interact in a process capable of defining a technically, financially and politically sustainable solution. Solid and continuously updated cost estimates play an important role in this process. However, they cannot, at least not at the current state of knowledge and the fluidity of social and political preferences, on their own constitute the horizon of RWM policy.

Addressing uncertainties in cost estimates

Ensuring adequate funding for decommissioning and RWM is subject to large uncertainties. Ultimately, the size and nature of such uncertainties and the conceptual and institutional changes their handling implies is the motivation behind this report. It is thus worth to consider the nature of these uncertainties in somewhat more detail. At the most basic level, uncertainties arise either on cost (implementation) side or on the asset (funding) side. These uncertainties are interwoven by a tight set of causalities: the need for an inflow of more resources depends on the management of already-collected resources, on the availability and quality of cost estimates, and on the uncertainties associated with the predictions when the resources are needed. Timing affects both costs and returns on investment. Of course, the nuclear industry in general is part of extraordinary industry-specific risks and uncertainties such as the political decisions that change framework conditions, the obsolescence of knowledge regarding highly technical and location-specific projects and rapidly evolving technological options.

More specifically, on the cost side, a wide array of long-standing, well-identified uncertainties affect estimates for both decommissioning and RWM-related projects. DGRs for HLW/SNF management remain especially sensitive to these uncertainties. In the area of decommissioning instead, a growing number of publications, especially by the NEA, have addressed the cost issues (see, for instance, NEA 2003b, 2010, 2015, 2016a and 2017). In addition, cost engineering standards (e.g. Association for the

Advancement of Cost Engineering International [AACEI] general guidelines), margins for technological and project risks (EPRI margins) and methodologies for decommissioning-specific cost estimation have been developed, notably through the International Structure for Decommissioning Costing (ISDC). Despite this large-scale effort, a recent NEA study identifies a lack of consistency and clarity in the analysis of uncertainties pertaining to decommissioning cost estimates (NEA, 2016a: p. 82).

An earlier review of eight studies on the costs on the back-end of the nuclear fuel cycle (NEA, 2013: p. 50, pp. 87-108) had also concluded that the uncertainties affecting cost estimates of nuclear fuel cycle back-end technologies were significant. Unsurprisingly given the long timeframes involved, cost estimates were especially sensitive to discount rates. The lack of experience from prior comparable projects and the lack of established methodologies and mature designs also weigh heavily and can lead to variations in labour productivity. Particularly important were also out-of-scope uncertainties such as changing regulations, notably changes in worker exposure limits or site release limits, major changes in design or project scope, delays caused by stakeholder intervention or funding limitations (NEA, 2015: pp. 23-25, NEA, 2016a: pp. 82-83 and NEA, 2017: pp. 17-26). Out-of-scope uncertainties relate to the notion of "uncertainty" according to Knight, without assigned probabilities, which was presented in Chapter 1. They cannot easily be translated into probability functions and expected utility and thus do not allow market hedging. They typically are part of what was also called non-diversifiable "residual risk", which requires handling by a party without profitability requirements or solvency constraints, i.e. the government or an organisation enjoying implicit or explicit government guarantees.

The IAEA has developed a risk analysis framework that specifically targets risk management in nuclear decommissioning activities (DRiMa project), based on previously published safety standards (see IAEA, 2014). The risk identification and assessment process is used to generate a project cost for risks beyond the defined project scope, which can be associated with a level of probability. Almost by definition, the greatest area of subjectivity in the funded risk calculation is the quality of the input data used to assess the out-of-scope risk.

Uncertainties regarding the accuracy of cost estimates can also be reduced by increasing the frequency and process of pertinent updates of existing cost studies (NEA, 2013: p. 52 and NEA, 2017: p. 9). A recent review of NEA countries indicated that decommissioning cost estimates were reviewed either by the operator, the operator in collaboration with the government or regulator, the administrator of the fund alone, or the regulator alone. The precise structure and frequency of the reviewing process were found to be widely dissimilar across surveyed countries (NEA, 2016a: p. 122). Clearly, establishing common international methodologies and processes with broader stakeholder involvement could contribute to more reliable and more relevant cost estimates capable of helping to structure the funding system as a whole to improve adequacy.

Chapter 5

Conclusions

This first part of this study aims at providing a broad conceptual framework for financially and politically sustainable financing arrangements for the back-end of the nuclear fuel cycle. It is a timely moment to discuss the adequacy of funding for three reasons. First, a large number of decommissioning projects are under way or coming on-line and the first concrete experiences with the building of DGRs, supported by a strong international scientific consensus regarding their feasibility, are being gathered in several NEA countries. Second, changes in macroeconomic circumstances are questioning many of the assumptions on which much of recent discussions about funding were predicated. The economic fallout of the Covid-19 health crisis in 2020 is only a stark reminder of long-run trends that will maintain the rate of return on traditional risk-free assets at low levels for the coming years. This will require a reassessment of investment strategies, which will include a diversification of portfolios into new asset classes, the adjustment of risk exposure as disbursement approaches and broad societal agreement on the specific risk profiles of the funds for financing decommissioning and RWM in a given country. Third, changes in funding arrangements are under way in a number of NEA countries (see also Part II on the country case studies). These changes reflect in part the shifting macroeconomic context and introduce to differing degrees genuinely new arrangements in terms of liabilities or possible solutions. However, these changes are taking place in an implicit manner without reference to a coherent framework. One objective of this study is to supply conceptual references and elements of language to allow a discussion of these changes in a more explicit and systematic manner.

The framework proposed here is based on the premise that in particular RWM has an intrinsic long-term political dimension. The latter can only be imperfectly accommodated by the "linear approach" that is currently widely used, in which the present value of estimated costs at a precise future date established on the basis of largely assumed discount rates is aligned with the current assets constituted by the operators of nuclear power plants. Discount rates and assumed rates of return on capital have here an outsized influence in determining the adequacy of funding in this framework. Current long-term rates suggest in particular that returns on the risk-free assets historically favoured by regulators will be much lower than implied by the social discount rates used by convention in many NEA countries.

This framework has instead advocated a "circular approach", in which all elements of the system – timing, technologies, funding requirements, societal and political preferences as well as the allocation and transfer of liabilities – are considered to have some flexibility. Regular reviews with broad stakeholder involvement at well-timed, pre-announced intervals would be an integral part of the circular approach. They would serve to reassess all elements of the system in light of changed circumstances and to realign them with each other. Finally, a circular approach is likely to improve incentive compatibility. By not attaching itself ex ante to a solution that in most countries has yet to be confirmed, it goes some way to avoid the temptation to design final RWM projects "to cost", i.e. with final available funds in mind, rather than to provide least-cost solutions to clearly defined societal objectives.

An important question in this context is: "Which party is best equipped to shoulder liabilities whose levels, mode of administration and disbursement might change radically due to changing societal and political circumstances in the years and decades to come?" If the question itself suggests a higher degree of public involvement, this in no way implies releasing nuclear operators and electricity customers of their historic obligations. The necessary follow-up question is indeed: "Under which circumstances could any transfer of constituted assets and liabilities take place that respects the fair distribution of economic burdens but that would improve dealing with any future not-yet-foreseeable residual risks?" Economic theory holds that the party best equipped to manage those risks should also be liable. Of course, the very fact that many of these risks relate to the realms of politics and societal debate also implies that different countries will adopt very different national solutions so that they best fit their specific circumstances and institutional arrangements.

Such forms of liability transfer would require a somewhat broader interpretation of the PPP. It is important here to distinguish the fundamental notion of fairness that polluters or users should be liable for the full costs of their activities from the economic efficiency principle of full internalisation of externalities. Under certain circumstances, i.e. partial equilibrium frameworks, fixed parameters, full control of the polluter over costs, the two notions do indeed coincide. It should also be reaffirmed that a broader interpretation of the PPP would not revise notions of fairness and historical obligations. However, as argued throughout this conceptual framework, polluters, or rather waste producers, have little influence either on the private costs of abatement or on the social costs of waste. Both depend on the solution that is determined, for good reason given the nature of the issue, by a third party. The requirement that both costs should be equated in the optimising framework of the PPP by the "polluter" at the margin thus no longer applies. In particular, the private incentive for social cost minimisation due to the "internalisation" of social costs is thus no longer operative. In the original context for which the PPP was devised, liability for pollution went hand in hand with autonomous cost control. In the area of RWM, this link no longer applies. This does not mean that the PPP as a general principle of fairness cannot continue to provide guidance.

Things are somewhat different in the area of decommissioning, where private and social objectives can be much more easily aligned. Constantly improving experience has allowed methodologies and technologies to mature. Private operators and their shareholders are increasingly capable of driving cost-minimising solutions that fully correspond to the charge sheet set out by regulators and the expectations of the public. In this situation, leaving liabilities and funding obligations with operators is the appropriate solution and there is little to be gained from changing current conventions in any major way. There is a good chance that decommissioning will move on in the coming years, also due to the codifying work on methodologies being done at the NEA and elsewhere, towards being a mature industrial activity, which does not require any public involvement beyond standard regulatory oversight. It is currently difficult to conceive that RWM will reach that stage in the foreseeable future. In both areas, however, the appropriate institutional arrangements need to be complemented by the careful building of human capacity, especially when designing funding schemes for the financing of decommissioning and RWM in newcomer countries.

This work could not have been undertaken without the large body of work that exists at the NEA, the IAEA and elsewhere on the funding of activities in the areas of decommissioning and RWM and its challenges. It has aimed to bring together much of this work and augment it with considerations drawn from the economic literature on efficient liability allocation in other areas, in particular insurance, which similarly straddles concerns about private and social optimality. Ultimately, this work is based on the conviction that the long-term sustainability of the financing of decommissioning and RWM depends on political and societal sustainability over time, in addition to the competent management of economic, financial and technical concerns, which remains indispensable.

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PART II

Twelve case studies of the funding arrangements for decommissioning and radioactive waste management in NEA countries

The following twelve case studies of Belgium, Canada, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, the United Kingdom and the United States have been elaborated in close co-operation with experts on the funding of decommissioning and radioactive waste management in the respective member countries.

Chapter 6

Belgium: Country case study

KEY FACTS	
Funding model	Internal segregated funds for decommissioning, spent nuclear fuel (SNF) management and RWM held by the industry; external funds for RWM held by ONDRAF for waste already transferred to the national agency.
Assets	Synatom – i.e. industry's – funds: • USD 13.8 billion, of which 45% for decommissioning and 55% for SNF (31.12.2018) • USD 16.5 billion, of which 44% for decommissioning and 56% for SNF (31.12.2019)
Public funds	ONDRAF (31.12.2018): The Long-Term Fund (which consists of three separated compartments to finance Interim storage, geological and surface disposal) around EUR 416 million (USD 520 million).
Liabilities	• RWM: No public figure • Decommissioning: No public figure
Avg. effective real return	• Synatom – i.e. industry's – funds (31.12.2018): ≥ 3.5% • Public funds: ca.1%
Discount rate	• Synatom – i.e. industry (31.12.2018): 3.5% • From 2019 on 3.25% for SNF funds and towards 2.5% for decommissioning • Public: 1%
Assumed operational lifetime of nuclear power plants	40 years, exceptionally prolonged to 50 years for 3 reactors. Ultimate shutdown dates between 2022 and 2025.
Investment rules	Synatom – i.e. industry's – funds: Until 2019, up to 75% could be lent back to the operator (upon credit rating and solvency requirements), and 25% had to be invested in other financial instruments on the condition that they meet the required liquidity and diversity to minimise the risk. From 2020, due to the 2019 revision, it was decided to put an end to the loan by 2025 for the part of SNF funds.
Public funds	ONDRAF funds must be invested in debt securities in euros, issued or guaranteed by a Member State of the European Community, its local authorities, or by public international bodies where one or more EC States are members. Compliance with European System of National and Regional Accounts.

Evaluation of fund adequacy	• General arrangements of Synatom's fund are reviewed every three years by the Nuclear Provision Committee; • Every five years through comprehensive inventory reports drawn up by ONDRAF for the all of the nuclear waste producers (including industry, research e.a.).
Issues at stake	• Possibility to lend back up to 75% of industry-supplied funds to the nuclear operators, subject to credit rating and solvency requirements. Although this practice is to cease by 2025 for the SNF Fund, it results in a significant concentration of risk to a single private entity and endangers the timely availability of assets, especially in view of unforeseen events. • Dedicated fund set up in 2016 by the national waste agency to finance the socioeconomic costs for the surface disposal facility. • Nuclear phase-out by 2025 despite nuclear share in the 2018 electricity production of around 50%. Initial shutdown of 3 reactors in 2015 was suspended until 2025 to ensure energy supply. Said extension led to a European Court of Justice (ECJ) lawsuit and decision in July 2019 for the Doel 1 and Doel 2 reactors. The Belgian Constitutional Court sets a final date for an environmental impact assessment in December 2022. • Low long-term risk-free interest rates led the public review authority to impose a gradual reduction of the nominal discount rate used in back-end cost estimates (from 4.8% to 3.50% by 31 December 2018 and further on from 2019). This is part of a longer-term trend of discount rate reduction that led Belgian liabilities to increase dramatically over the last decade (see Figure 6.3).

Decommissioning and RWM in Belgium

Belgium has a functional but complex funding system in place to cover its costs arising from decommissioning and RWM activities (Figure 6.1), embedded in an elaborate interim storage system.

The liability for all costs arising from decommissioning and RWM activities is to be fully borne by nuclear operators. For this purpose, Synatom – Société Belge des Combustibles Nucléaires, a separate legal entity owned by Engie-Electrabel with the Belgian government having one "golden" share, giving it special rights and powers – holds two funds respectively for decommissioning and SNF management, which are fed by contributions from nuclear operators. The SNF Fund is to finance all costs associated with SNF assemblies from interim storage to final disposal in in a deep geological repository (DGR), as well as SNF conditioning and reprocessing. The Decommissioning Fund is meant to cover all the activities from final facility shutdown to final site release, including RWM costs for all waste categories except SNF. Activities to be included comprise: facility shutdown, decontamination and dismantling, waste processing, storage and disposal, site clean-up and restoration, project management, and engineering and site support.

The Belgian state, through its National Agency for Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS, in the following referred to as "ONDRAF"), manages the final disposal of all radioactive waste in exchange for payments from nuclear waste producers, thus also from the nuclear operator via Synatom. To effectively manage the financial resources transferred by nuclear waste producers over the long term, ONDRAF possesses the Long-Term Fund, which consist of three earmarked compartments to finance interim storage, geological and surface disposal, each with different activity-dependent timeframes.

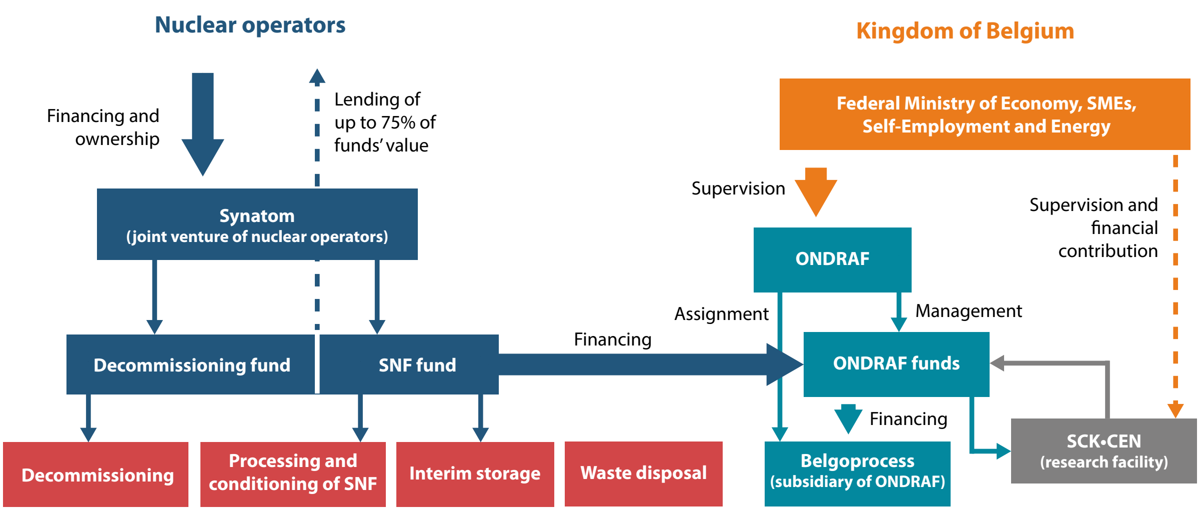
While nuclear operators are responsible for leading decommissioning activities, Synatom is charged with the management of SNF. To such end, Synatom must retain at all times sufficient liquidity in form of cash investments or disposable assets to be able to finance all expenses related to dismantling and the management of SNF for the next three years of operation. Still, and although this practice will cease by 2025 for the SNF funds, up to 75% of Synatom's fund provisions can be lent back to the nuclear operators, subject to credit rating and solvency requirements and upon approval of the public Commission for Nuclear Provisions (CPN) (ONDRAF, 2018; Cortvriendt, 2017).

The clear separation of private funds for decommissioning and SNF management (held by the industry) from funds for long-term RWM activities (held by a public entity) appears to be a promising approach to ensure adequate management of the financial assets dedicated to the respective field of activity. However, the possibility for operators to borrow back a part of the funds for future decommissioning and RWM liabilities (partly until 2025) appears to endanger the objective of ensuring adequate, accessible, and reliable financial resources. Such a lending scheme also hampers transparency regarding the location of assets dedicated to settling decommissioning and RWM liabilities, raising concerns on the on-time availability of assets, especially in the case of unpredicted events. Finally, the scheme raises questions regarding the supervision of the investments on the second or third investment level, i.e. the investments that are made with the loans once they are reinvested by a nuclear operator. In case a nuclear operator goes bankrupt, the Belgian state would indeed become directly liable for financing any RWM costs that might arise (NEA, 2013).

Nonetheless, the recent commitment by Engie-Electrabel and decision of the Commission on Nuclear Provisions during the three-year review at the end of 2019 to put an end by 2025 to the practice of borrowing and of investing up to 75% of Synatom's SNF funds represents a major breakthrough in terms of funding consolidation and convergence with international best practice. Even though this practice will remain possible for Synatom's decommissioning funds, this share is expected to decline as a result of upcoming decommissioning activities sped up by the obligation of retaining at all times sufficient liquidity to finance the next three years of operation.

Indeed, such a dramatic change in asset management and investment vision should further decorrelate the performance of the Synatom Funds from that of Engie-Electrabel, thereby sizably improving the reliability and availability of funding by decreasing the Synatom Funds' degree of risk exposure by a significant margin. Overall, the funding system for decommissioning and RWM in Belgium is therefore in the process of accomplishing an important leap forward to its long-term sustainability.

Figure 6.1:
Simplified overview of the Belgian funding system for decommissioning and RWM



Nuclear power plant lifetime

Currently, seven nuclear reactors are operated in Belgium, and they provided about half of the Belgian energy supply in 2018 (WNA, 2018). All Belgian reactors are concentrated in two nuclear power plant sites, Doel and Tihange, which are operated entirely and owned almost exclusively by Engie-Electrabel, a subsidiary of the French multinational utility company Engie.

In January 2003, a Federal Act prohibited the construction of new reactors and limited the operational lifetime of nuclear reactors to 40 years. This resulted in a scheduling of shutdowns for all reactors between 2014 and 2025, raising concerns regarding the security of Belgian energy supply. In 2013 and 2015, due to energy supply concerns, three reactors that were initially to be shut down in 2015 were finally granted ten-year lifetime extensions until 2025. The Belgian government subsequently announced that it had changed the 2003 Federal Act in a way that it could not be subject to any future changes, setting definite phase-out dates for the two reactors Doel 3 and Tihange 2 respectively in 2022 and 2023 and for five reactors in 2025 (WNA, 2018).

In 2008, the Belgian government introduced a levy on nuclear power generation to, among other things, subsidise the development of alternative energy production technologies. The levy is based on generating costs, the volume of electricity generated, and wholesale prices. Collected fees are introduced into the national budget (IEA, 2016). In 2018, this special contribution amounted to USD 188 million (Synatom, 2019). Next to the special contribution, the 10-year lifetime prolongation for three reactors was agreed under the condition that a special tax contribution from nuclear operators be set up, amounting to USD 25 million per year for the Doel 1 and 2 reactors, and based on an individual formula for the Tihange 1 reactor.

In accordance with the new phase-out decision by the government, cost estimates in Belgium are based on the real operational lifetime of the nuclear reactors of respectively 40 and 50 years. The prolongation of the lifetime for the Doel 1 and 2 reactors was effected in 2015 via governmental law, which was preceded by an agreement between the government and nuclear operators for the latter to invest USD 875 million in modernisation and safety-related upgrades for their reactors. However, the absence of environmental assessments or public consultation processes preceding the lifetime extension decision led two Belgian environmental associations to file a lawsuit before the Belgian Constitutional Court and eventually the European Court of Justice (ECJ) for breach of several European directives. In 2019, the ECJ ruled that despite an effective breach of European directives in terms of environmental assessment and public consultation, the potential threat to the Belgian internal electricity supply, the public-private agreement for modernisation and safety improvements of nuclear power plants allowed for continued operation of the two reactors (ECJ, 2019). This emphasises the importance of well-thought-out and sustainable decision-making in matters of nuclear energy policy. The Belgian Constitutional Court confirmed this point of view in March 2020 and decided that the environmental impact assessment and the public consultation should take place by the end of 2022.

Waste management

For the time being, a central interim storage facility in Dessel constitutes the main storage capacity for all categories of radioactive waste in Belgium. SNF is still largely stored on site at the two nuclear power plant sites. Due to the anticipated exhaustion of on-site storage capacity for SNF by 2023, an enlargement of the on-site storage facilities is planned (Synatom, 2019). The construction of a new near-surface facility for the final disposal of low-level radioactive waste (LLW) and intermediate-level waste (ILW) (CatA in Belgian classification) in Dessel was scheduled to start in 2017. Originally scheduled to start in 2020, the operation of this near-surface facility is as of September 2020 foreseen to start in 2022, thereby equipping Belgium with a solid overall storage scheme despite remaining uncertainties regarding a final disposal site for SNF and high-level waste (HLW). Overall, although a strategy towards a final underground repository for HLW and SNF has not been definitively decided upon yet, substantial R&D efforts are being made, including an ongoing project that examines boom clay as a potential host layer for wastes (WNA, 2019; IEA, 2016).

Financial responsibilities for back-end

In Belgium, the responsibilities for decommissioning and RWM are split between nuclear operators and the state, although nuclear operators must fully finance both activities. The Belgian state, through ONDRAF, manages the final disposal of all radioactive waste in exchange for payments from nuclear operators. Correspondingly, operators hold common financial provisions to pay for ONDRAF's RWM-related services, and for their own management of decommissioning and SNF management costs – which include conditioning, SNF reprocessing, and interim storage of SNF before its handover to ONDRAF.

The operators' provisions are managed by Synatom, a separate legal entity fully owned by Engie-Electrabel, with the Belgian government having a "golden" share giving it special rights and powers. In particular, two government representatives from the Minister of Energy sit on the board of directors. They have the right to appeal decisions which endanger Belgian energy policy, energy supply security or nuclear provisions sufficiency. Engie-Electrabel operates and owns all nuclear power plants in Belgium, with EDF-Belgium and Luminus having parts in production of certain units. With regards to the back-end activities, Synatom is solely responsible for collecting funds from the operators on behalf of the Belgian state, and for ensuring that financial provisions are available to cover the costs of decommissioning and SNF management (including interim storage, reprocessing and conditioning). Synatom is supervised by the government-appointed Nuclear Provisions Commission (EC, 2018), in the following referred to as "NPC".

The NPC was created in 2003, by the Law of April 11th, and has to advise Synatom on all aspects of nuclear provisioning. Its eight members gather five representatives from the government with permanent seats and three representatives from ONDRAF, the Federal Agency for Nuclear Control (FANC) and Synatom with an advisory role. The NPC exercises a prudential control of the existence, sufficiency and availability of the decommissioning and SNF funds.

To effectively manage the financial resources transferred by nuclear operators over the long term, ONDRAF also possesses several funds, each with different timeframes, to finance their respective cost items, including the short to long-term management activities, the technical inventory, and R&D that is carried out by the public Belgian Nuclear Research Center (SCK•CEN). Payments made by nuclear operators cover the costs for the short-, medium-, and long-term management of their radioactive waste and are due at the time at which the waste is handed over and its ownership consequently transferred to ONDRAF. This means that, to pay for its waste disposal activities, Synatom has to transfer the required funds to ONDRAF once the radioactive waste is handed over to ONDRAF. Moreover, a recent modification of the Royal Decree of 1981 which sets and organises ONDRAF activities, gives the organisation the right to ask the operator for compensation if there are cost increases after the transfer. In other words, to ensure adequacy of funding for RWM the financial responsibility of the waste producer is not limited in time. If need be, waste producers must adjust at each time the sum paid to ONDRAF according to the allowance level.

The funding system

The liability for all costs arising from decommissioning and RWM activities is to be fully borne by nuclear operators. For this purpose, Synatom holds two funds respectively for decommissioning and SNF management, which are fed by contributions from nuclear operators. The SNF Fund is to finance all costs associated with SNF assemblies, from interim storage to final disposal in a DGR, as well as SNF conditioning and reprocessing. The Decommissioning Fund is meant to cover all the activities from final facility shutdown to final site release, including RWM costs for all waste categories except SNF. The Belgian state, through ONDRAF, manages the final disposal of all radioactive waste in exchange for payments from nuclear operators via Synatom (see Figure 6.1 above). To effectively manage the financial resources transferred by nuclear operators over the long term, ONDRAF also possesses several funds, each with different activity-dependent timeframes. In 2015, the Belgian Ministry of Economy reported to the European Commission a net present value of USD 11.5 billion for the total provisions made for RWM in Belgium, which presumably includes ONDRAF's and Synatom's funds; and USD 5.75 billion for the provisions registered by the nuclear operator for the decommissioning of Belgian nuclear power plants (EC, 2017, 2015).

Purpose and scope of the Funds

Before 2003, electricity generators were entirely financially responsible for decommissioning and RWM in Belgium. From 1985 to 2003, a convention between the operators and the Belgian state created the first obligation to build provisions for future nuclear liabilities. These provisions were based on the initial investment amount, and funding was ensured through a lump sum, fixed for five years, during a given period. A 2003 law on the nuclear power plants dismantling provisions and the management of irradiated fissile materials imposed a prudential control of the existence, sufficiency and availability of decommissioning funds (Cortvriendt, 2017). This law stipulates that costs associated with RWM are still to be paid by those who produce radioactive waste, but are to be managed via a public entity, meaning that nuclear operators must pay all costs for ONDRAF's RWM-related activities at cost price and in proportion to their share of the overall volume of radioactive waste generated (IEA, 2016). Synatom is responsible for ensuring, on behalf of the owners of the nuclear power plants, the coverage of the costs of decommissioning nuclear power plants and of the management of the arising SNF (KOB, 2015). As per this arrangement, nuclear operators therefore take care of decommissioning on Synatom's behalf, while Synatom is responsible for managing the SNF until it is handed over to ONDRAF. At that point Synatom has to transfer to ONDRAF the financial means from its relevant funds for radioactive waste.

The scope of the SNF provisions includes all costs associated with SNF assemblies, from interim storage to final storage in DGRs. The provisions for decommissioning are meant to cover all the operations needed to completely decommission Belgian nuclear power plants, including the costs of shutdown, defueling, facility decommissioning, site remediation, and of the management of resulting radioactive waste. The provisions for decommissioning are established in a way that they cover the whole discounted amount of the decommissioning costs at the time of a plant's final shutdown: the funding is equal to the net present value of all future decommissioning expenses.

Synatom's decommissioning and SNF funds

Synatom is a private entity owned by Engie-Electrabel with an embedded "golden" share held by the Belgian federal government, which appoints representatives to Synatom's board of directors. The funding system managed by Synatom can be characterised as internal and segregated – or as a segregated internal investment company (EC, 2018). Synatom's provisions are indeed split into two funds, one for decommissioning and one for the management of SNF. While the percentage amount reserved for each task is specified in Synatom's financial reports, the management of the provisions as segregated funds is not fully clear (Synatom, 2019). Engie-Electrabel and the companies with a share in industrial electronuclear production must pay to Synatom contributions for building up provisions for their back-end obligations. Accordingly, Synatom holds two funds respectively for decommissioning and SNF management, where contributions are accrued. For the Decommissioning Fund, Synatom collects funds from nuclear power generators on a trimestrial basis and on a levelised total cost approach, in form of a levy per kWh of electricity sold that is part of the electricity production costs and is passed on to utility customers (IEA, 2016). Regarding payments into Synatom's SNF Fund, they are included in the cost that Synatom charges Engie-Electrabel for the use of the nuclear fuel (ONDRAF, 2018).

RWM financing via ONDRAF

ONDRAF takes charge of the radioactive waste from producers against the payment of a tariff intended to cover the cost of the short-, medium- and long-term management of the waste. Payments for this purpose are made out of Synatom's SNF Fund. ONDRAF can create various funds with different associated timeframes depending on the time horizon of associated disbursements, in order to finance different cost areas. ONDRAF manages these funds following rules set by the Minister of Economic Affairs and by ONDRAF's Board – which is appointed by Royal Decree, based on scientific or professional expertise, upon proposal of the Ministers of Economy and Energy after deliberation of the Belgian Council of Ministers. The financing of short-term RWM activities, including the treatment and conditioning of radioactive waste, is based on contractual agreements between nuclear operators and ONDRAF. They are financed by nuclear operators, who pay their share of the fixed costs according to the contractual schedule and the tariff amounts corresponding to the variable portion of the costs for the treatment and conditioning of their non-conditioned waste as ONDRAF takes charge of it. Pursuant to said agreements, the tariffs can be revised every five years (KOB, 2015).

A *Long-Term Fund* (LTF) ensures the financing of long-term RWM activities and hence of ONDRAF's long-term mission, which consists of future radioactive waste disposal. The LTF is provisioned by the nuclear operators every time they transfer new waste to ONDRAF, according to a mechanism that ensures that ONDRAF will eventually be able to cover its fixed costs and enables it to cover its variable costs as they arise. A change, implemented at the end of 2018, amended the LTF's structure that is now to be composed of three compartments, assigned respectively to storage, surface storage, and geological storage of waste. Each of these compartments is to be subdivided into three sub-compartments relating respectively to infrastructure construction, operation, and dismantling or closure. This new structure is meant to improve the traceability of the fees paid by producers and the transparency of the LTF's management. Before the implementation of the new decree in 2018, the LTF mechanism was such that tariff increases were carried forward on waste still to be taken charge of by ONDRAF from the tariffs' revision date. This meant that the very last producer delivering waste to ONDRAF would potentially have to cover RWM cost overruns from all other producers if left unpaid by the latter (KOB, 2015). Since late 2018, the financing mechanism takes into consideration both, the waste that has already been transferred to ONDRAF and the waste that is still to be transferred, i.e. charges are payable by producers as long as all costs necessary for the long-term management of their waste are not covered (KOB, 2015). Furthermore, although the fees are in principle still payable when the waste is taken over by ONDRAF, the latter may now request advance payments to ensure it has sufficient resources at all times and thereby guarantee the continuity of long-term RWM. ONDRAF's fees for long-term disposal of radioactive waste are calculated relative to the cost of the geological repository project. As of December 2018, the method used to assess the project costs included project- and technology-related margins of uncertainty in order to reflect its one-of-a-kind nature, as well as the very large time lapse between construction and operation activities, particularly for geological repository. The margins have been applied in accordance with a methodology developed by De Bock and Baldwin in 2013 at the Electric Power Research Institute. However, ONDRAF's cost estimates do not reflect or take into account the different back-end scenarios (ONDRAF, 2018).

A *Medium-Term Fund (MTF)* established in 2010 is dedicated to financing the socioeconomic costs of integrating radioactive waste disposal projects into local communities – particularly the costs related to activities and projects of local communities which, through participative processes, ensure the continuity of societal support for the final repository. The obligation for producers to contribute to the MTF will begin as soon as a relevant repository is commissioned and receives an operating license as well as the required non-nuclear permits. The money will be transferred to the fund from radioactive waste producers when waste is handed over to ONDRAF. The MTF will be financed by a so-called "integration contribution" levied among radioactive waste producers and calculated based on the final repository's total capacity and on the total waste volumes to be disposed of per producer. The MTF was officially implemented in 2016 (KOB, 2015).

An *Insolvency Fund (IF)* was launched in 1992 to ensure the necessary financial means for ONDRAF to take over the responsibility for RWM from "small" waste producers (medical, industrial, etc.), other than nuclear power plant operators, that become bankrupt or insolvent. The IF is financed by small radioactive waste producers through a 5% reserve that ONDRAF invoices based on the costs of transportation, treatment, conditioning, and storage services charged to producers by ONDRAF. Management and use of the IF are supervised by the Audit and Advisory Committee of the Insolvency Fund (CAAFI), a contractual advisory body where both the main waste producers and the Belgian state are represented. ONDRAF holds further funds for the financing of its technical inventories, its R&D and other activities, including inter alia co-ordination and administrative duties (ONDRAF, 2018).

The cost side

Process and responsibilities

In Belgium, the legal and regulatory framework includes an obligation for operators to estimate the decommissioning costs they must cover and, where applicable, the costs of managing the nuclear materials for which they are responsible at the time they arise. It does not provide a framework for monitoring the evolution of these costs over time. Future liabilities are generally estimated using reference scenarios elaborated by ONDRAF for radioactive waste disposal, by Synatom for recycling or direct disposal of the SNF, and by the operators for decommissioning.

For decommissioning of the nuclear power plants and the management of the SNF, a specific Law of April 11th, 2003, imposes a closer follow-up by the Nuclear Provisions Commission (NPC). Every three years, Synatom's cost calculation is submitted to the NPC who can solicit ONDRAF for review and comparison with their own estimates. If need be, the NPC has the authority to ask for Synatom to adjust their calculus.

Methodology

Belgian law specifies that all costs should be calculated as overnight costs based on best estimate assessment, and should be presented as activity-dependent and period-dependent, using the work breakdown structure and standardised list of cost items from the NEA's Yellow Book (ONDRAF, 2018). Still, the law precludes ONDRAF from compelling operators to use a specific format, method, or approach for estimating and presenting costs. Any guidelines are to be solely indicative. Operators can – and do – exercise their own discretion for organising and estimating costs. ONDRAF must accommodate differences (NEA, 2010a).

Every five years, as part of its remit, ONDRAF draws up an inventory of nuclear facilities and sites containing radioactive substances, and estimates their management cost, i.e. all the costs for decommissioning, remediation, RWM, and managing of SNF to be charged to each financially liable entity (KOB, 2015). All decommissioning and RWM cost estimates are, whenever possible, to be carried out independently by the operators and by ONDRAF. ONDRAF then assembles the various cost estimates to compile its inventory report and provide all-inclusive back-end cost figures (ONDRAF, 2018). Nuclear facility operators are obliged to provide ONDRAF, under their responsibility and in due time, with all the necessary information concerning these facilities' decommissioning forecasts, as well as the nature, quantities and dates of transfer of the resulting waste (NEA, 2016). With implementation of the April 11th, 2003 Law, Synatom has presented every three years an estimate of the total cost of dismantling nuclear power plants and managing SNF to the NPC.

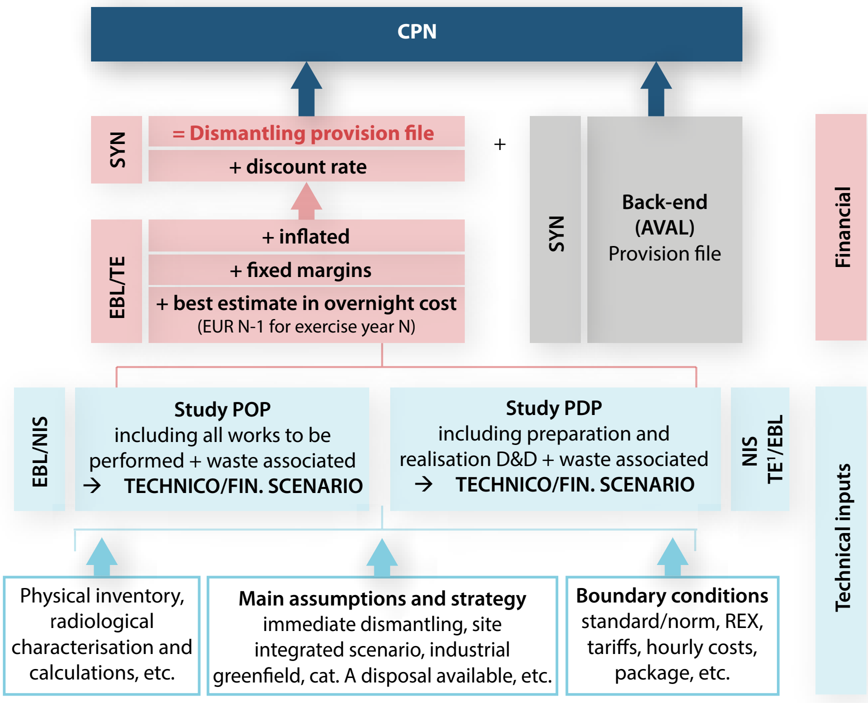
The provisions reserved for decommissioning correspond to the discounted value of the best estimate of the future costs of shutdown, decommissioning, and decontamination of nuclear power plants. The provisions made for SNF management are determined on the basis of an average unit cost established using the discounted value of the best estimate of the costs corresponding to all the quantities of fuel used during the nuclear power plant operation (Synatom, 2017). In a 2010 NEA report Belgium has remarked that the discount rate was not a cost estimate consideration, but rather one of funding in Belgium (NEA, 2010a).

Decommissioning costs

Decommissioning cost estimates in Belgium are prepared in current monetary units. Estimates are linked to a reference year of the decommissioning plan review and must encompass all activities from final facility shutdown to final site release, including RWM costs for all waste categories except SNF. Activities to be included comprise: facility shutdown, decontamination and dismantling, waste processing, storage and disposal, site clean-up and restoration, project management, and engineering and site support. Belgium specifies the inclusion of RWM for all waste categories except for SNF on a codified list of radioactive waste (NEA, 2010a).

Decommissioning costs are determined by the nuclear power plants' operators, following a technical scenario that is a conservative bottom-up approach based on the overnight dismantling of all units of the same nuclear power plant site in sequence, and on the decommissioning of the common site facilities after the decommissioning of the last unit on each site (NEA, 2016; Spinoy, 2018) (Figure 6.2). Recently, all actors agreed that immediate decommissioning with greenfield end state is the only possible strategy. It is therefore chosen as a reference scenario for nuclear power plant operators to ensure that adequate financial resources will be available. There is however no specific national policy and no legal obligation regarding decommissioning up to greenfield (EC, 2013). Decommissioning costs estimates are then submitted to the NPC and reviewed by ONDRAF. In particular, to cover hazards and uncertainties linked to imperfect or partial knowledge of technical data, ONDRAF includes a 15% uncertainty margin. ONDRAF reports all differences between the two estimates to the NPC, and ultimately decides whether the nuclear power plant operators have to review their cost assessment. The mechanism for periodically updating inventories and cost estimates is supposed to gradually reduce the uncertainties associated with this imperfect knowledge.

Figure 6.2:
Belgian nuclear operators' cost estimation methodology for nuclear power plant decommissioning and associated wastes



Source: Spinoy, 2018: p.16.

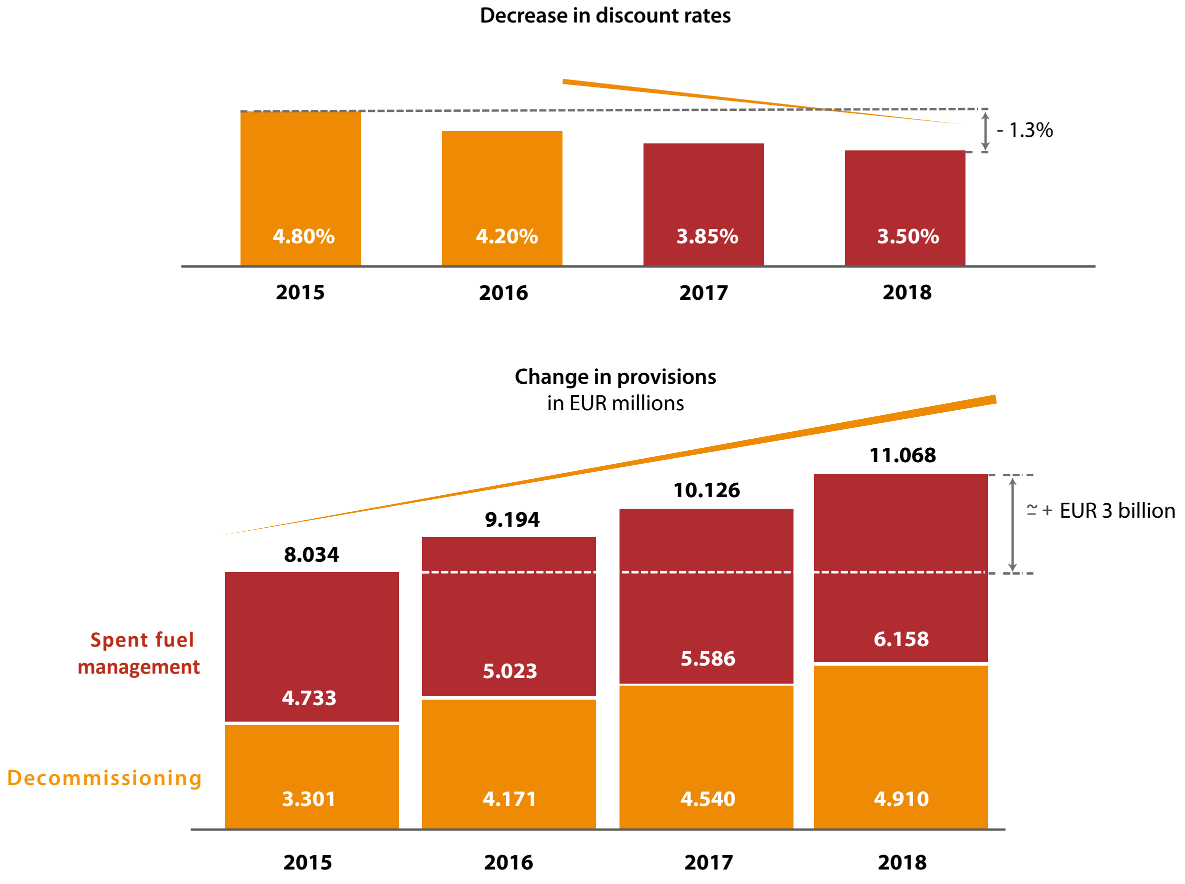
RWM costs and discounting

There is no standard model for estimating nuclear material management costs in Belgium. Cost estimates rely on the expertise of the operators and ONDRAF. Estimates of RWM costs by ONDRAF include the costs of managing physically present radioactive waste from infrastructure and equipment, including costs of transport, treatment, conditioning, storage and storage of radioactive waste, and the costs of managing nuclear materials. The cost estimates are based on a series of assumptions, in particular that all regulatory, technical and economic conditions are those at the reference date of the inventory. Moreover, as a general rule, the estimates are made as if all operations were carried out instantaneously on the inventory reference date. In the absence of a political decision, ONDRAF's assumptions for radioactive waste storage and disposal costs over the 2014-18 period were: a) 40 years of operational lifetime for the nuclear power plants; b) full reprocessing; c) disposal of long-lived LLW/HLW in Boom clay at 200m depth; d) geological disposal of HLW over the 2100-10 period; e) geological disposal of long-lived LLW to begin in 2047 with packaged historical radioactive waste. In 2018, ONDRAF declared that the RWM expenses that were estimated in overnight costs were discounted using a net discount rate of 1% for the last five-year period 2014-2018. The rate is estimated based on the average value of the envisaged annual return on ONDRAF's financial investments of around 3% and a projected average value of inflation of 2%. This assumes that future liabilities are calculated in current price levels. The discount rate is regularly reviewed to assess in particular whether it remains compatible with changes in the economic situation (ONDRAF, 2018).

The periodical cost estimates issued by ONDRAF regarding some aspects of final disposal of radioactive waste have been volatile over the last years, and nearly tripled since the last similar exercise in 2011. These cost increases for the operators of nuclear power plants are due to changes in the estimated costs of decommissioning for the Tihange and Doel nuclear power plant sites; to an increase in the quantity of SNF corresponding to the additional years of operation of nuclear power plants; and to a revision of discount rates applied in the costs estimates.

Synatom's cost estimate for the provisions of SNF management is based on the most expensive scenario for the back-end of the nuclear fuel cycle, which is reprocessing (EC, 2013). From 2016 onward, this assumption was changed to partially reprocessing. Synatom's Funds must be based on discounted decommissioning cost estimates, with an applied discount rate of 4.8% until the end of 2015. As mentioned above for ONDRAF's cost estimates, in December 2016, due to very low long-term risk-free interest rates, the NPC decided to lower the discount rate considerably to 3.5%. Moreover, in 2019, the NPC imposed a distinction between the SNF and the decommissioning discount rates with specific decreases plans. As of 2019, the SNF discount rate was lowered to a fix value of 3.25% and the decommissioning discount rate is decreasing gradually from 4.8% in 2015 to 2.5% in 2021, with thresholds of 3.5% in 2018, 3% in 2019 and 2.7% in 2020 (Figure 6.3, upper graph) (Cortvriendt, 2017; Synatom, 2017). This led to an increase in Synatom's provision requirements of +USD 3.75 billion in 2018 (Figure 6.3).

Figure 6.3:
Changes in Synatom's provisions relative to changes in discount rates between 2015 and 2018 in billions of euros (USD/EUR = 1.25)



Source: Synatom, 2019: p.10.

Recent developments on costs

In June 2018, a new baseline scenario for the long-term management of medium-level waste and HLW was presented and agreed by ONDRAF. This new reference scenario includes notably a maximum estimate for delivery of a DGR for radioactive waste, as well as an upward revision of a set of costs reassessed by ONDRAF (Engie, 2019b). On the side of decommissioning costs, an updated scenario has been developed by Engie-Electrabel for the final shutdown and dismantling of nuclear power plants and of the management of ensuing radioactive waste. This scenario aims to benefit from international lessons learned in the area of decommissioning, as it is based on industrial experience such as pressurised water reactor (PWR) dismantling works currently carried out in Germany, e.g. on the German nuclear power plants sites of Stade, Würgassen, Obrigheim, Mülheim-Kärlich, and Biblis. Focus is especially given to work breakdown structure (WBS) optimisation, decommissioning and dismantling strategies and phases, project organisation and staffing, operational effort during dismantling, and waste management (Spinoy, 2018).

Assets, investment rules and performance

Asset management rules (Synatom's Funds)

Synatom's investment strategy largely resembles a loan to Engie-Electrabel, with additional holdings in short-dated, liquid assets (EC, 2018). Indeed, by 2019, as per the legislation in force, up to 75% of Synatom's provisions could still be lent to electricity producers, i.e. to Engie-Electrabel, subject to credit rating (i.e. superior to BBB) and solvency requirements and upon approval of the NPC. In case of decrease of this solvency, the loan had to be paid back gradually (NEA, 2010b). It must however be noted that, due to the three-year revision of the provisions in 2019, Engie-Electrabel has committed to putting an end to this practice by 2025 for the SNF funds and will be progressively restituting to Synatom the full amount of spent nuclear fuel provisions until that date.

Engie-Electrabel is prohibited from subjecting its lent assets to any mortgage or other security for its financial debt, except if it can constitute or procure an equivalent security for Synatom, on the understanding that this prohibition shall include the usual exceptions for existing securities, securities established in the normal course of business and securities for the acquisition of new assets. As of 31 December 2016, Synatom had outstanding loans to Engie-Electrabel of about USD 8.4 billion, that is, roughly 73% of the value of Synatom's total funds. As such, Synatom does not hold an earmarked portfolio of capital market investments to meet future decommissioning and RWM costs – n.b. beyond the short-dated assets required by liquidity rules (see next paragraph). In that regard, Synatom is dependent on Engie-Electrabel to provide the required funding through repayment of these loans in the future, more precisely in advance of decommissioning. In that sense, as observed by a recent audit published by the European Commission, this portion of the Belgian funding scheme "does not quite match the concept of a segregated internal fund" (EC, 2018: p. 70).

The remaining 25% of Synatom's assets are either lent to other entities meeting required credit criteria or invested in short-term financial assets. A change of the law in 2007 had made it possible to use 10% of the remaining 25% funds for loans to other power sector investments unrelated to nuclear power plants, such as loans to projects and legal persons, under the condition that this does not endanger the existence and sufficiency of the funds.

Belgian law requires that Synatom retain, at all times, enough liquid assets, in the form of cash investments or disposable assets, to cover the next three years' worth of expected decommissioning and SNF management costs. In December 2016, the value of these liquid assets was circa USD 1.9 billion (EC, 2018). The legal framework grants a general lien on Engie-Electrabel's movable property, in favour of Synatom, as soon as the Commission for Nuclear Provisions orders Synatom to demand the full or partial repayment of the loans concerned. This lien guarantees the repayment of the loans concerned up to the repayment amount set by the NPC (KOB, 2015; EC, 2018).

In 2015, a minimum acceptable rate of return (MARR) of 4.8% was established for Synatom's funds. The fact that up to 75% of Synatom's provisions could still be lent to electricity producers directly correlates the MARR value to the financial performance of Engie-Electrabel. Thus, the electricity producer is required to settle the balance with Synatom if the return on investments is different from the MARR – i.e. for any investment underperformance – or in case of a revision of the future liabilities (IEA, 2016; EC, 2018).

Asset management rules (ONDRAF's Funds)

The MTF and the LTF managed by ONDRAF must be invested in debt securities in euros, issued or guaranteed by an EU Member State of the European Community, by its local authorities, or by public international bodies of which one or more EU Member States are members. Moreover, as ONDRAF falls within sub-sector S.1311 under the European System of National and Regional Accounts (ESA), it must also comply with the following rules: a) it has to place its current liquid assets in an account opened with the institution designated by the Federal State; and b) it has to invest its liquid assets other than those referred to above directly with the Belgian Treasury or invest them in financial instruments issued by the Federal State. Recently, ONDRAF declared that its funds cannot, in the short term, meet the 3% return target provided for in its economic model. This is explained by the current situation on financial markets and by the investment constraints to which ONDRAF is subject. This currently leads, all other things being equal, to a structural shortfall in the amounts funded in the LTF, due to the difference between the real and expected returns on ONDRAF's investments (ONDRAF, 2018). No further action has yet taken place in this regard. Future reforms will thus likely be in order to clarify the respective responsibilities of ONDRAF and the Belgian government in finding an adequate response to such kind of developments.

Funding adequacy review mechanisms

The dedicated advisory and control body, the government-appointed NPC, gives binding advice about issues such as methods for establishing provisions and the appropriateness of these methods. It also checks: a) the data relating to the adequacy of provisions; b) the proper application of the methods for establishing the provisions; c) the conditions under which Synatom lends its funds; d) the availability of the funds (Spinoy, 2018). The NPC submits an annual report to the Minister for Energy. The Minister communicates this report to the Federal Legislative Chambers and ensures that the report is properly published. Further, the 2003 law stipulates that Synatom, from 2004 onwards, must also provide a general report to the NPC every three years, in which are described, among other things, the basic arrangements for making provisions.

Generic reviews of provisions for the back-end are also carried out by the ONDRAF for each liable entity, be it private or public, with financial responsibilities. Summary tables and analyses are compiled at the end of each publicly *Nuclear Liability Inventory* (NLI) report. Hence, a comprehensive overview of the nature, status and matching liabilities of the funding mechanisms is made publicly available in Belgium and is updated every five years with each new ONDRAF inventory. Regarding ONDRAF's own Funds, they are controlled by various supervisory entities: the auditor of ONDRAF, during the annual audit of annual accounts; the Belgian Court of Auditors; and the Funds' respective Supervisory Committees, composed of the signatory parties to the agreement setting up the respective funds – i.e. generally the government and ONDRAF; for instance, for the Long-Term and the Insolvency Funds, by the Audit and Advisory Committee Long-Term Fund (CAAFLT) and the Audit and Advisory Committee Insolvency Fund (CAAFI).

The financing system for back-end activities in Belgium is periodically improved based on recommendations by ONDRAF drawn in five-yearly *Inventories of Nuclear Liabilities* (INL) reports. The latest INL recommendations (2018) called for large-scale reforms in the funding arrangements in place, and suggested reforms of the legal regime towards more clarity in the formulation of the objectives of funding availability, continuity, and adequacy. For almost every public or private operator whose funding system ONDRAF analysed, the availability of financial resources corresponding to the operator's provisions was deemed insufficient, insofar as the constituted provisions were in the form of accounting provisions, which does not guarantee that resources will be available when needed (ONDRAF, 2018). Further, ONDRAF pointed out that the current legal and regulatory framework does not address the issue of the time limit of a producer's financial liability. In accordance with regulations as they stand, a producer is responsible for financing RWM until such management is completed (ONDRAF, 2018). However, this is likely to be incompatible with a private company's decision to cease operations early, bearing a potential financial risk for the Belgian RWM funding scheme.

Recent progress on funding adequacy

In December 2019, the NPC submitted its findings on the detailed three-year assessment report on nuclear provisions prepared by Synatom. As mentioned above, the NPC imposed a reduction in the Synatom's discount rates used for back-end cost estimates in Belgium. This aims to mirror the current environment of low interest rates and to take into account distinct expenditure horizons according to various dismantling and radioactive waste management expenditures. Thus, after having been set at 3.5% in December 2018, and including an unchanged inflation rate of 2%, the discount rates are henceforth to be gradually reduced to 2.5% by 2021 for decommissioning, for which expenditure starts as early as 2020, and to 3.25% for SNF management, for which expenditure will take place in the coming decades (Engie, 2019b).

In total, the NPC's 2019 decisions, together with the implementation of the nuclear operators' financial responsibilities for nuclear back-end, are expected to lead to a revaluation of Engie-Electrabel's nuclear liabilities of +USD 2.6 billion, reaching a total back-end provision of USD 16.4 billion by December 2019. To this amount of additional funds to be provided by the nuclear operator, a recurring annual sum of USD 0.5 billion, which corresponds to the discounting effect of the pre-existing provisions must also be added (Engie, 2019b). This recent hike in future estimated costs is not the sole result of the NPC-decided change in discount rates. Indeed, it is also underpinned by the shift to a new scenario for HLW disposal, by the clarification of assumptions on the decommissioning of Belgian nuclear power plants as well as the management of their SNF, based in particular on the experience of Germany (L'Écho, 2019).

Furthermore, Engie-Electrabel has committed to finance via Synatom the full amount of nuclear waste provisions – i.e. USD 7.5 billion in 2019, including the increase resulting from the triennial revision and the unwinding discount impact of the period – along a funding schedule to be spread until 2025. The management strategy for these to-be-released funds has been announced to focus on investing in financial assets that will guarantee optimal availability and adequacy (Engie, 2019a). In other words, Engie-Electrabel has therefore pledged to gradually putting an end by 2025 to the practice of borrowing from Synatom SNF funds and of investing up to 75% of the funds earmarked for financing the nuclear back-end. From 2020 on, no new loans are granted on the SNF funds. The NEA applauds this dramatic change in asset management vision, which should further decorrelate the nuclear funds' performance from that of Engie-Electrabel, and thereby sizably improve the reliability and availability of funding by decreasing the Funds' degree of risk exposure by a significant margin. In parallel, Engie-Electrabel also announced that the governance structure of Synatom will be overhauled to increase its capability, with the upcoming hiring of two external fund administrators with financial expertise. The Commission for Nuclear Provisions also prepares an amendment of the Law of April 11th to incorporate these changes and to enhance the legal framework.

Conclusion

The funding system for decommissioning and RWM in Belgium is functional but complex and at the dawn of a new structural reform that should unfold throughout the early 2020s. An elaborate interim storage system for radioactive waste is in place and a surface disposal facility for LLW is in the licensing phase, despite the absence of a political decision regarding a final disposal solution for HLW.

The funding scheme for decommissioning and RWM in Belgium is complex but the adequacy of funding provisions is regularly assessed through comprehensive inventory reports every five years. The clear separation of private funds for decommissioning (held by the industry) from funds for long-term

RWM activities (held by a public entity) appears to be a promising approach to ensure adequate management of the financial assets dedicated to the respective field of activity. The installation of a dedicated fund to facilitate the social acceptance of the future final surface repository appears to deal with the socioeconomic dimension of radioactive waste disposal in an exemplarily and pioneering manner.

However, the management by the industry of the assets for financing long-term RWM activities – which is ensured via Synatom until radioactive waste is transferred to ONDRAF – appears less straightforward than a direct collection and management of such funds by ONDRAF could be. Additionally, the possibility for operators to borrow back up to 75% of Synatom's funds for future back-end liabilities and to invest them into the operations of their parent companies endangers the objective of ensuring adequate, accessible, and reliable financial resources. Indeed, the size of these loans relative to Synatom's other investments results in a significant concentration of risk to a single entity, namely Engie-Electrabel, as recently highlighted by the European Commission (2018: p. 98). As described before, this risk will be considerably lower due to the 2019 decision to stop all loans on the SNF Fund. Although the funding system fully complies with accounting rules, the risk of correlation of performance makes for higher volatility and higher default risk than with a well-diversified assets portfolio unconcerned by this level of self-investment and thereby uncorrelated to any financial performance of the nuclear operators. As a result, the Belgian state would indeed become directly liable to finance any potentially arising RWM costs.

Nonetheless, the recent change to put an end by 2025 to the practice of borrowing and of investing up to 75% of Synatom's SNF funds represents a major breakthrough in terms of funding consolidation and convergence with international best practice. Indeed, such a dramatic change in asset management and investment vision should further decorrelate the Synatom Funds' performance from that of Engie-Electrabel, thereby sizably improving the reliability and availability of funding by decreasing the Synatom Funds' degree of risk exposure by a significant margin. Even though this practice will remain possible for Synatom's decommissioning funds, this share is also expected to decline as a result of upcoming decommissioning activities and the obligation of retaining at all times sufficient liquidity to finance the next three years of expenses.

Given the mandatory and mechanical transfers of funds set to take increasingly from Synatom towards ONDRAF, it might also be gainful that both entities converge in using identical technical assumptions regarding nominal rates of return and discount rates, which were, as of 2019, still differing to a notable degree. The separation between Synatom's decommissioning and SNF discount rates starts this convergence and both ONDRAF and Synatom long-term liabilities are meant to be discounted at close values of approximatively 3.00%.

Finally, the absence of a time limit of nuclear waste producers' financial liability spurs further potential risks that demand consideration and factoring-in.

Overall, the funding system for decommissioning and radioactive waste management in Belgium is therefore in the process of accomplishing an important leap forward to its long-term sustainability.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 7

Canada: Country case study

KEY FACTS	
Funding model	As per the national legislation, all licensees are required to maintain financial guarantees for decommissioning which include: • Internal segregated funds or financial instruments (such as letters of credit) to cover all decommissioning and RWM liabilities • Special external trust fund for SNF (NFWA Fund)
Assets	• Decommissioning: USD 5.77 billion (OPG) • RWM: USD 7.69 billion, of which USD 3 billion in dedicated trust fund (OPG)
Liabilities	• USD 16.33 billion (OPG) • USD 530 million (Hydro-Québec) • USD 5.74 billion (AECL) • USD 469 million (NBP)
Avg. effective real return	Different for each licensee
Discount rate	• 5.15% (OPG) • 5.00% (NBP) • 4.30% (AECL) • 5.00% (H-Q)
Assumed operational lifetime of nuclear power plants	25-30 years, can be doubled if major refurbishment is conducted
Investment rules	Individually-defined investment rules for each contributor to the NFWA Trust Fund
Evaluation of fund adequacy	Annual actualisation reports on the funding levels. Re-evaluation of cost estimates every five years.
Issues at stake	• Differentiated funding system between (1) external NFWA Fund for long-term management of SNF as per the national RWM plan and (2) internal funds for decommissioning and RWM including interim management of SNF. • Full financial responsibility for funding of licensees, some of which are publicly owned.

Decommissioning and RWM in Canada

Canada's financing system for decommissioning and RWM is stable, well-developed and benefits from the country's over 60 years of experience among the world's largest uranium producers and nuclear-powered nations, relying on a fleet of domestically designed and built CANDU reactors.

Canada has an established and fully functional system in place to finance future decommissioning and RWM liabilities. This system combines comprehensive internal segregated funds held and managed by nuclear licensees, and a state-supervised external trust fund for long-term SNF disposal. This scheme is completed by clear time- and standards-bound plans for a future centralised final disposal facility for SNF. Canada's Adaptive Phased Management (APM) approach to a final repository strategy for radioactive waste permits a noteworthy degree of flexibility in approaching final waste disposal choices as social and technical conditions evolve.

Ontario Power Generation (OPG) is the largest commercial nuclear operator in Canada, owning 18 of the country's 19 nuclear operating reactors and being responsible for around 90% of the country's non-research and non-legacy RWM liabilities. As a public – i.e. wholly Ontario Province-owned – nuclear operator, OPG represents a pivotal entity in the allocation of corporate responsibilities for future decommissioning and RWM costs. It also provides an example for the sharing of nuclear liability management roles between corporate actors and administrative authorities in Canada.

The Canadian funding scheme is characterised by the sharing of responsibilities between the national level, the provincial level and the license holders. The largest licensee, the publicly owned OPG, is regulated both by the Ontario Nuclear Funds Agreement (ONFA) structure and Canadian Nuclear Safety Commission's (CNSC) Financial Guarantee structure. ONFA is designed to demonstrate OPG's financial prudence and transparency to the customers of Ontario. The cost estimates done every five years for ONFA are used to provide the input for CNSC Financial Guarantees and the two processes are aligned from a timing perspective to ensure there is no duplication of efforts.

Nuclear power plant lifetime

Currently, there are 19 nuclear reactors operating in Canada, producing around 15% of the country's electricity. They are distributed across four industrial sites, mostly in Ontario. Among the existing nuclear operators, the largest is OPG, a public company exclusively owned by the Province of Ontario and possessing 18 reactors all located in the Province – 8 of which are currently leased and operated by Bruce Power. All reactors operated in Canada are "CANDU" builds domestically developed and deployed in the 1960s. These reactors use heavy water as a moderator and coolant, and are fuelled by natural uranium (as opposed to enriched uranium), which is advantageous in terms of reduced reactor downtime from refuelling and maintenance and of fuel cost (as no enrichment is required), although these savings are partially offset by the cost of producing heavy water (WNA, 2019). Canadian CANDU reactors typically operate between 25 and 30 years and require a major refurbishment if long-term operation is envisaged. The refurbishment work involves a lengthy shutdown, after which reactors should be able to operate for another 25-30 years. Current licenses of the operating reactor fleet are set to expire between 2022 and 2037 (WNA, 2019; NEA, 2015). Refurbishment decisions have been taken by the governments of New Brunswick and Ontario. The 2017 Long-Term Energy Plan (LTEP) foresees the refurbishment of up to ten existing reactors and also leaves open the possibility of constructing new reactors of the small modular kind (SMR). The government of Québec has decided not to proceed with refurbishment.

Waste management

Based on extensive studies, large public consultations, and social-ethical considerations for each option, the approach for the management of SNF adopted by the Canadian government in 2007 is called "Adaptive Phased Management" (APM). The APM approach foresees the centralised containment and isolation of all Canadian SNF in a DGR. A key APM feature is its flexibility allowing adjustments to changing social and emerging technological developments (IEA, 2015; WNA, 2019). The operation of the future DGR is currently estimated to start between 2040 and 2045 (NWMO, 2019). For the time being, all existing LLW/ILW from nuclear generation is stored on site in individual dedicated facilities operated by nuclear operators. SNF is currently stored in five facilities located at nuclear power plant sites in Ontario, Québec and New Brunswick, and at nuclear research facilities in Ontario and Manitoba. Storage of SNF is usually done in wet storage pools for the first seven to ten years, before it is moved to a dry cask storage facility, the Western Waste Management Facility (IEA, 2015). These interim sites are designed for a respective operational lifetime of 50 years (NEA, 2013).

Financial responsibilities for nuclear decommissioning and back-end

In Canada, nuclear licensees are responsible to fully finance their decommissioning and RWM liabilities, following the "Polluter Pays" and "Intergenerational Equity" principles promoted by the international community. The overarching framework for operators to fulfil these obligations is that of "Financial Guarantees", which must be established by every licensee and approved by the CNSC during the licensing process and throughout the facility's lifecycle. Financial guarantees are a tangible commitment by a nuclear license applicant or a licensee that there will be sufficient resources to safely terminate licensed activities (CNSC, 2019). Financial guarantees must be sufficient to cover all decommissioning activities, including dismantling, decontamination and closure, but also any post-decommissioning monitoring or institutional control measures that may be required, as well as subsequent long-term management of all waste, including SNF (NEA, 2008). Many financial instruments – or combinations thereof – can qualify as financial guarantees, provided that the CNSC deems the resulting financial arrangement sufficient, secure and stable over time. Accordingly, in practice, for Canadian operators, the typical financial arrangement is threefold.

Most nuclear operators hold a part of their assets destined to cover their future decommissioning and RWM liabilities within internal segregated funds, which often take the form of two distinct funds that cannot be mixed: a Decommissioning Fund (1) to cover costs related to dismantling and interim and long-term management of LLW/ILW; and a Used Fuel Fund (2) to finance costs related to interim dry storage and definitive storage ("APM") of SNF. National regulation specifically requires that each operator's Used Fuel Fund be integrated into the Federal Trust Fund for Long-Term Management of SNF, or NFWA Fund (3). The NFWA Fund is an independently managed third-party fund maintained by the Canadian Nuclear Waste Management Organization (NWMO), which was itself established in 2002 as a joint venture of Canada's nuclear operators under the 2002 Nuclear Fuel and Waste Act. The NWMO's key responsibilities are calculating the total liability annually, informing the members of the required annual funding amount that is due under the NFWA, update every five years the discount rates and publish key information related to funding in the NWMO annual report. This fund is earmarked for the long-term management of SNF and for the construction and operation of an eventual DGR for SNF as part of the APM. It is fed by contributions collected annually from nuclear operators by the NWMO, while funds can only be accessed by the NWMO to finance activities in regards with its remit.

Assets for the long-term management of SNF, as distinct from assets constituted to fund decommissioning, are thus jointly held by the licensees under the oversight of the state with annual reporting from the NWMO. This emphasises the role of the public authority as a pivotal actor regarding the planning, implementation and oversight of long-term RWM in Canada.

A brief focus on OPG

With 18 nuclear reactors, OPG is the largest nuclear operator in Canada and responsible for around 90% of the country's SNF liabilities. Its share in LLW and ILW is substantially smaller though and even below that of Atomic Energy of Canada Limited (AECL).

OPG's contributions to its Decommissioning and Used Fuel Funds are determined by reference plans built into the 1999 ONFA, an agreement between OPG and the Province of Ontario that wholly owns OPG (OPG, 2017b; NWMO, 2018). This should be compared to Hydro-Québec, which significantly relies on a provincial guarantee. The ONFA Reference Plans are updated every five years. They set a level of OPG contributions to nuclear funds defined following a schedule that is modulated in function of the Fund's funded status (OPG, 2017b). On the other hand, the NFWA Fund is built up via OPG and the other Canadian nuclear operators' contributions required up to year the DGR is planned to go operational (date to be determined by NWMO). As per the 2002 Nuclear Fuel and Waste Act, nuclear operators made an initial payment into their respective share of the NFWA Fund upon creation thereof. Regarding ongoing annual contributions to the NFWA Fund, a NWMO-computed funding formula is applied, based inter alia on projections of SNF to be generated by each nuclear operator. Costs common to all waste owners, such as the construction and maintenance of a future DGR, are split based on a cost-sharing ratio agreed to between nuclear operators. In 2015, the costs for the implementation of the APM from 2010 until the end of its operational lifetime were estimated at USD 17.69 billion (2015 price-level) (NWMO, 2019).

Currently, the CNSC is modernising its regulatory framework. While there will be no substantial changes to the financial guarantee requirements in place since 2000, updated regulatory requirements will provide additional guidance on how those requirements may be met.

The funding system

Overarching regulatory framework: the "financial guarantees"

Pursuant to the 1997 Nuclear Safety and Control Act (NSCA), proponents and operators of all nuclear facilities including SNF and RWM facilities are required to have Preliminary Decommissioning Plans (PDP) for all stages from site preparation to dismantling, mirrored by acceptable funding measures ("financial guarantees") as part of their licenses from the CNSC. This regulatory requirement applies to all nuclear facilities – i.e. licensees of nuclear power plants, uranium processing plants, waste disposal facilities, uranium mines, and uranium mills. PDPs must be sufficiently detailed in order to, among other things, ensure credible estimates of financial guarantee amounts. PDPs must be on file with the CNSC and remain in effect during all operation time for all concerned nuclear facilities, with revisions at least every five years. Accordingly, each licensee has in place "financial guarantees", based on its PDPs, ensuring that sufficient funds are in place and accessible to the CNSC to carry out any required decommissioning should the licensee be financially unable to do so (NEA, 2008). Financial guarantees are a tangible commitment by a nuclear license applicant or a licensee that there will be sufficient resources to safely terminate licensed activities. It does not relieve licensees from complying with regulatory requirements for decommissioning of nuclear facilities or termination of licensed activities (CNSC, 2019).

Scope of the financial guarantees

An operator's financial guarantees must be sufficient to fund all activities approved as decommissioning and RWM. Such activities include dismantling, decontamination and closure, but also any post-decommissioning monitoring or institutional control measures that may be required, as well as subsequent long-term RWM, including SNF (NEA, 2008). Hence, guarantees must cover 100% of the calculated liability for LLW, ILW, HLW, SNF and decommissioning obligation at all times, that is, they must be in place through the entire lifecycle of the facility. The NSCA allows the CNSC to include any condition in a license, including the requirement of a financial guarantee. The legal basis by which a licensee is required to provide a financial guarantee and its decommissioning plan is through the addition of specified conditions in each facility license which is issued, pursuant to Section 3 of the General Nuclear Safety and Control Regulations (NEA, 2008).

Approval and use of financial guarantees

Financial guarantee instruments are subject to financial and legal review by CNSC staff and must be accepted by the CNSC's Commission. Guarantees acceptable to the CNSC may include the following financial instruments (CNSC, 2019):

a) *cash funds*, which should feed into an account which is controlled by the federal government (either the CNSC or the Receiver General for Canada) or by a Canadian chartered bank listed in Schedule I or II of the Bank Act;

b) *funds*, for which, in the case of investment funds, several economic estimates are made including the rate of inflation over time, and the estimated rate of return of the portfolio. Information on planned disbursements should be included in order for the CNSC to review the financial guarantee to ensure it is sufficient to cover costs of decommissioning;

c) *letters of credit*, issued by a Canadian chartered bank, and providing for specific sums of money to be paid on demand to designated parties or their agents should a triggering event occur, such as a licensee defaulting on its obligation to decommission;

d) *surety bonds*, which may be appropriate as primary security or a complement. They should name the CNSC as a beneficiary and the insurance or bonding agents should be Canadian companies subject to Canadian regulatory oversight;

e) *insurance policies*;

f) *legally binding commitments* from a Canadian government, either federal or provincial, to the condition that it "is used to cover all otherwise unfunded aspects of decommissioning".

Parent company guarantees and pledges of assets do not satisfy the acceptance criteria and are not acceptable. The acceptability of the above measures will be ultimately determined by the CNSC on the basis of the following general criteria (CNSC, 2019): liquidity, certainty of value, adequacy of value (sufficiency of funding at predetermined points in time), and continuity (financial guarantees should be maintained on a continuing basis). Since the administration of financial guarantees should be accomplished by clearly defined and legally enforceable arrangements acceptable to the CNSC, funding should be structured so as to ensure that the funds or securities set up by an operator are separated from its other assets. This might require the inclusion of terms restricting access to, or use of, funds or their returns. Withdrawals from a fund, or access to monies realised from other security vehicles, should only be permitted for approved and earmarked purposes, in particular, to pay for approved decommissioning activities or to refund excess monies to the licensee (NEA, 2016). The financial guarantee must be at arm's length from the licensee and the CNSC must be assured that it can access or direct adequate funds to supplant any licensee that should not be able to fulfil its back-end obligations under the NSCA (CNSC, 2000).

Operators' internal funds: purpose and build-up

Waste producers and owners are responsible for the funding, organisation, management, and operation of long-term RWM facilities and required to dispose of these materials. Like most Canadian nuclear operators, OPG fulfils its financial guarantee-related obligations by accruing Decommissioning and Used Fuel Funds. The former covers costs related to dismantling and interim and long-term management of LLW/ILW, while the latter covers costs related to interim dry storage and permanent disposal ("APM") of SNF.

Contributions by OPG to its internal nuclear funds are determined by five-year ONFA Reference Plans, which must be validated by the Province of Ontario, with reference to the funding liabilities contained in the ONFA Reference Plan in effect and corresponding fund balances at a point in time. The said plan sets a level of contributions to OPG's internal funds determined pursuant to an approved contribution schedule that is modulated based on the funded status of OPG's internal Nuclear Funds (OPG, 2017b). The ONFA system does allow for some limited inter-fund transfers (up to 50% of any funds above 120% coverage) from the Decommissioning to the Used Fuel Funds upon the approval of a new or amended Reference Plan. There exists no transfer mechanism in the other direction. On the one hand, OPG's Decommissioning Fund has been fully funded since its inception thanks to a substantial initial contribution made by the Province of Ontario, which, together with fund performance since that time, has been sufficient to ensure that the fund remained fully funded. On the other hand, OPG's Used Fuel Fund reached fully funded status in 2016. It was notably built up through a USD 257 million one-time special payment by OPG in 2007 meant to accelerate the funding of the underlying SNF liabilities, as well as through quarterly contributions by OPG that also included OPG's payments to the independent NFWA Fund (OPG, 2017b).

NFWA Fund: purpose and build-up

The NFWA trust fund is owned by OPG and overseen by NWMO, which was itself established in 2002 as a joint venture of Canada's nuclear operators under the 2002 Nuclear Fuel and Waste Act. It is earmarked for the long-term management of SNF and for funding 100% of the construction and operation costs of an eventual DGR for SNF as part of Canada's APM approach. Costs common to all waste owners are split based on a cost-sharing percentage agreed to by the members. In 2018, that percentage among waste owners was approximately 92% for OPG, 3.5% for Hydro-Québec, 3.5% for New Brunswick Power, and 1% for AECL. Costs specific to each nuclear fuel waste owner, such as SNF and transportation costs, are directly attributed to said owner (NWMO, 2018). Annual contributions for nuclear licensees are in place to fund both the SNF programme's fixed costs and its variable costs represented by new SNF production, as follows:

- *Funding for legacy SNF ("committed liability")*: represents all fixed costs for the facility and variable costs attributed to the management of historical SNF bundles in Canada. Contributions are to be amortised in equal present value payments to the year 2045 (tentative date for DGR availability). This method helps distribute obligations evenly to each year taking into account the time value of money.
- *Funding for SNF to be produced each year ("future liability")*: covers the incremental cost of transferring to the repository, facility expansion, and additional operating and monitoring costs of SNF bundles to be produced each year. Each future SNF bundle would incur the same cost in present value terms taking into account the time value of money.

Regarding the NFWA Fund's build-up, as per the 2002 Nuclear Fuel and Waste Act, utilities made a one-off initial payment into their NFWA Fund shares when the Fund was created. This payment ranged from USD 7.69 million (which was paid by AECL) to USD 384.6 million (which was paid by OPG). The NFWA Fund is currently fed by annual contributions from each nuclear licensee up to the year the DGR is planned to go operational (date to be determined by NWMO). Regarding these periodic contributions, a NWMO funding formula has been in place since its development and approval by the Natural Resources Minister (NRCan) in 2009. The formula allocates liabilities and Fund contribution targets to each waste owner. Contribution to the NFWA Fund increase annually based on the expected returns of the various producers' trust fund shares – i.e. an equal present value basis of contributions.

The contribution payable to the NFWA Fund is based on the NWMO's most recent and approved cost estimates and considers projections of used fuel generated by each waste owner. The contribution fee is periodically reviewed and updated together with the costs. This review is carried out under NWMO's responsibility and the Natural Resources Ministry is responsible for approving the funding formula (CNSC, 2017).

The cost side (early 2000s – early 2020s)

Process and responsibilities

Canada requires that operators use lifecycle planning, and consider it from the early stages of licensing to ensure that future decommissioning is taken into account as soon as the facility design stage. The requirement for filing a cost estimate mirrors requirements for a financial guarantee and for a PDP for the licensing of most nuclear facilities – notably Class I Nuclear Facilities that comprise nuclear reactors, uranium processing plants and RWM management facilities. Indeed, where a financial guarantee is required, the license applicant has the obligation to propose and justify its value by submitting a decommissioning cost estimate based on a PDP. On the other hand, prior to decommissioning, a nuclear licensee must also file with the CNSC a Detailed Decommissioning Plan (DDP) that updates and adds procedural and organisational detail to the initial PDP. Licensees have discretion to use their own costing methodology, but Canadian regulations require review and acceptance by a regulator (NEA, 2010). There is a single cost estimate for decommissioning and RWM, although the entities responsible for carrying out subparts of the cost estimation work may differ from each other (NEA, 2016).

Scope and methodology

Cost estimates associated with financial guarantees for every nuclear facility are required to cover: planning and preparation, complete decontamination and/or dismantling, site decontamination, restoration and stabilisation, final radiation survey and long-term surveillance for restricted or free release of the nuclear site, management or disposal of all wastes, including SNF, nuclear substances and hazardous materials (NEA, 2010). The CNSC will not permit credit for salvaging equipment or materials in estimating the implementation of proposed decommissioning plans. Such equipment or materials must be considered as waste (CNSC, 2000). Boundary conditions are defined and sample worksheets are provided by the government as examples, but operators have large discretion in preparing the filing. If the submission does not meet the expectations of the regulator and is not of sufficient quality to be independently verifiable, it will be rejected by the CNSC (NEA, 2010). The cost estimates must first be prepared at current value, that is, assuming that the decommissioning will be executed at the time the cost is estimated.

Decommissioning costs

Decommissioning cost estimates can be realised by external consultants. For instance, OPG resorts to, among other things, a key external service provider, TLG Services, to assist in its estimates. TLG estimates incorporate large-scale decommissioning experience from recent projects such as the decommissioning of Maine Yankee and Vermont Yankee nuclear power plants. TLG also provides decommissioning cost estimates for all the CANDU reactors in Canada. OPG also regularly involves other internationally recognised consultants to develop decommissioning cost estimate studies and assessments specifically to the CANDU technology. The methodology used to develop OPG's decommissioning cost estimates follows the guidelines developed by TLG for producing commercial nuclear power plant decommissioning cost estimate and the US Department of Energy's (DOE's) Decommissioning Handbook. The estimation process is based on a unit cost factor integrated with OPG's site-specific information which includes local labour rates and costs. Also applied are work difficulty factors that factor in work site access conditions and the "As Low As Reasonably Achievable" (ALARA) approach to radiation protection (CNSC, 2012; CNSC Staff, 2017).

RWM costs

Regarding radioactive wastes produced by operators, the costs are to be included in the operators' cost estimates for nuclear back-end. Regarding the particular case of radioactive waste, notably the SNF, produced by Bruce Power's reactors, which are operated under the commercial lease between OPG and Bruce Power, a charge rate is determined by OPG in collaboration with Bruce Power. This rate takes into account several factors, among which: a) how the SNF is going to be generated at the Bruce site; b) how the SNF will be stored at the site and eventually moved; and c) whether Bruce Power's waste stream is SNF or LLW/ILW. OPG updates these rates every five years, and updates its own cost estimates accordingly. In the end, the OPG-Bruce Power commercial arrangement is negotiated so that OPG charges Bruce Power for the amount of SNF bundles and volume of LLW/ILW generated by Bruce Power.

Regarding cost estimates for the APM DGR project for SNF, the majority of them is developed by the federally-incorporated NWMO under the mandate of the 2002 NFWA, with help from engineering companies. The estimates are prepared by the engineering consultants and independently reviewed by the NWMO (CNSC, 2012). The existing inventory of SNF in Canada in 2019 was approximately 2.9 million bundles. Based on the expected volume of 5.2 million fuel bundles, the total lifecycle cost of APM – from the beginning of site selection in 2010 to the completion of the project decades from now – is approximately estimated by NWMO to be USD 17.7 billion (in 2015 dollars) over the course of the entire project (NWMO, 2019). The costs included in the calculation of the contributions to the NFWA trust fund are transportation, encapsulation, final disposal, siting and pre-construction costs (NEA, 2013). As regards cost estimates for Canada's planned DGR for SNF, the estimate includes the full lifecycle costs, with adequate allowances and contingency, through the phases of siting, licensing, construction, operation, monitoring, and closure. This basis of estimate is applicable to all lifecycle cost estimates for the APM Project for a scenario of 3.6 million used CANDU-SNF bundles, as well as for a scenario of 7.2 million used CANDU-SNF bundles (NWMO, 2016).

OPG's total cost estimates

OPG's estimates include the following activities (OPG, 2017a):

a) for decommissioning: a deferred dismantling strategy that assumes a nominal 30-year safe storage period. Related assumptions include the refurbishment of Darlington and Bruce nuclear power plants and an extension of operations at the Pickering nuclear power plant;

b) for LLW/ILW: OPG's LLW/ILW Operations Program encompasses all activities to transport, process and package operational LLW/ILW and also the retrieval of operational LLW/ILW in interim storage at OPG's Western Waste Management Facility (WWMF). LLW/ILW from station dismantlement were planned to be permanently placed in OPG's planned DGR for LLW/ILW. However, following Saugeen Ojibway Nation's decision on the project in January 2020, OPG is evaluating alternative options, which will be reflected in the next update to the ONFA estimates due to the Province in 2022;

c) for SNF: costs include an interim storage of SNF at each nuclear power plant site until a national long-term SNF management facility is available. Cost assumptions also include the costs of OPG's contribution to the NFWA Fund for building the SNF DGR. OPG uses individual cost estimates for each nuclear power plant, which are combined to reach total cost figures. A contingency is applied to each cost estimate as "specific provision for unforeseen elements of cost within the defined scope of the project" (CNSC, 2017).

Discounting approach

Canada requires that cost estimates account for escalation (NEA, 2010). OPG's practice is based on escalating the costs yearly and on applying the appropriate inflation factors for each year that costs would be expended during the expenditure period defined using forecasts prepared by external experts. Then, a discount factor is used to derive a present value. OPG's escalation and discount rates are obtained from external consultants updated on a five-year cycle.

The CNSC staff has deemed OPG's factors to be "very similar" to those used by the Hydro-Québec and New Brunswick Power operators for their respective financial guarantee calculations (CNSC, 2017). OPG used a 5.15% discount rate for the 2013-2022 period. This discount rate is selected because it is consistent with the discount rate employed under the ONFA, and also corresponds to the targeted growth in OPG's Nuclear Funds (OPG, 2017a). This discount rate is composed of a 3.25% real rate of return and of a 1.9% assumption on the growth of Ontario's Consumer Price Index. As in 2016, OPG's calculations assumed that nuclear power plant decommissioning activities were projected to occur over about the next 80 years, with cash flow estimates for nuclear power plant decommissioning for approximately 40 years after nuclear power plant shut down, and to 2088 for placement of SNF into the assumed long-term SNF DGR, followed by extended monitoring (OPG, 2016).

Assets, investment rules and performance (early 2000s – early 2020s)

Current asset portfolios and management strategy (OPG)

The investments of OPG's internal Nuclear Funds comprise a diversified portfolio of equities and fixed-income securities invested across geographic markets, as well as investments in infrastructure, real estate, and agriculture. In 2018, OPG's Nuclear Funds investment portfolio comprised the following types of securities (OPG, 2018):

a) cash and cash equivalents and short-term investments;

b) pooled funds, which primarily include a diversified portfolio of fixed-income securities issued mainly by Canadian corporations, and diversified portfolios of Emerging Market listed equity. There are no significant restrictions on the ability to sell the investments in this class;

c) marketable equity securities;

d) fixed-income securities;

e) alternative investments, comprising 1) infrastructure investments, including investments in funds whose investment objective is to generate both long-term capital appreciation and current income, generally via investments such as energy, transportation and utilities; 2) real estate investments; and 3) agriculture investments, including a diversified portfolio of global farmland and timberland.

The target rate of return on OPG's funds in the long term correspond to the rate of growth of the ONFA funding liability, i.e. to the discount rate specified in the ONFA, currently at 5.15% per annum. This results in the same projected funded status of the funds, in percentage terms, as the actual status at the time the projection is made (OPG, 2017b). Under the ONFA framework, the Province of Ontario guarantees OPG's annual return in the Used Fuel Fund at 3.25% plus the change in the Ontario consumer price index (CPI) for the funding related to the first 2.23 million of SNF bundles ("committed return"). The difference between the committed return and the actual market return is determined based on the fair value of the Fund's assets related to the first 2.23 million of SNF bundles, and is recorded as due to – or due from – the Province of Ontario. This latter amount represents the amount OPG would pay to, or would receive from, the Province if the committed return were to be settled as of the consolidated balance sheet date. Upon approval of a new or amended ONFA Plan, the Province is obligated to make an additional contribution to the Used Fuel Fund in relation to the first 2.23 million of used SNF bundles if the Fund's assets earned a rate of return that is less than the guaranteed rate of return. If the return on the Fund's assets exceeds the Province of Ontario's guaranteed rate of return, the Province is entitled to withdrawing any portion of the excess market earnings, upon approval of a revisited ONFA Plan. However, to date, the Province of Ontario has never done so. The 2.23 million threshold represents the estimated total life cycle fuel bundles based on the initial estimated useful lives of the nuclear power plants assumed in the ONFA.

Besides, as prescribed under the ONFA, OPG's contributions attributed to used SNF bundles in excess of 2.23 million are not subject to the Province's guaranteed rate of return, and earn a return based on changes in the market value of the assets of the Used Fuel Fund (OPG, 2018). This portion is intended to fund the incremental costs associated with SNF bundles in excess of 2.23 million, which currently represent about one-quarter of the SNF funding liability (OPG, 2017b). Furthermore, in accordance with the cost recovery methodology established by the Ontario Energy Board, the performance of the portion of OPG's Nuclear Funds attributed to the nuclear power plants leased to Bruce Power has been subject to a Bruce Lease Net Revenues Variance Account, which partially mitigates the income impact of the rate of return risk related to OPG's Nuclear Funds, as it captures the differences between actual and forecast earnings from the Nuclear Funds related to these nuclear power plants (OPG, 2016).

NFWA Fund

By 2009, the target interest rate earned on the NFWA trust fund was 5.15% (NEA, 2013). In order to reach that rate, each holder of a part of the NFWA Fund determines its own fund investment policies, which are periodically reviewed, updated, and approved. The legislative obligations for the trust funds are the responsibilities of the individual waste owners and not the NWMO. Each year, the NWMO publishes the audited financial statements of the trust funds when they are provided by the financial institutions.

In the case of OPG's share of the NFWA Fund, a Statement of Investment Policies and Procedures (SIPP) was established for the fund that includes investment assumptions, permitted investments and various investment constraints. It also sets the long-term target asset mix of the trust fund pursuant to the ONFA and takes into account the funded status of OPG's internal Nuclear Funds in relation to the projected profile of the underlying long-term liability and cash flows; historical experience of investment vehicles; the appropriate level of diversification to optimise risk and return; and the risk preferences of OPG and the Province of Ontario. OPG as well as the Province of Ontario's Financing Authority (OFA) jointly make decisions on the fund's asset mix and investment manager selection and retention. The SIPP is reviewed annually by the Province of Ontario's Ministry of Finance (OPG, 2017c). In 2016, OPG's part of the NFWA Fund had its investments distributed as pointed out in Table 7.1.

Table 7.1:
Investments of OPG's NFWA Fund as at December 2018 (in USD million, CAN/USD = 0.77)

Investment type	Fair value (USD m)	% of net assets
Cash and cash equivalents	9	–
Pooled funds	820	27%
Short-term investments	–	–
Fixed-income investments	2 220	73%
Other	22	
United States	51	
Domestic	2 148	
Government	1 420	
Financial	404	
Utilities	69	
Energy	65	
Real Estate	45	
Other	145	99%
Total investments	3 059	

Source: OPG, 2019: pp. 11-12.

Funding adequacy review mechanisms

Regarding financial guarantees, the CNSC must be assured that it can, upon demand, access or direct adequate funds if a licensee is not available to fulfil its obligations for decommissioning. The funds must be structured such that the instrument can be drawn upon only with the prior acceptance of the CNSC and that such pay-out is not prevented, delayed or compromised, and must be structured such that the instrument can provide full assurance of value (CNSC, 2019). All licensees must report annually to the CNSC of their financial guarantees status, that is, whether they remain valid, in effect and adequate to fund future decommissioning and RWM costs. As set out in the operators' License Condition Handbooks, the financial guarantees, along with PDPs and cost estimates, must be reviewed, revised, and approved at least every five years or when requested by the CNSC's Commission. The CNSC oversees the status of financial guarantees and sets the guarantees-related requirements for the review period. The CNSC's staff carry out the review work and report to CNSC Commission Members on the status of the operators' financial guarantees through "regulatory oversight reports" that provide, among other things, the value of the operators' respective nuclear funds for the year. In the case of OPG, the company reports to the CNSC annually on the status of the financial guarantee by submitting annual financial guarantee reports and, pursuant to the ONFA, by also submitting to the Province of Ontario's Financing Authority the required ONFA Reference Plans and year-end statements for the company's internal nuclear funds (CNSC, 2017).

Regarding the NFWA Fund, the law states that the NWMO shall provide the Natural Resources Ministry with yearly financial statements, audited at its own expense by an independent auditor. Every financial institution – that is, every nuclear licensee – that holds a share of the NFWA Fund shall also provide the Ministry and NWMO with yearly financial statements, audited at their own expense by an independent auditor too. The NWMO makes available to the public, by way of online releases, both its yearly financial statements and those it receives from NFWA Fund holders.

Conclusion

Canada possesses a well-established system to manage the financing of future decommissioning and RWM liabilities, completed by well-defined plans for a future centralised final SNF disposal facility, bound by time and standards. Canada's APM approach to a final repository strategy for radioactive waste allows for a noteworthy degree of flexibility in approaching final waste disposal choices as social and technical conditions evolve.

The largest commercial nuclear operator in Canada and a public (wholly Ontario Province-owned) firm, OPG plays a pivotal role in the allocation of corporate responsibilities for future decommissioning and RWM costs. It also provides an insightful example of efficient articulation between provincial and national governments and policies for the management of nuclear lifecycle, in particular in terms of sharing the burden of back-end costs between licensees, Provinces and the national government of Canada.

The Canadian funding scheme appears to be fundamentally sound. Also, the formal allocation of responsibilities is clear. On the basis of the Polluter Pays Principle (PPP), the National Radioactive Waste Policy Framework of 1996 specifies that owners of nuclear facilities are responsible for costs of decommissioning and long-term management of nuclear wastes. The ownership of OPG by the Province of Ontario nonetheless geographically concentrates in that Province a significant share of the financial risks of the country's nuclear power generation and phase-out. As in other countries, the risk of potential funding shortfalls has increased with a decline in long-term interest rates. The long-term management of such residual risks will involve careful monitoring and flexible responses from all stakeholders.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 8

Finland: Country case study

KEY FACTS	
Funding model	External joint fund – Nuclear operators pay annual fees or provide securities to State Nuclear Waste Management Fund (SNWF)
Assets	• USD 3.316 billion (assets covering nuclear waste produced until 2017)
Liabilities	• USD 8.125 billion (overall costs)
Avg. effective real return	• 2.81% (2009-2018)
Discount rate	No discount rate applied
Assumed operational lifetime of nuclear power plants	60 years
Investment rules	Assets can be loaned back to nuclear operators against long-dated securities. Remaining assets are mostly invested in state bonds.
Evaluation of fund adequacy	Review of cost assessment every three years, with yearly updates to be provided to the Ministry of Economic Affairs and Employment.
Issues at stake	• Possibility to lend back up to 75% of the fund to the nuclear operators, their shareholders or the Finnish state in exchange for the provision of financial securities to the fund; • DGR under construction, expected to apply for operating license by the end of 2021 and to be operational from 2025.[1] If schedule is upheld it would be the first operation license and the first operational DGR in the world.

Decommissioning and RWM in Finland

Finland has an advanced and well-structured infrastructure for managing its decommissioning and RWM, based on a sophisticated storage and solid funding system. A final DGR facility for SNF and HLW is being built, with a construction license granted in 2015, the first of its kind worldwide. The application for an operating license is expected to be submitted by the end of 2021 and its handling

1. For more information see NS Energy (n.d.), *Onkalo Nuclear Waste Disposal Facility*, www.nsenergybusiness.com/projects/onkalo-nuclear-waste-disposal-facility (accessed 28 April 2021).

will take several years. The DGR is constructed at a depth of 400-450 metres in igneous rock, with initial operational lifetime currently expected to end in the 2120s (WNA 2019). Until final disposal in the DGR, SNF is temporarily stored on site at the two nuclear power plant sites. LLW and ILW from reactor operations are disposed of in waste disposal facilities in the bedrock of the nuclear power plant sites, at 60-110 metres' depth. The facilities have been operating since 1992 and 1999 respectively, with anticipated closing dates estimated at 2111 and 2068 (NEA, 2016). Further, the construction of a new final disposal facility for LLW and ILW operational waste is expected to begin around 2030, with its commissioning foreseen for 2035 at the earliest. Finally, a disposal facility for the very low-level waste of nuclear operator Teollisuuden Voima Oyj (TVO) will be taken into use approximately after 2025.

In Finland, nuclear operators are financially responsible for the management of all radioactive waste and the decommissioning of their nuclear sites. They have to take care of their waste including that of decommissioning until it has been disposed of in a manner accepted by the authorities. Responsibilities cover planning, research and implementation, including all costs up to the definite closure of the repository after which no long-term post-closure monitoring will be needed to ensure safety (EC, 2013 [2011]; MEAE, 2015; NEA, 2013). To this end, nuclear operators have to contribute to the State Nuclear Waste Management Fund (*Valtion ydinjätehuoltorahasto*, further referred to as "SNWF"), which covers treatment, storage and final disposal of radioactive waste, as well as the decommissioning of nuclear facilities. The SNWF is a special-purpose fund independent of the state budget, existing under the administration of the Ministry of Economic Affairs and Employment of Finland (MEAE). In practice, it acts as a kind of guarantee fund from which potential remaining decommissioning and RWM measures are paid if a nuclear operator does not fulfil its waste management obligations, as the SNWF does not pay for the measures but ensures that assets correspond to the remaining liabilities (NEA, 2016).

This Finnish funding system is based on the requirement that at any moment there shall be sufficient funds available in the SNWF to cover the liabilities for remaining future decommissioning and RWM duties for the radioactive waste produced up to that moment (WU, 2007). There is no levy on nuclear energy produced, but nuclear operators pay annual fees, due each March, to cover their liabilities. In case of surpluses in the fund, the nuclear operators receive reimbursements at the same date. In Finland, nuclear operators are entitled to borrow back a part of the accumulated assets from the fund in exchange for the provision of securities. The part of the liabilities that is not covered through assets available in the fund must always be guaranteed by full securities that are to be separately accepted and then monitored by the MEAE, including securities for unforeseen events (NEA, 2013). Such guarantees may only be provided in certain forms defined by law. The loans from the fund to the nuclear operators may not exceed 75% of the confirmed fund holding of the loan-taker at any given time. This includes a right of the nuclear operator's shareholders to use the above-mentioned funds to the extent that they remain unused by the operator himself. Finally, the Finnish state has a right to borrow the sum not borrowed by the nuclear operators or their shareholders. This capital can be transferred to the state budget from the fund for a fixed period. The remaining funds are invested by the SNWF against full securities yielding the best possible return. While the possibility to lend up to 75% of the SNWF back to the nuclear operators appears to raise questions regarding the on-time availability of and transparency regarding the funding assets, the legal obligation to provide financial securities for the missing assets in the funds appears to compensate at least the risk of funding unavailability.

For the time being, there are four nuclear reactors operating at two nuclear power plant sites in Finland. They produce around 30% of the country's electricity and are operated by the two main nuclear operators in Finland: a) Fortum (Fortum Power and Heat Oy), a nuclear operator and listed public company, 50.8% of which is owned by the Finnish state; and b) TVO, a nuclear operator and non-listed public company owned by a consortium of energy and industry companies. The current operating licenses of the reactors of both companies are currently expected to end between 2027 and 2030, after an average operational time of 60 years (WNA, 2019). In June 2019, a governmental decision on a new energy policy was adopted, aiming to reach carbon neutrality as of 2035. Next to a potential prolongation of the current lifetimes for the operational reactor fleet, the policy also envisages the commissioning of two new nuclear reactors to replace coal as an energy source (WNA, 2019). The fifth nuclear reactor has been under construction since 2005 and was granted its operating license in 2019. Commercial operation is foreseen as of 2022 at the earliest.

The construction of a second new reactor is currently planned to start by the end of 2021, allowing for commercial operation as of 2028 (WNA, 2019). The planning of this sixth nuclear reactor in Finland, Hanhikivi 1, is the reason for ongoing discussions between the established nuclear operators and the new nuclear operator and owner of Hanhikivi 1, Fennovoima Oy. Fennovoima Oy is a joint venture of 67 industrial and energy companies that received approval for construction of a new nuclear reactor in 2010 (WNA, 2019). TVO, Fortum, and their joint venture responsible for the management of SNF from the existing four reactors, Posiva Oy, have routinely said that they will not accept waste arising from Fennovoima's future reactor to be deposed in their DGR currently under construction (WNA, 2019). First, because Posiva only assumes the liabilities of its own shareholders and second, because recent opinion surveys have shown the local Eurajoki population to be reluctant to host waste from Fennovoima. However, according to the 1987 Nuclear Energy Act, the MEAE may order various operators to undertake RWM measures jointly, if doing so can increase safety or reduce costs substantially, or if any other weighty reason requires it. In 2012, the government threatened to use its legal authority if necessary to ensure that Fennovoima's SNF and HLW is included in the other operators' RWM plans. Finally, it set up a working group to collect existing material for comparison of alternatives, to perform preliminary comparison of the final disposal alternatives if necessary, and to give recommendations for future work. The working group's January 2013 final report recommended that the companies continue negotiations towards a solution for Fennovoima's SNF management. It did not take a clear position on whether one joint or two individual repositories should be built, saying that the difference in cost would be insignificant. This is due to two reasons. On the one hand, enlarging the DGR under construction in order to accommodate waste from Hanhikivi 1 would require a number of costly additional measures such as new geological investigations as well as environmental impact and safety assessments. On the other hand, the planning and the construction costs of a second repository facility could be minimised by replicating the Onkalo design by Posiva and by optimising technical co-operation between Posiva and Fennovoima. Overall, the cost difference between a single combined repository and two separate repositories solutions would be between USD 118 and 945 million (TEM, 2013). When Fennovoima successfully submitted an environmental impact assessment for its individual DGR project in 2016, the Finnish government urged the companies to find a common solution (WNA, 2019; NEA, 2013).

While Finland has an overall well-considered system for ensuring the adequacy of financing of decommissioning and RWM in place, the government is currently preparing a number of amendments that are likely to be adopted during the course of the coming year. This includes changes in the scope, framework, investment strategy and management of the SNWF. It also includes a reorganisation of the fees to be paid by operators in the 2026-2032 period and a reorganisation of the R&D programme. The new investment strategy will likely allow for greater diversification, organise SNWF investment activities under the Financial Supervisory Authority and transfer some operational responsibilities from the board of directors of the SNWF to the Executive Director. Last but not least, nuclear operators could be obliged to share some of the risks associated with SNWF investments and see their possibility to borrow back part of the accumulated assets reduced. Overall, the proposed changes, if implemented, aim at enhancing the efficiency of the operations of the SNWF while preserving the overall structure of the Finnish financing system for decommissioning and RWM.

The funding system

The main goal of the Finnish financing system for decommissioning and RWM that was established in its present form with the 1987 Nuclear Energy Act is to ensure that costs for decommissioning and RWM are included in the price of nuclear electricity and to ensure that assets are available even in case of insolvency of the nuclear operator, or preliminary termination of electricity production. To this end, nuclear operators pay annual fees to the SNWF, a special-purpose joint external fund under the administration of the MEAE, independent of the national budget. The amendment of the Nuclear Energy Act in 1994 stipulated that the nuclear waste generated in Finland shall be handled, stored, and permanently disposed of in Finland. Until then, the Finnish nuclear waste strategy included exporting nuclear wastes as well as the option of reprocessing SNF (WNA, 2019).

The SNWF collects, holds, and invests the assets to cover the respective future liabilities for each nuclear operator. It does not directly pay for the individual measures but keeps safe the money corresponding to the costs of the remaining measures. This means that, theoretically, all the funds have been returned to the nuclear operators when these have carried out the neccessary decommissioning and RWM operations. Accordingly, the SNWF could be described as guarantee fund from which the decommissioning and RWM measures are paid if the utilities or nuclear operators do not fulfil their future obligations (NEA, 2016). Following the 2004 amendment to the Nuclear Energy Act (1131/2003), the SNWF technically speaking consists of three separate funds that are collected individually and can exclusively be used for the purposes defined in the relevant provisions of the Nuclear Energy Act. The reserve fund is the main fund, holding financial provisions for decommissioning and RWM obligations, in which nuclear operators have to pay in yearly amounts to reach individual funding targets (SNWF, 2018; MEAE, 2015). Next to the reserve fund, two research funds exist: the nuclear safety research fund and the nuclear waste research fund. Their assets are dedicated to financing nuclear research, with a view to guaranteeing that nuclear expertise is available to the state agencies controlling and supervising nuclear operations in Finland. Nuclear operators have to pay annual fees, amounting to USD 300 per Megawatt (thermal), to finance the research funds under the SNWF. Previously, such financing was taken care of by the relevant agencies in voluntary co-operation with the nuclear operators (NEA, 2008).

The financing system covers all costs for RWM and decommissioning activities in the present and the future, including also R&D, LLW/ILW operational waste, decommissioning waste, regulatory and administrative costs, as well as real estate taxes. All liabilities have to be covered through the fund, either by assets or by secturities, to ensure all future measures in relation to decommissioning and RWM of radioactive waste produced up to that moment (NEA, 2014a). The Nuclear Energy Act, completed by the State Decree on the General Terms and Conditions of Loans to the Nuclear Waste Management Fund (83/2010), set out that nuclear operators are entitled to borrowing back up to 75% of their respective confirmed fund holding against the provision of full securities. The shareholders of the nuclear operators shall have the right to borrow any remaining amount between the amount borrowed by the operator and the 75% ceiling. The Finnish state has the right to borrow any remaining sum not borrowed by the nuclear operators or their shareholders. This capital can be transferred to the national budget from the SNWF for a fixed period. However, the state has not used this right since 2013, as the market has allowed it to borrow at a more favourable interest rate (MEAE, 2019a). The remaining funds are invested by the SNWF in a way to ensure the best possible return on the assets. No specific asset consitution strategy is determined by the legislation (NEA, 2016). Borrowing from the fund is tied to interest rates that are based on the Euribor index. The government seperately decides to what market rates interests the loans are tied. If necessary to ensure preservation of the value of the fund capital and to secure the return in yields, the government may decide to add special interest margins to the market interests applied. For example, securities that are provided to the fund to cover the future liabilities for decommissioning and RWM, or to cover any loan that was taken from the SNWF, may only be provided in the form of a) credit insurances issued by an insurance company; b) direct liability guarantees provided by a Finnish savings bank; or c) real estate mortgage or direct liability guarantee by a Finnish corporation. The latter need to be considered by the government as secure as the two prior categories of security. A real estate mortgage that has been confirmed on a nuclear facility property cannot be accepted as a security, while a real estate mortgage that is used as a security cannot exceed three-fourths of the probable transfer price of the real estate. Further, only securities with a validity period of at least five years can be accepted. Securities provided by the nuclear operators have to be seperately accepted and then monitored by the MEAE.

The MEAE is responsible for overseeing the plans for decommissioning and RWM by the nuclear operators regarding their compliance with national policy before and throughout their implementation. It further ensures that the operation of the SNWF complies with the corresponding legislation and determines each year the amount of money that each operator must provide to the fund (WU, 2007). The SNWF is managed by a board of directors, appointed by the government for three years at a time. The board has to include representatives from the MEAE, the Ministry of Finance, and the State Treasury. The director of the fund is a chief counsellor from the MEAE that is responsible for managing the fund's operations and the preparation, implementation, and enforcement of decided measures. Further, the fund has two auditors, one of whom is selected by the nuclear operators (*Ibid*.). To meet their funding liabiltities, nuclear operators have to pay annual fees, in the form of payments or provision of securities, to the SNWF to offset their newly assessed liabilities. To that end, nuclear operators have to provide annual cost estimates to the MEAE, which evaluates the assessed liabilities and the proportion of liaibility to be paid into the SNWF, i.e. the funding target, in co-ordination with the Radiation and Nuclear Safety Authority (STUK). In case of surpluses in the fund following the reassessment of liabilities, the nuclear operators are eligible to receive reimbursements from the fund. Payments effectuated in year n apply to the liabilities in year n-1 (WNA, 2019). The 1987 Nuclear Energy Act sets out that the annual fee shall amount to 0.08% of the assessed liabilitites, though the government may decide on a lower amount. Further sources of income for the SNWF include returns on loans issued and returns on investments made by the fund. These sub-funds are dedicated to ensure that a sufficient level of nuclear-related R&D is undertaken at all times.

A nuclear operator's responsibility for a radiation source expires when the source of radiation has been returned to the supplier, the radiation source has been surrendered to a recognised installation for transfer to the state permanent storage in a DGR, or the radiation source has been transferred to some other operator with a safety licence for the use of the radiation source (MEAE, 2015). After its approved disposal, the Finnish state is responsible for the radioactive waste. It also has the secondary responsibility in any situation where a producer of nuclear or other radioactive waste is incapable of fulfilling its waste management obligations (NEA, 2016b). In such a case, the nuclear operator shall compensate the state for the expenses incurred, if that is deemed possible. The holder of a safety licence shall furnish a financial security if the expenses of rendering harmless the radioactive waste generated in its operations are assessed to be considerable (MEAE, 2015). According to the 1987 Nuclear Energy Act, the legal person whose activities lead to the production of radioactive waste is fully responsible for the respective RWM and decommissioning duties. It can be released from that obligation only by the consent of the Finnish government. So, if a nuclear power company ceases to exist or becomes unable to fulfil its obligations, the task is transferred to the state. However, the fact that the part of the liabilities not covered directly through assets in the SNWF has to be covered by securities at all times appears to reduce the overall vulnerability of the system regarding bancruptcy of an operator or the earlier than anticipated shutdown of a reactor. Further, preparations are made each year by the SNWF for the event that the operating reactors are decommissioned earlier than planned (MEAE, 2015). In the case where a facility unexpectedly stops its operation and the funds are transferred to the state, the SNWF has the right to require the operator to pay its loans back to the fund or, alternatively, to realise the securities pledged by the operator (NEA, 2013). As such, the system appears to be protected against unexpected developments such as the bancruptcy of an operator or the preliminary shutdown of a reactor.

The cost side

Nuclear operators in Finland are responsible for estimating annually the future costs of managing the existing waste, including SNF disposal and nuclear power plant decommissioning. As described earlier, the MEAE confirms the assessed liabilities and the proportion of liability to be paid into the SNWF, i.e., the fund target. The cost estimates are always calculated in current prices, on the basis of current plans and technology. No discounting is used (WU, 2007). The Nuclear Energy Act provides that back-end cost estimates in Finland must be based on remaining management costs of existing waste amounts, current price level with no discounting and on the use of currently available technology (NEA, 2014b). In practice, the cost estimates are based on a decommissioning work plan and the experiences from the plant operation phase. Labour costs are based on the actual and realised costs at the power plant for own staff, subcontractors, and consultants. Final disposal costs are included in the cost estimate based on the licensing, construction and operational costs of the on-site repository for LLW/ILW. Dismantling costs are based on in-house expertise as well as on budgetary offers from the equipment suppliers and dismantling companies (NEA, 2016). In 2016, an NEA study indicated that, as regards Finnish decommissioning cost estimates, the following items were included in the estimates' scope: a) de-fuelling; b) on-site storage of radioactive waste from decommissioning; c) removal of the reactor building; d) transport and disposal of radioactive waste; e) final site surveys; and f) de-licensing of the site.

The decommissioning cost estimates for the Loviisa nuclear power plant do not include SNF management (NEA, 2016a). The decommissioning plan for the Loviisa nuclear power plant is based on immediate dismantling after 50 years of operational lifetime. The SNF storage remains on site after the plant is decommissioned until all SNF has been transported to the DGR for final disposal. The decommissioning plan for the Olkiluoto nuclear power plant units 1 and 2 is based on deferred dismantling after a safe storage period of 30 years, while the decommissioning strategy of the new third unit foresees immediate dismantling. Dismantling of all the units at the Olkiluoto site is expected to be done in one campaign (EC, 2013 [2011]). Contingencies in Finland are to be estimated based on experience. According to the Nuclear Energy Act, in order to provide for unforeseen costs, the government can decide on an extra security of up to 10% of the total liability (NEA, 2016). The average contingency used was reportedly 9%, with a 9.08-9.1% range. Based on previous engineering projects at the Loviisa nuclear power plant, decommissioning cost estimates include a 10% contingency of total cost (NEA, 2016a).

Assets, investment rules and performance

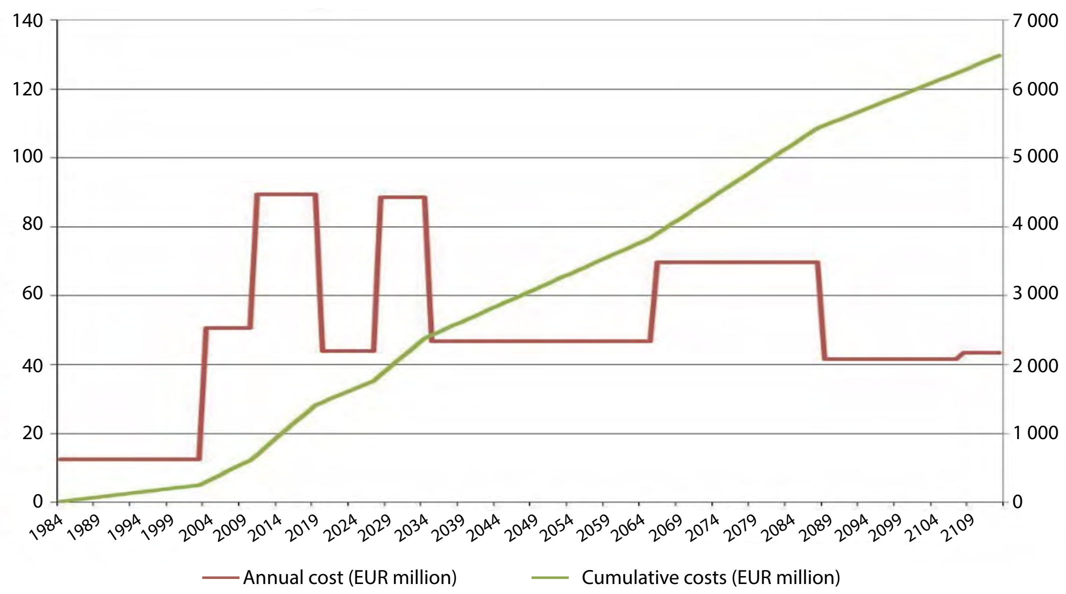
The total value of the SNWF main reserve fund, including assets and securities, at the end of 2018 was USD 3.31 billion, compared to USD 3.22 billion at the end of 2017. Following the n-1 rule explained earlier, the assessed future liabilities in 2017 should be equal to the fund value at the end of 2018, i.e. USD 3.31 billion. The SNWF's assets dedicated to R&D amounted to a total of USD 15.37 million at the end of 2018, USD 11.12 million of which reserved for nuclear safety research and USD 4.25 million for radioactive waste research (MEAE, 2019a). In 2015, the accumulated overall costs for decommissioning and RWM for the four already operating reactors and the fifth reactor under construction were estimated to amount to approximatively USD 8.125 billion over the entire operating time of the reactors (2012 price-level). Of this, the costs for the final disposal of SNF accounted for around USD 4.37 billion. The costs of managing operational waste were expected to be around USD 125 million, while the decommissioning costs of the nuclear power plants were estimated at around USD 1.25 billion (MEAE, 2015, see Figure 8.1). The remaining costs consist of, for example, R&D costs, interim storage costs, fees charged by authorities and taxes. These estimates did not include the costs for the planned sixth nuclear reactor, operated by Fennovoima. The overall costs of the RWM and decommissioning scheme appear to be rather moderate in Finland. This is likely to be the result of a combination of technological factors coupled with the well-advanced DGR project, as well as the clear structure, straightforward allocation of responsibilities and manageable size of the Finnish nuclear energy sector. The average return on the invested share of the fund amounted to 2.81% between 2009 and 2018 (MEAE, 2019a). As regards the securities to be provided against loans from the SNWF, in practice, TVO has used direct liability guarantees of its shareholders, while Fortum provided real estate mortgages related to its conventional power activities (WU, 2007).

The SNWF uses the same investment services as those of the State Treasury to invest the relatively small part of the fund's total assets that is not lent back. The investors are to comply with the Fund's asset investment policies by investing in moderately risky investments. Indeed, the Fund's investment policy derives from Article 52 of the Nuclear Energy Act, which provides that the unused funds are to be "invested in security against other best possible return on investment". In practice, the fund invests mostly in state bonds. Returns on investments and income accrued during the financial year are decided on by the State Treasury's investment services, relying on the government's guidelines. Regarding the fund's profits, it is to be noted that in 2003 a law passed that clarified the principles underpinning the system for sharing the profits made by the fund. They are to be divided between the nuclear operators in proportion to their shares in the fund. Recently, SNWF's board submitted a legislative initiative to the MEAE in accordance with section 51 of the Nuclear Energy Act so that the distribution of the fund's profits would be explicitly directed to the fund's main reserve (SNWF, 2019, free translation).

Section 88 of the 1988 Nuclear Energy Decree provides that nuclear operators submit every three years to the MEAE a decommissioning and RWM scheme with the related cost calculations and liability assessments. Each operator shall annually complement the approved scheme for decommissioning and RWM with a revised and supplemented version, which should include the following updates:

a) information on the costs and prices of RWM measures, including disposal; b) information on the amounts of radioactive waste included in the RWM and decommissioning obligations; c) information on the necessary RWM measures; d) statement on the resultant calculation of the total costs of RWM and decommissioning, including disposal. The MEAE has the obligation to review the submitted data and must request statements from STUK and from an organisation having competence in technological cost assessments. While the content of the cost calculation is updated every three years and the costs themselves are updated on a yearly base to the current price level, there is no external review of the methodology by which the decommissioning and RWM cost liability is established (NEA, 2013; NEA, 2016a). The MEAE releases yearly fund statements through the SNWF, which are to be controlled by independent external auditors appointed by the MEAE. When preparing the financial statements, the board of directors and the managing director of the SNWF are required to assess the adequacy of the fund and, where appropriate, to present the facts relating to the continuity of operations (MEAE, 2018). The MEAE must annually examine the fund-related collateral securities and estimate whether their security value can still be considered sufficient. If this is not the case, the Ministry of Trade and Industry has the right to demand a supplementary or a new security and to set a deadline by which such security is to be supplied.

Figure 8.1:
Decommissioning and RWM costs of the Olkiluoto and Loviisa nuclear power plant sites according to TVO. EUR/USD = 1.25.



Source: MEAE, 2015: p. 26.

Conclusion

Finland is on track to build the world's first DGR and possesses a sophisticated decommissioning and RWM scheme. With an estimated operational lifetime of around 100 years, the DGR promises to bring an element of certainty to the management of radioactive waste. Next to the DGR project, Finland maintains already two near-surface facilities in direct proximity of its two nuclear power plant sites to store the LLW and ILW waste at a depth of around 100 metres. Funding adequacy is assessed every three years, including annual updates that are to be provided by the nuclear operators to the MEAE, ensuring sufficiency of the fund's assets to meet future liabilities accumulated until the respective date. Up to 75% of the joint external fund dedicated to guarantee financing of future decommissioning and RWM liabilities can be lent back to the nuclear operators, in exchange for the provision of securities to the fund. Plans for a sixth nuclear reactor in Finland, under the responsibility of a business consortium separate from the traditional nuclear operators, led to discussions about whether it was preferable to have a common DGR or two separate DGRs for the disposal of radioactive waste. Securities for the fund have to be provided where future liabilities are not covered by assets in the fund. As such, the Finnish SNWF could be characterised as guarantee fund from which future liabilities are paid if a nuclear operator does not fulfil its obligations. Future liabilities are calculated without the application of a discount rate, avoiding a number of accounting and financial issues in the context of a negative market interest rate environment. The reliance on securities to guarantee that future liabilities in decommissioning and RWM are covered appears to ensure that any loans taken from the fund or uncovered liabilities will not lead to a transfer of financial responsibilities to the state in case of bankruptcy or preliminary shutdown of a facility.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 9

France: Country case study

KEY FACTS	
Funding model	Internal segregated funds, i.e. separate funds held by the nuclear operators to finance both decommissioning and RWM liabilities
Assets	• USD 34.62 billion (EUR 27.7 billion) (EDF)
Liabilities	• USD 35.25 billion (EUR 28.2 billion) (EDF)
Avg. effective real return	• 5.7% (2004-2018) (EDF)
Discount rate	• 3.9% (regulatory ceiling: 4.0% max) (EDF)
Assumed operational lifetime of nuclear power plants	50 years for 900 MW reactors (excepted Fessenheim), 40 years for others
Investment rules	No investments in securities issued by the licensee or other consolidated companies/ subsidiaries. No investments in real estate property located close to the licensee's industrial sites.
Evaluation of fund adequacy	Assets reviewed annually, fund adequacy reviewed every six months by licensees and annually by the administrative authority. Cost estimation methodologies reviewed every year.
Issues at stake	• Nuclear operators in France are majority-owned by the French state. This can potentially create mutual dependence of public and private (operator) liability, especially in case of long-term economic unprofitability of the nuclear

Decommissioning and RWM in France

With a large nuclear fleet of 58 reactors, France has a sophisticated and well-organised decommissioning and RWM funding scheme in place, based on an advanced storage and reprocessing infrastructure, as well as a transparent allocation of liabilities. In France, the discounted values of future liabilities for decommissioning and RWM costs have to be entirely held by the nuclear operators in form of "dedicated assets", which the law renders inalienable even in case of an operator's bankruptcy. A particularity of the French system is the fact that a notable share of its SNF is being reprocessed for future use as nuclear fuel in electricity production. Further, France possesses an advanced interim storage scheme. A final DGR for HLW is expected to obtain a final authorisation in the coming years, potentially enabling its pilot-operability as of 2025.

As an exclusive primary operator of commercial nuclear power plants, this country case study shall focus on the role of EDF – 85% of which is owned by the French state – in the French decommissioning and RWM funding system. France's particularity lies in the fact that nuclear operators are owned to a large extent by the French state, which gives them fairly comprehensive responsibilities regarding the estimates of their future liabilities for decommissioning and RWM.

While the large role of the French state provides added security with respect to the adequacy of funding in case of needs, it also imposes on all parties to be particularly rigorous with regard to transparency. Further, given the specific ownership constellation in the French nuclear energy scheme, and especially in the case of EDF, the question remains whether a potential failure of the operators to provide adequate funding would not also imply a liability of the French State in the first (e.g. for EDF and Orano) or second degree (e.g. for Framatome).

Nuclear power plant lifetime

For the time being, there are 58 nuclear reactors operating at 19 nuclear power plant sites in France, owned and managed by EDF. They delivered around 70% of the French power production in 2018 (EDF, 2019a). EDF currently assumes an effective lifetime of 50 years for 900 MW reactors – except Fessenheim – and of 40 years for the rest of its operating reactor fleet. While the general policy regarding nuclear energy remains positive, including the option of building new reactors, the government in 2018 adopted a preliminary strategy foreseeing the reduction of nuclear energy in the French energy mix to 50% by 2035 (WNA, 2019). This would include the shutdown of four to six reactors until 2030 and a total of 14 reactors until 2035. At the same time, a new reactor that was under construction at the Flamanville nuclear power plant site since 2007 is awaiting its final licensing before connecting to the grid, which is not expected before 2022. Further, there are plans to replace the currently operating reactor fleet with new reactors by the end of the 2020s (WNA, 2019).

Waste management

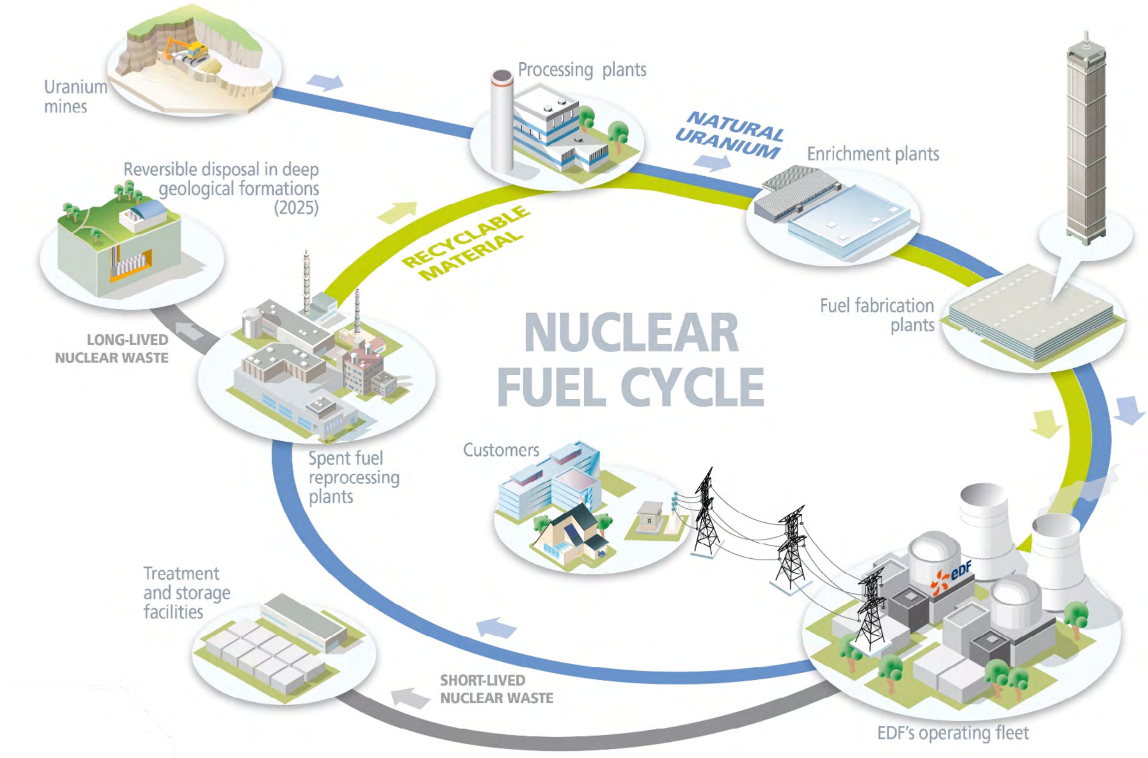
In France, SNF is reprocessed and, in this regard, mainly treated at the La Hague plant, which has the capacity to reprocess up to 1 700 tons of SNF per year (WNA, 2019). This operation of a largely closed fuel cycle makes France a unique case among OECD countries. Indeed, all French SNF is interim-stored at the La Hague site. A major part of it will be going into reprocessing, while another part awaits final disposal. The French strategy for disposal of HLW foresees a DGR, "Cigéo", as final repository for which the authorisation request was submitted in 2020 and pilot-operability foreseen as soon as 2025 (EDF, 2019a). The Cigéo repository is planned to permit reversibility of SNF storage throughout the duration of its more than 100 initial years of expected operation, allowing for potential changes in France's RWM strategy to be implemented far into the future. The French storage scheme is completed by two final storage facilities for LLW and ILW, currently also serving as interim storage sites for waste awaiting final disposal in the Cigéo DGR (Figure 9.1). A final disposal site for LLW and ILW waste, the Manche storage center (CSM), has operated between 1969-1994 before being sealed and coated successfully with layers of grassed cover (WNA, 2019).

Financial responsibilities for nuclear decommissioning and back-end

The financing of the decommissioning of France's nuclear reactors is to be entirely ensured by the nuclear operators. The decommissioning is expected to take 15 years per reactor. Nuclear operators are responsible to hold internal provisions in form of segregated and dedicated funds that are backed by assets of sufficient security and liquidity to cover their liabilities for decommissioning, SNF management and RWM. Electricité de France (EDF), of which 85% is owned by the French state, is the exclusive owner and operator of all commercial nuclear reactors in France. Other nuclear industry actors must also hold funds for their nuclear liabilities following an identical scheme. These other actors include: a) Orano, a company of which a majority is owned by the French state and that is involved in the nuclear fuel cycle; b) Framatome, a company that offers services for nuclear reactors and which is 75% owned by EDF; c) the public French Alternative Energies and Atomic Energy Commission (CEA), performing civilian and military nuclear programmes; and d) the

National Radioactive Waste Management Agency (Andra). As an exclusive primary operator of commercial nuclear power plants, this country case study shall focus on the role of EDF in the French decommissioning and RWM funding system. In this context, the substantial share of ownership held by the French State in EDF should be kept in mind when further analysing the funding system.

Figure 9.1:
Simplified overview of the French nuclear fuel cycle



Source: EDF, 2019a.

Regarding the responsibility – i.e. ownership – for radioactive wastes generated by nuclear licensees, it ought to be noted that the Andra does not take over the legal ownership of the nuclear waste it receives for processing. Indeed, waste producers are and remain responsible for the waste they produced, even when materials are to be physically transferred to the Andra's disposal facilities. The Andra is responsible for the verification, the monitoring of waste and the operation of its centres and is liable in case of a nuclear incident. However, Andra has the possibility to mention, in all radioactive waste management contracts, that it has a right of recourse against the waste producer. Should a responsible party default on its obligations or not be identifiable, the French state can also entrust the management of spent fuel and radioactive waste, as well as the remediation of contaminated sites, to the Andra, pursuant to the Environment Code (Article L. 542-12).

Regarding decommissioning and RWM, the French regulatory framework is based inter alia on Act 2006-686 on Nuclear transparency and safety (the "TSN Law"), on Decree 2007-243 on securing the financing of nuclear charges, on the 2006 Planning Act on the sustainable management of radioactive wastes and materials, and on the Environment Code. Act 2006-686 and the 2006 Planning Act were part of a major change in the laws framing the nuclear sector in 2006, creating inter alia an independent Nuclear Safety Authority (ASN) and a High Committee for Transparency and Information on Nuclear Security (IEA, 2010). According to this framework, nuclear operators, chiefly EDF, Orano, Framatome, and incidentally the French state (for public operators as the CEA), are entirely responsible for financing all costs arising in the context of the management of their waste and the dismantling of their nuclear installations.

To establish the legally required assets, each of the above entities applies different methods. The fund-liable entities either raise funds from their commercial activities or are funded directly by the state in accordance to their public nature (e.g. as is the case for the CEA). The overall responsibility to provide adequate funding for decommissioning and RWM activities remains with the respective nuclear operator, even in case of insufficiency of its funds. In the event of an increase in estimated or effective costs; in case of losses in the assets portfolio; or under any other circumstances leading to an estimated insufficiency of its funds, the nuclear operators are to add resources to the funds. The administrative authority, that is, the French Ministry for the Ecological and Inclusive Transition, might also impose the operator's parent companies to finance accrued costs if the nuclear operator fails to do so (Du Pasquier, 2017).

Recent nuclear back-end developments

In 2017, Areva, a private company involved – and offering services – in all stages of the nuclear fuel cycle, from mining to fuel manufacturing and reprocessing, was restructured following a multitude of economically challenging events. Next to others, unexpected financial liabilities for the Olkiluoto nuclear power plant in Finland and a general slowdown of the nuclear energy sector following the Fukushima Daiichi accident in 2011 have put pressure on Areva (NEI, 2018; Reuters, 2018; Areva, n.d.). The part of Areva that was formerly undertaking maintenance and construction work for nuclear reactors was sold to EDF and is today operating under the name of Framatome. The French state, as the main shareholder of Areva, decided to recapitalise the company and in particular the branch of Areva that offered services in the nuclear fuel cycle with around USD 3.12 billion. During this process, the nuclear fuel cycle branch of Areva became Orano. Minor parts of Orano's shares were later acquired by Japan Nuclear Fuel Limited and Mitsubishi Heavy Industries (NewCo, 2017; Orano, 2019b).

The reconstruction of Areva, including its refinancing through the French state, underlines the particular ownership constellation in the French nuclear energy scheme. While the restructuring of Areva did not concern the already established nuclear provisions, whose inalienability is protected by the law, the long-term unprofitability of a publicly owned nuclear operator might potentially jeopardise the continuity of funding streams. The case of Areva highlights the potential risks of unforeseen public liabilities to ensure such funding streams.

The funding system

The French regulatory system holds nuclear operators entirely responsible for carrying all costs related to their decommissioning, SNF management and RWM liabilities. To that end, they have to hold one internal segregated fund holding assets "dedicated" to (i.e. inalienable, and strictly earmarked for) the financing of costs related to decommissioning, SNF management (excluding reprocessing expenses) and RWM.

Purpose and structure of French financing schemes

To ensure the secure financing of back-end activities, French regulation requires that assets be dedicated to financing the costs of decommissioning and RWM, and that, as such, they be clearly identified and managed separately from the company's other financial assets and investments (EDF, 2016). Provisions held by the nuclear operators have to be equal to the discounted value of the expected future liabilities at all time. Further, the legislative framework obliges nuclear operators to allocate more assets to cover their provisions for long-term liabilities than they withdraw as long as the coverage rate of these provisions is less than 110% (Decree 2007-243, Article 2). The assets in the nuclear operator's funds are protected by the law and nobody can claim any right over the assets, besides the state if it acts in the execution of its right to enforce the operators' obligations to decommission their facilities and to manage their spent fuel and radioactive waste. This measure aims to protect the assets in case of an operator's insolvency or bankruptcy (EC, 2013). Furthermore, if the administrative authority observes that there could be an obstacle to the application of the legislative provisions, it may require that the licensee concerned pay the necessary sums into a fund set up with Andra – the national public RWM company – with a daily penalty if need be, to cover nuclear charges

(Environment Code, Article L. 542-12-2). Hence, these arrangements appear appropriate to ensure the inalienability of the assets, including in case of the potential bankruptcy of an operator. The majority ownership by the French state of the main nuclear operators strengthens this assessment.

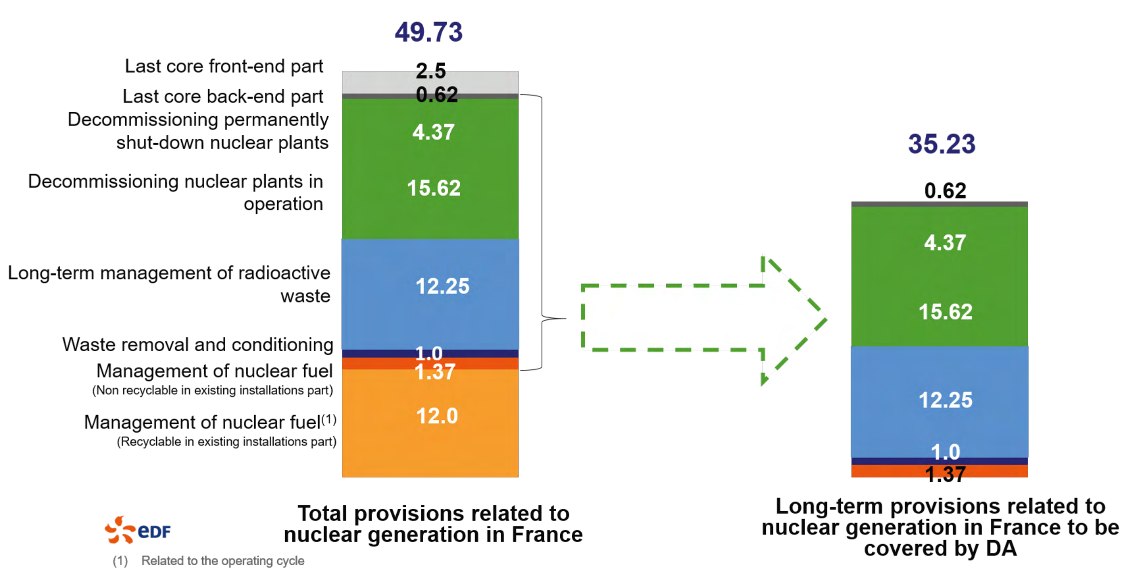
EDF's financial provisions

EDF's decommissioning provisions cover future decommissioning expenses, excluding costs for removing and storing waste. They also include provisions devoted to costs for final cores, which cover future expenses resulting from scrapping fuel that will only be partially irradiated, including costs that arise from the loss associated with non-reusable fuel due to technical and regulatory constraints, as well as the costs of reprocessing and removal in this regard.

The scope of EDF's provisions for long-term RWM covers all future expenses for the removal and storage of radioactive waste resulting from decommissioning of nuclear installations operated by EDF, the interim storage, removal and disposal of radioactive waste packages (including those resulting from SNF reprocessing), and EDF's share of the costs of studies, construction, operation, maintenance, shutdown and surveillance of existing and future storage facilities (Figure 9.2) (EDF, 2016; EDF, 2019). EDF's provisions for SNF management cover, inter alia, services associated with the removal of SNF from EDF's generation centres and the reprocessing of SNF, including conditioning and storage of recyclable matter and waste arising from fuel reprocessing. Reprocessing expenses exclusively concern SNF that can be recycled in existing facilities, including the portion in reactors not yet irradiated. Finally, the provisions for the management of SNF also cover the long-term storage of SNF that cannot be recycled in the existing installations for the time being, mainly plutonium fuel (MOX), and reprocessed uranium fuel. In 2018, the provisions covering interim storage of waste arising from SNF reprocessing, formerly classified as "SNF reprocessing provisions", were reclassified as "provisions falling under EDF's responsibilities for long-term RWM" (EDF, 2019b).

The practice of SNF reprocessing introduces an interesting differentiation between long-term liabilities and current expenditures in the financing of RWM in France. Indeed, SNF reprocessing costs are to be paid directly by revenues from operation and there is no obligation to set aside dedicated assets for those costs, even though they are taken into account in the operators' reserves (Figure 9.2) – accordingly, these charges are not included in French electricity prices.

Figure 9.2:
Scope of EDF's total provisions related to nuclear generation compared to liabilities that have to be covered by dedicated assets (DA) to comply with the legal obligations, indicated in billions of USD



Source: Adapted from EDF, 2019a: p. 5.

Financial provisions held by other operators

The funds held by the CEA are financed by the French government, while the funds held by Andra are financed through payments from the operators' internal funds at the time when Andra is required to conduct operations (CEA, 2015; EC, 2013). Besides, specific public funding has been implemented for the collection and management of waste from "small-scale nuclear" activities – e.g. radiation sources produced by medical or research activities.

The cost side

Process and responsibilities

In France, nuclear operators are entirely responsible for conducting the cost estimations to assess the liabilities arising from future decommissioning and SNF management and RWM-related activities regarding their facilities. In this regard, two key principles are laid down by French accounting law: that a) any future cost that is certain to occur, even if the exact amount or date are uncertain, shall be accounted for as liability; and that b) the estimation of liabilities shall be carried out in a prudent and conservative manner, e.g. by applying margins in the cost estimations that surpass the best estimate (Du Pasquier, 2017; Art L. 594-1 of the Environment Code and Art L. 123-20 of the Commerce Code).

Decommissioning costs: EDF's methodology

The costing method used by EDF until the end of 2016 for its decommissioning cost estimates was commonly referred to as the "Dampierre 09" method, because EDF realised a detailed study of decommissioning costs for its Dampierre nuclear site in 2009 as a representative case study for its entire reactor fleet. The study was based on a three-step approach including a) the measurement of decommissioning costs for the Dampierre site, taking into consideration the most recent developments in regulations, past experience in decommissioning of shutdown plants, and recommendations issued by the French Nuclear Safety Authority (ASN); b) a review of the timeline for decommissioning operations, in which the total duration of decommissioning operations for one reactor was estimated at 15 years following the shutdown; and c) the determination of the rules for extrapolation of cost estimates for the entire reactor fleet currently in operation. Between 2014 and 2015, an audit of the dismantling costs for EDF's nuclear fleet was conducted by specialised consulting firms at the request of the French Ministry of Energy's DGEC Section. Published in 2016, it confirmed overall that EDF's estimate of decommissioning costs for its nuclear fleet complied with auditory standards without major objections – further information can be accessed from the French Ministry for Ecology's release dated 15 January 2016, which states that the audit confirms EDF's own estimate of the cost of decommissioning its nuclear power plant fleet.

After the 2016 audit report, EDF revised its decommissioning estimate to incorporate recommendations and experience gained from dismantling of France's first-generation reactors. A detailed analytical approach was used to revise EDF's estimation methodology, identifying all costs for the engineering, construction work, operation, and waste processing relating to future dismantling of reactors currently in operation. This led to figures based on detailed timetables for plant decommissioning. The approach adopted made it possible to explore more thoroughly the assessment of costs specific to the initial units of each series, the subsequent units of the series as well as mutualisation effects, which all depend on the overall fleet's size and configuration. EDF also supports its analyses through an international comparison. The results of the methodology revision led to limited changes in EDF's cost estimates and the associated provisions at the end of 2016 – i.e. only an increase of USD 401 million in estimated decommissioning costs and of USD 620 million in estimated costs for long-term management of long-lived radioactive waste, as well as a decrease of USD 564 million in EDF's provision for plant decommissioning costs (EDF, 2016). To estimate its further future RWM costs, EDF mainly relies on internal estimates based on management data from its information system, as well as independent external expert opinions (EDF, 2017).

The calculation of nuclear provisions by EDF incorporates a level of risks and uncertainties regarding the operations concerned to comply with the regulatory framework. The valuation of costs carries uncertainty factors such as a) changes in legislation, particularly regarding safety, security and environmental protection, and financing of nuclear expenses; b) changes in the regulatory decommissioning process and the time necessary for issuance of administrative authorisation; c) future methods for storing long-lived radioactive waste and provision of storage facilities by Andra; and d) changes in certain financial parameters such as discount rates, notably in view of the regulatory limits, inflation rates, or changes in the contractual terms of SNF management (EDF, 2016).

Radioactive waste management costs

Nuclear operators in France are responsible for taking into account the payment of their attributed share of the costs for the Cigéo DGR project in their RWM cost estimates. The respective share of the costs is fixed by the responsible Ministries, based on estimates of the produced radioactive waste and the common project costs. The provisions for RWM held by the nuclear operators were until recently based on the initial 2005 cost estimate for the DGR project, amounting to USD 17.62 billion in 2003 price levels over 140 years. In 2016, based on an estimate from national public waste agency Andra which especially included the observations of waste producers – the Environment Code defines a precise process for estimating the cost of the DGR – the French Ministry for Ecology, Sustainable Development and Energy announced that the estimate of future expenses related to the DGR project had been revised upwards, to USD 31.25 billion (EUR 25 billion) in 2011 price-levels over 140 years as of 2016 (CEA, 2015). This new reference baseline cost for the DGR project prompted EDF and the CEA to commit additional net provisions for their RWM liabilities of about USD 1 billion each.

Discounting approach

In France, the future costs for nuclear liabilities are estimated using a discount rate. The rate has to comply with a regulatory limit tied to a formula increasingly dependent on the TEC-30 performance. The regulatory ceiling is calculated as the "weighted averages of a first term fixed at 4.3% and second term corresponding to the arithmetic average over the last 48 months of the TEC 30 plus 100 base points (1%). The weighting assigned to the first constant term (…) decreases linearly from 100% at the end of 2016 to reach 0% at the end of 2026" (EDF, 2019a: p. 29). The application of this formula resulted in a regulatory ceiling for the discount rate of 4.0% in 2018 (ibid).

EDF determines the discount rate applied in its cost estimates based on long-series data for a sample of bonds with maturities as close as possible to that of the liability. The benchmark used to determine the discount rate is the sliding ten-year average of the return on French OAT 2055 treasury bonds, which have a similar duration to the obligations, plus the spread of corporate bonds rated A to AA, which include EDF itself. The methodology used to determine the discount rate, particularly the reference to sliding ten-year averages, is able to prioritise long-term trends in rates, in keeping with the long-term horizon for disbursements. The discount rate is therefore revised in response to structural developments in the economy leading to medium- and long-term changes (EDF, 2016). The discount rate applied by EDF at the end of 2018 was 3.9%, which is close to the national regulatory ceiling of 4% (EDF, 2019a).

Assets, investment rules and performance

As of 31 December 2018, the future value of the discounted nuclear liabilities of EDF was estimated at USD 35.25 billion, of which USD 34.62 billion (USD/EUR = 1.25) were covered by dedicated assets, resulting in a coverage ratio of 98.3% (compared to a coverage rate of 108.5% on 31 December 2017). That change in coverage ratio was mainly due to a negative return on EDF's dedicated assets for the year 2018 and also, to a lesser extent, to changes in the discount rate applied. In accordance with French regulation, the administrative authority required EDF to allocate additional dedicated assets (USD 1.67 billion) and authorised the company to spread this allocation over the following three years. The pre-tax return on

EDF's dedicated assets for the year 2018 amounted to -1.6%, while the average real return between 2004 and 2018 was 5.7%. In 2018, EDF's yield assets brought a return of 7%, while the return on growth assets amounted to -7% and the return on fixed-income assets was at -0.4% (EDF, 2019a).

Management rules for dedicated assets

In France, the discounted values of future liabilities for decommissioning and RWM costs have to be entirely held by nuclear operators in the form of "dedicated assets", which the law renders inalienable even in case of operator bankruptcy. The categories of assets admissible for the funding of future liabilities of the nuclear operators in France, as well as the respective maximum authorised weights of each asset class are defined in the Decree 2007-243 on securing the financing of nuclear charges. Said decree is mainly based on, and largely referring to, the categories of the French insurance code (R-332-2 and sq.), which are non-nuclear-specific. In particular, the decree comprises two measures concerning dedicated assets:

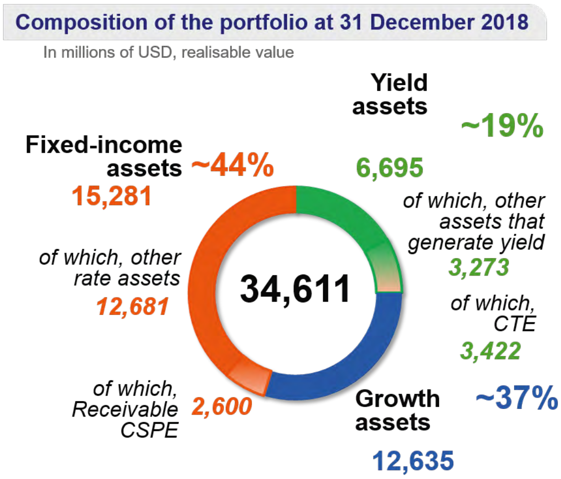
1. the annual allocation to dedicated assets, net of any increases to provisions, must be positive or zero as long as their realisable value is below 110% of the amount of the provisions concerned;
2. real estate property owned by the operators of nuclear facilities may be allocated to coverage of these provisions, but only if this property takes the form of buildings for tertiary use that are located outside of the company's industrial complexes.

In the case of EDF, the constitution plan is defined to match the regulatory target of funding 100% of the long-term liabilities by the prescribed date, assuming a constant yearly contribution in real terms. The strategic asset allocation is defined by EDF's board of directors. Since inception of the dedicated assets in 1999, EDF has maintained a strategic allocation that is balanced between bonds and internationally diversified equities (NEA, 2016). In June 2018, EDF adopted a change in its strategic investment approach, which had been in place since 2013, with the aim of decreasing the share of fixed-income assets in favour of yield assets (Figure 9.3). This change was not fully implemented at the end of 2018, with EDF's asset portfolio containing around 37% growth assets, 44% fixed-income assets and 19% yield assets (Figure 9.4).

Figure 9.3:
EDF's planned changes in its investment strategy between 2013-2018

Source: EDF, 2019a: p. 16.

Figure 9.4:
Composition of EDF's asset portfolio as at 31.12.2018, in million USD



NB. CSPE = contribution to electricity public service; CTE = coentreprise de transport d'électricité, i.e. a company holding 100% of the shares of RTE (France's public electricity transmission system operator).

Source: Adapted from EDF, 2019a: p. 19.

Funding adequacy review mechanisms

The French Environment Code specifies that every three years nuclear operators must provide to the Ministry of Energy and the Ministry of Economy a status report describing the assessment of long-term liabilities, the methodology and choices to manage these liabilities, and an inventory of the dedicated assets in terms of provisions. Further, a yearly update of this triennial status report has to be provided, while nuclear operators are required to report every three months on their dedicated assets portfolios (Decree 2007-243 Article 10). Finally, statutory auditors also review said dedicated assets portfolios as part of the operators' half-yearly financial exercise closing (NEA, 2016).

French Ministries may request additional supporting documents from the operators, and commission complementary studies from independent expert bodies. These expert bodies notably include the French Nuclear Safety Authority and the French Central Bank's Prudential Supervision and Resolution Authority (ACPR) for the specific review of the economic and financial hypotheses that underpin the management of the long-term liabilities. If ministerial administrations detect insufficient or inadequate liability evaluation or dedicated assets, they can, after hearing the nuclear operator's observations, prescribe the recovery measures deemed necessary, along with a delay. In case of non-compliance within the prescribed delay, the Ministries can mandate, under financial penalty, an asset constitution plan and any measure regarding their management (Environment Code, Articles L594-5 and L594-9).

Conclusion

The French decommissioning and RWM scheme is both sophisticated and well managed. It is operated jointly by industrial and public actors. France runs one of the world's largest fleets of nuclear reactors and a particularity of its system is that a notable share of its SNF is being reprocessed for future use as nuclear fuel in electricity production. Further, France possesses an advanced interim storage scheme: a final DGR for HLW is expected to obtain final authorisation in the coming years, potentially enabling its pilot-operability as of 2025; two final repositories for LLW and ILW are already in operation. As an exclusive primary operator of commercial nuclear power plants, this country case study focused on the role of EDF – 85% of which is owned by the French state – in the French decommissioning and RWM funding system.

In France, the discounted values of future decommissioning and RWM liabilities have to be entirely held by nuclear operators in the form of "dedicated assets", which are strictly earmarked as well as inalienable – even in the case of an operator's bankruptcy. Funding adequacy is reviewed every six months by licensees and every year by the administrative authority, while the dedicated assets are reported on a quarterly basis. In this context, the issue of SNF reprocessing requires a more differentiated approach when assessing long-term liabilities and current expenditures in accounting terms. Further, the cost estimation methodologies are reviewed every year for EDF. With the nuclear operators owned to large extend by the French state, they have rather comprehensive responsibilities regarding the estimates of their future liabilities for decommissioning and RWM.

Despite the allocation of all responsibilities to finance all costs of decommissioning and RWM to nuclear operators, the structure of industrial ownership might imply a certain degree of public liability to ensure the continuity of funding streams in case of the long-term unprofitability or bankruptcy of a nuclear operator. Indeed, the specific ownership constellation in the French nuclear energy scheme, especially in the case of EDF, might raise questions as to whether a potential failure of the operators to provide adequate funding would not also imply a liability of the French state in the first (e.g. for EDF and Orano) or second degree (e.g. for Framatome). While the large role of the French government provides added security with respect to the adequacy of funding in case of need, it thus also imposes on all parties to be particularly rigorous with regard to transparency. In this regard, the OECD's latest economic survey of France has also highlighted the path forward by recalling how "the ASN underlined [in 2017] that the information provided by EDF is not complete enough for a fair assessment of its financial provisions for decommissioning and long-term waste management (…), suggesting that efforts are needed to improve the transparency of the adequacy of the provisions for decommissioning and long-term RWM" (OECD, 2019: p. 180).

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 10

Germany: Country case study

KEY FACTS	
Funding model	One public external fund for RWM and individual internal provisions for decommissioning.
Assets	RWM Fund: • EUR 23.58 billion (USD 27.83 billion) Internal Provisions for decommissioning: • EUR 21.9 billion (USD 25.8 billion) of which: - EUR 5.4 billion (USD 6.4 billion) (RWE) - EUR 5.0 billion (USD 5.9 billion) (EnBW) - EUR 9.4 billion (USD 11.1 billion) (E.ON) - EUR 1.7 billion (USD 2.0 billion) (Vattenfall) - EUR 0.4 billion (USD 0.5 billion) (Stadtwerke München)
Liabilities	• EUR 38.5 billion (USD 45.45 billion) (based on undiscounted costs of EUR 47.5 billion at 2014 price-level, 1.6% general inflation rate, 1.97% nuclear-specific inflation rate and 4.58% discount rate, WKGT).
Avg. effective real return	• RWM Fund: 6.2% (07.2017-07.2019, KENFO, 2019b)
Discount rate	• 4.58% (average rate used by the main nuclear operators for disposal and decommissioning liabilities before the Act Reorganizing Responsibility for Nuclear Waste Management of December 2016, WKGT, 2015: p. 9) • 0.4% to 1% (individual rates used for decommissioning liabilities only after the Act Reorganizing Responsibility for Nuclear Waste Management of December 2016; RWE 2019, EnBW 2019, E.ON 2019, Vattenfall 2019, Stadtwerke München 2019).
Assumed operational lifetime of nuclear power plants	Final shutdown of all commercial reactors mandated by the end of 2022.
Investment rules	No investments in businesses operating nuclear reactors or owning entities that run nuclear reactors. Investments only in businesses in line with the UN Global Compact.
Evaluation of fund adequacy	Yearly reports of provisions made by the nuclear operators for decommissioning costs with subsequent assessment by Federal authority. One single evaluation of funding adequacy for RWM in 2015 prior to the Reorganization Act.

Issues at stake	• In 2011, the decision to ultimately phase out of nuclear energy until the end of 2022 at the latest, following the Fukushima Daiichi accident. Eight reactors permanently shut down in the same year. • Split of responsibility between decommissioning and long-term RWM, the former to be borne by the nuclear operators, the latter entirely transferred to the state under the condition of a one-off payment by the nuclear operators. • Reimbursement of nuclear operators for investments made shortly before the phase-out decision of 2011 and for tax payments made subsequently, following lawsuits between the government and the operators.

Decommissioning and RWM in Germany

Due to its "Atomausstieg", decided on in 2011 and foreseeing a total nuclear phase-out by 2022, Germany's handling of decommissioning and RWM is closely watched and will likely serve as a benchmark for other countries regarding their own decommissioning and RWM schemes.

The organisation of financial liabilities in the German decommissioning and RWM scheme was subject to profound changes following the decision to implement the "*Atomausstieg*" in 2011. A reassessment process of the funding system for decommissioning and RWM, including the set-up of a Federal Cabinet Commission to Review the Financing for the Phase-out of Nuclear Energy (KFK), was run in 2015. It included a "Stress Test" audit that was requested by the German Federal Ministry for Economic Affairs and Energy in order to assess the overall back-end costs and provisions associated with each nuclear power plant (further referred to as "WKGT 2015"). The process resulted in the Act Reorganizing Responsibility for Nuclear Waste Management, adopted in December 2016 and entered into force in June 2017. The Act re-allocates responsibilities for decommissioning and liabilities for RWM between nuclear power plant operators and the state. The liability for the management and financing of decommissioning, including the packing of radioactive waste, remains entirely with the nuclear power plant operators. In order to respond to the funding needs in this regard, they hold internal provisions (WNA 2017). The liability for the management and financing of storage and disposal of radioactive waste was instead entirely transferred to the German Federal Republic. The transfer of liabilities was accompanied by a one-off payment of USD 30.12 billion by the nuclear operators, used by the federal government to establish the Fund for the Financing of Nuclear Waste Disposal (KENFO), an external public fund.

Germany has a rather decentralised infrastructure and management system regarding decommissioning and radioactive waste. There are four central storage facilities: 1) the Gorleben storage facility, hosting mostly vitrified waste from reprocessing and SNF elements in dual purpose casks; 2) the central storage facility Ahaus, accommodating SNF mostly from research and prototype and demonstration reactors; 3) the storage facility North, hosting and treating different kinds of radioactive waste, including SNF; and 4) the AVR cask storage facility in Jülich, accommodating the spent fuel spheres from the operation of the AVR in 152 transport and storage casks of the CASTOR® THTR/AVR type. Next to the central storage facilities, there are 12 decentralised on-site storage facilities that host SNF elements arising from nuclear power plant operation. The on-site storage facilities are permitted to operate for 40 years, accommodating waste up to an individually licensed capacity ranging from 200 to 1 850 tons of heavy metal. Further, 11 Land collecting facilities exist, where waste from medical use, research and industry is collected. Finally, Germany has a final disposal facility for low- and medium-level radioactive waste, "Konrad", which is currently under construction and expected to be operational from 2027. The Morsleben repository and the Asse II mine, two final repositories for low- and medium-level waste that were operated between the 1960s and the 1990s, are to be decommissioned in the near future due to complications in the storage process (BMU 2019; World Nuclear Association 2019). Preceding decommissioning, the radioactive waste emplaced in the Asse II mine will be retrieved unless the execution of the retrieval is deemed unjustifiable due to the radiological impacts on workers and the public or other safety-relevant reasons. This highly decentralised storage scheme raises questions of economic efficiency, as the costs to sustain it might be higher than for a centralised scheme.

Regarding the final disposal of HLW, the German legislation foresees a three-level process in order to identify a suitable location for a future deep geological repository (DGR). Currently, Germany is in the first of three phases, determining siting regions for the surface exploration. The second phase consists of the exploration of the surface and a proposal for underground exploration, while the third phase includes the underground exploration, a siting proposal and the final decision on the site. After each of the three phases, the responsible Federal Company for Radioactive Waste Disposal (BGE) will present its proposals for evaluation to the Federal Office for the Safety of Nuclear Waste Management (BASE). A parliamentary decision concludes each phase (BMU, 2019).

Despite this multi-level procedure, the federal government is striving for a decision on the DGR site selection for 2031, while the operation of the disposal facility is estimated to start by 2050 (KFK, 2016). In 2016, a commission of the German Bundestag on the storage of high-level nuclear waste concluded however that the 2050 goal might be difficult to attain (Kommission Lagerung hoch radioaktiver Abfallstoffe, 2016).

The policy approach to nuclear energy in Germany was highly volatile over the last decades. In 2001, the German government first introduced lifetime limits for each of the 19 nuclear reactors operating at that time, in form of an overall limit of 2.62 million TWh of energy produced, which corresponds to an average lifetime of about 32 years. In 2010, a newly elected government decided to grant additional lifetime extensions of eight years for reactors that were constructed before 1980 and a lifetime prolongation of 14 years for those reactors constructed after 1980, relative to the lifetime limits agreed on in 2001. Contemporaneously with the lifetime extension, a nuclear fuel tax of USD 181 per gram of fissile fuel was agreed. In 2011, however, the Fukushima Daiichi accident caused the government to prompt the immediate and permanent shutdown of eight nuclear reactors, as well as the ultimate phase-out of nuclear energy by 31 December 2022 at the latest (WNA, 2019).

Currently, six nuclear reactors are still operating in Germany, which contributed for 13.8% of the net electricity generation in Germany in 2019 (Fraunhofer ISE, 2020). Philippsburg 2 was shut down at the end of 2019, while three reactors are anticipated to be shut down in 2021 and 2022, respectively. Following the German Atomic Energy Act, they will be shut down once they have reached their individual prescribed maximum volume of electricity production, but not later than their respective scheduled shutdown date. The remaining permitted electricity production volume for the six reactors ranged between 5.50 and 30.27 TWh with a total of 93.2 TWh at the end of 2019 (BASE, 2020). Between 2017 and 2019, nine licenses for the decommissioning of nuclear reactors were granted, regarding mainly the reactors that were shut down in 2011. Together with three research reactors that are currently waiting for a decommissioning licence and five research reactors that are under decommission, Germany faces large efforts in decommissioning and RWM in the close future (BMU, 2019). The way Germany handles the phasing-out of nuclear energy and the removal of its nuclear capacities will serve as an important example in the management of decommissioning and radioactive waste, in particular their financial resolution.

Following the Fukushima Daiichi nuclear accident, the German legislature decided to accelerate the phase-out of nuclear energy and to immediately shut down eight reactors. The nuclear operators filed constitutional complaints against the government's amendment of the Nuclear Energy Act. In its judgement, the Federal Constitutional Court found the 13th Act Amending the Atomic Energy Act to be compatible with constitutional law, except for two marginal areas that required adjustment on account of Article 14 Para. 1 of the Basic Law (freedom of property). With regard to the first area, the Federal Constitutional Court found the 13th Act Amending the Atomic Energy Act to be incompatible with Article 14 Para. 1 insofar as it does not provide for appropriate settlement for investments that had been made in legitimate expectation of the additional residual electricity volumes allocated in 2010 by means of the 11th Act Amending the Atomic Energy Act (lifetime extension), but were devalued by the revocation of these additional volumes by the 13th Act Amending the Atomic Energy Act. With regard to the second area, the Federal Constitutional Court found the 13th Act Amending the Atomic Energy Act to be incompatible with Article 14 Para. 1 insofar as it does not provide for appropriate settlement for residual electricity volumes that were allocated to the Brunsbüttel, Krümmel and Mülheim-Kärlich nuclear power plants under the 2002 Phase-out Act and cannot be produced otherwise within the same group of companies by 31 December 2022. Further, the operators in separate claims demanded the reimbursement of taxes payed on nuclear fuel until 2016. The German Federal Constitutional Court ruled in June 2017 that the taxes on nuclear fuel paid between 2011 and 2016 were formally unconstitutional and void, leading to the reimbursement of USD 7.8 billion plus interest to E.ON, RWE and EnBW.

The funding system

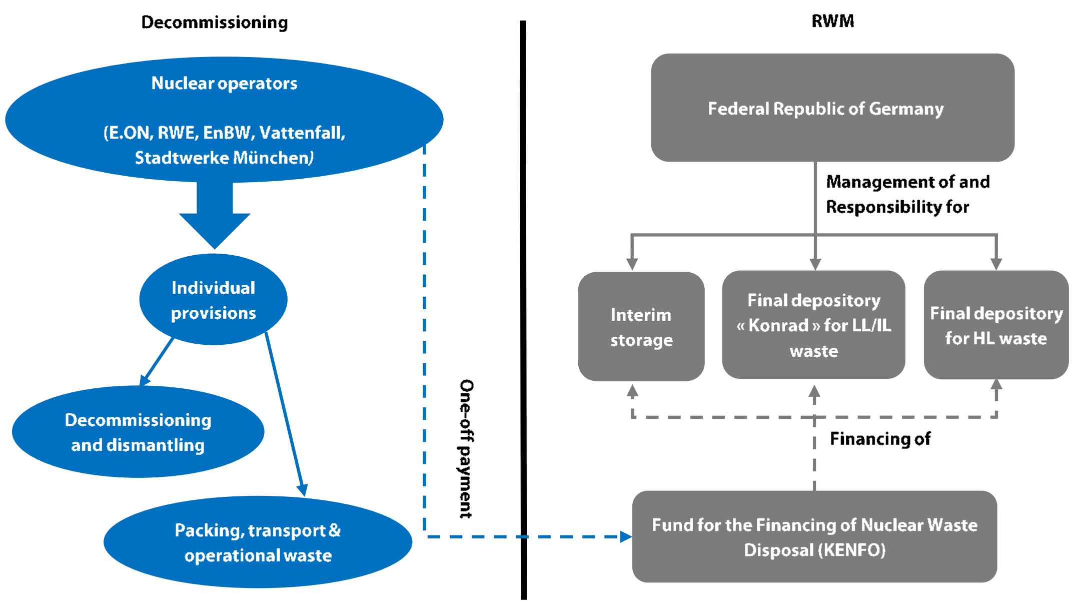
Historically, the general underlying principle in the German decommissioning and RWM system was to hold nuclear operators, i.e. owners or shareholders of nuclear reactors, liable for the follow-up costs associated with the operation of nuclear power plants, such as the decommissioning of installations and the treatment, as well as disposal of radioactive waste, including SNF (IEA, 2013). To that end, nuclear operators were also responsible for the current and future costs for the procedure selecting a repository site. Until the implementation of the 2016 Reorganization Act, the nuclear operators held internal provisions for this purpose under their autonomous supervision and in accordance with the German Commercial Code (HGB). Following the HGB, all companies had to classify provisions for nuclear assets retirement as liabilities in their balances of accounts, which had to be held available in adequate amounts (BMU, 2015a). In accordance with international accounting standards, the internal provisions to cover the costs for decommissioning and RWM had to be accounted separately (EC, 2013).

With the implementation of the 2016 Reorganization Act, the above responsibilities were changed. Management and financial liabilities of the decommissioning and dismantling of nuclear power plants and of packaging the nuclear waste continues to lie entirely with the nuclear power plant operators but the financial responsibility for interim and final storage is transferred to the government. This includes the operation of interim storage facilities and the search for a DGR. In exchange for the transfer of responsibilities, the nuclear operators had to pay a one-off fee to finance a newly established, public and external fund, the KENFO, on 3 July 2017 to comply with the Polluter Pays Principle. The amount payed into the fund by the nuclear operators amounted to EUR 24.1 billion (USD 28.5 billion) and included a base amount, corresponding to the internal provisions for RWM accrued by the companies, of EUR 17.93 billion (USD 21.17 billion), as well as a 35.47% surcharge in order to cover for any uncertainties on the cost side (WNA, 2017). Only by paying the entire sum, including the uncertainty margin, could the operators avoid paying any subsequent charges that might potentially arise due to an insufficiency in funding assets (BMU, 2019). All nuclear operators settled their liabilities to the fund in 2017, resulting in the ultimate transfer of all further financial and operational liabilities for RWM to the Federal Republic (KENFO, 2019a). The KENFO fund is supposed to reimburse the Federal Republic for all expenses related to waste disposal, including the costs for interim storage and final disposal, as well as any other measures in accordance with the Disposal Transition Act, the Site Selection Act and the Atomic Energy Act (Figure 10.1). The fund is excluded from tax duties and no borrowing from the fund or contributions to the fund from the federal budget are permitted. Accordingly, nuclear operators settled all their financial liabilities, despite the transfer of responsibilities to the German state. The fund bears its own administrative costs and is supervised by a Board of Trustees that decides on all fundamental questions arising with the fulfilment of the fund's purpose. The Board of Trustees consists of representatives of the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry of Finance (BMF), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), as well as members of the German Bundestag (Disposal Fund Act, §4 and §6).

The financial liability for costs arising in the context of the management of the shutdown of nuclear power plants and their decommissioning, including the packing of radioactive waste, will continue to lie entirely with the nuclear operators Figure 10.1) as will the task itself. As indicated, all five nuclear operators hold provisions to that end in their financial resources. If a nuclear company's payment obligations regarding nuclear power plant decommissioning can no longer be incurred or imposed on the company because it has ceased to be a legal entity, payment obligations may be imposed on a controlling company, or any personally liable shareholder of a nuclear company. Turning to a controlling company presupposes a serious and definitive refusal to pay by a nuclear company, its cessation of payment, impending insolvency, insolvency or over-indebtedness, or other special circumstances (2017 Act on Extended Liability, §1). Through these measures, the liability regarding the costs of decommissioning is effectively allocated to the industry. In order to supervise the sufficient allocation of resources for the purpose of decommissioning by the industry, the nuclear operators are obliged – according to the Transparency Act – to report every year the provisions they made for the decommissioning and dismantling of their nuclear power plants as well as for the correct packing of radioactive waste to the Federal Office for Economic Affairs and Export Control (BAFA).

BAFA assesses the correctness of the provisions held for decommissioning. The findings of BAFA constitute the basis for the report the federal government has to submit to the Parliament by 30 November of each year (Bundestag, 2018 and 2019). At the end of 2017, the provisions held by the nuclear operators to finance their decommissioning liabilities amounted to around EUR 21 billion (USD 24.79 billion). By the end of 2018, the provisions held by the nuclear operators to finance their decommissioning liabilities amounted to around EUR 21.9 billion (USD 25.86 billion).

Figure 10.1:
German funding scheme for decommissioning and RWM following the 2016 Reorganisation Act



The clear separation between long-term liabilities, arising in the context of RWM, and shorter-termed liabilities, occurring in relation with decommissioning, makes the German system particularly interesting. While the short-term liabilities are understandably allocated to the nuclear operators, the acquisition of the long-term RWM liabilities by the Federal Republic underlines the inalienability of the long-term responsibility arising in the context of RWM. By embracing this responsibility, the German state ensures a sustainable management of all aspects of its RWM scheme, all the while respecting the guidelines set out in the Polluter Pays Principle.

The cost side

The German nuclear operators were fully responsible for drawing up and updating their entire back-end cost estimates before the transfer of liabilities to the government. Today, this responsibility includes especially their decommissioning costs. Yet operators only present aggregated cost figures in their annual financial statements, which gives little information on the cost estimation methodologies used by these companies. BAFA, however, assesses the provisions reported by the operators every year and on this basis, the federal government delivers annually a report on the provisions for decommissioning and dismantling costs to Parliament. It has been highlighted previously that the estimates of decommissioning costs by the German commercial nuclear power plants were not public (see, for instance, WU, 2007). During the reassessment process of the funding system for decommissioning and RWM in 2015, a "Stress Test" audit was requested by the German Federal Ministry for Economic Affairs and Energy in order to assess the overall back-end costs and provisions for each nuclear power plant. The audit was drawn by the Warth & Klein Grant Thornton (WKGT) audit firm and, in the federal administration's own terms, represented "*the first [audit] to provide the general public with a transparent breakdown of the expected costs across five different categories (from dismantling to final storage)*. *The EUR 38.3 billion [USD 45.22 billion] in provisions made by the companies concerned are based on cost estimations of around EUR 47.5 billion [USD 56.1 billion] in current prices*" (BMWi 2015). The 2015 WKGT report reassessed the cost estimates made by the industry and confirmed their appropriate calculation method. Only marginal differences arose between the cost estimates issued by the industry and the revised estimates by the WKGT report (Table 10.1). The revised cost estimates in Table 10.1 were later used as the base amounts for calculating the one-off payment accompanying the transfer of RWM responsibilities.[1]

Table 10.1:
Disposal cost estimation (price-level 2014), industry estimates and WKGT 2015 reassessment

Disposal costs (2014 price-level)	Industry estimates Mio. EUR (USD)	Revised WKGT 2015 etimates Mio. EUR (USD)
a. Decommissioning and dismantling	19 614 (23 157)	19 719 (23 281)
b. Packing, transport and operational waste	10 252 (12 104)	9 915 (11 706)
c. Interim storage	5 653 (6 674)	5 823 (6 875)
d. Final depository "Konrad" for LL/IL waste	3 824 (4 515)	3 75 (4 427)
e. Final depository for HL waste	8 109 (9 574)	8 321 (9 824)
Sum	47 451 (56 022)	47 527 (56 112)

Source: WKGT, 2015: p. 8.

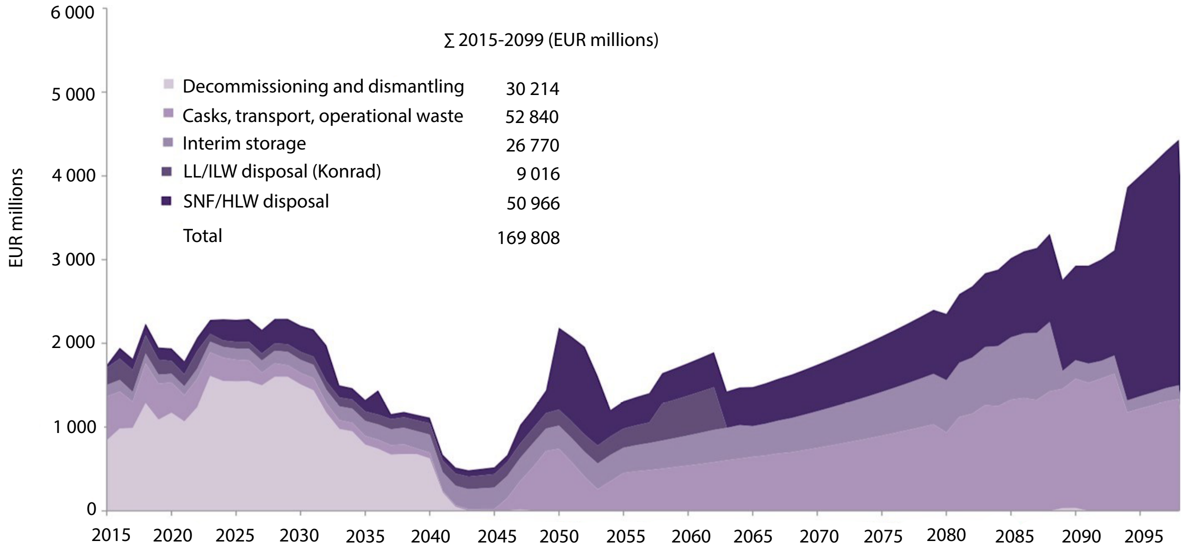
The costs related to commercial nuclear power plants were calculated following plant-specific assumptions, while estimates of RWM costs were based on existing contracts with storage facilities, taking into account the costs of future disposal obligations from 2015 until 2099, the assumed span of RWM obligations in the estimates (WKGT, 2015). For each nuclear power plant, the costs of dismantling, decontamination and demolition were customarily estimated through specifically developed software analysis, which relied on deterministic budgetary cost estimates for generic reactor models, on integration of decommissioning experience, and on integration of site-specific parameters. The cost estimates included the following items: a) decommissioning and dismantling of nuclear power plants; b) packing of SNF elements, HLW from reprocessing, and other LL/IL-waste; c) containers required for interim storage and final disposal; d) interim storage; f) final disposal in the "Konrad" repository; g) final disposal of SNF elements and HL-waste in a dedicated repository, including research and the site selection process (KFK, 2016).

The 2015 WKGT report indicated that, to determine the 2014 value of the future expenses associated with decommissioning and RWM, the nuclear companies used different discount rates varying between 4.0% and 4.8% in their accounting (notably 4.7% for E.ON, 4.6% for RWE, 4.8% for EnBW and 4.0% for Vattenfall), which corresponded to a present value weighted average interest rate of 4.58%. These interest rates were based on the average yields on long-term German government bonds over different timespans (WKGT, 2015, p. 9). The retained inflation rate was 1.6% and a nuclear-specific inflation rate of 1.97% was taken into account on top of the inflation rate. These parameters resulted in an estimated total cost figure of nominal EUR 38.5 billion (USD 45.45 billion) with a 4.58%

1. The numbers in Table 10.1 correspond to the undiscounted costs at 2014 prices. However, these expenditures will fall due in future years. The discounted total costs over the full period of decommissioning and radioactive waste management, which include a 1.6% general inflation rate, a 1.97% nuclear-specific inflation rate and a 4.58% discount rate, correspond to the EUR 38.48 billion that constitute the actuarial value of the liabilities that needed to be matched by corresponding assets by the nuclear operators.

average interest rate (WKGT 2015: 67, §254–5). This translates into total liabilities of around EUR169.81 billion (USD 200.48 billion) between 2015 and 2099, of which EUR 83.05 billion (USD 98.05 billion) for decommissioning duties and EUR 86.75 billion (EUR 102.42 billion) for RWM (Figure 10.2).

Figure 10.2:
German nuclear companies' forecast of yearly decommissioning and RWM expenses (2015-2099) in millions of euros



Source: Text adapted from WKGT, 2015: p. 57.

Following the 2016 Reorganisation Act and the settlement of funding liabilities to the KENFO fund, the nuclear operators were only responsible for the financing of the expenses listed in sections a and b of Table 10.1. Based on their financial reports, the scope of cost estimates issued by the nuclear operators includes:

a) a several-year post-operation phase, including the removal of fuel assemblies, operational waste and operational equipment;
b) dismantling, including of the facility, removal of radioactive contamination from the structures and radiation protection;
c) conditioning and packaging of radioactive waste; and
d) transportation of waste to the storage facilities (E.ON, 2016, 2019; RWE, 2017, 2019; Vattenfall, 2019).

The discount rates used by the nuclear operators for the estimations of provisions to be held for decommission costs were significantly adjusted downwards towards market rates following the 2016 Reorganisation Act and amounted to 0.59% (EnBW), 1% (Vattenfall) and 0.4% (RWE and E.ON) (see E.ON, 2016, 2019; RWE 2017, 2019 and Vattenfall, 2019).

The application of these recent and substantially lower discount rates, compared to those applied in 2014 and observed in the WKGT report (4.0-4.8%), indicates a substantial change in assumptions by the nuclear operators. A certain change in the discount rate applied would appear coherent in view of the remaining decommissioning liabilities and the shorter timeframe over which they are likely to accrue (Figure 10.2). However, the sharp decline in applied discount rates after the segregation of liabilities remains remarkable. The sudden and significant change points toward the large potential differences between the market-based discount rate used by private operators for their decommissioning liabilities and the discount rates used to assess the costs for future RWM that inevitably are closer to politically relevant social discount rates. It also shows that the WKGT audit adopted an accountability perspective rather than an economic one.

Assets, investment rules and performance

As of 31 December 2018, the total assets of the KENFO fund amounted to EUR 23.58 billion (USD 27.83 billion), of which some EUR 4.33 billion (USD 5.11 billion) were already invested. The share of the invested assets reached around 40%, or EUR 9.1 billion (USD 10.74 billion), in mid-2019 and 50.9% by the end of 2019. The average return for the invested capital amounted to 6.2% p.a. since the build-up of the fund in 2017. So far, the fund has transferred around EUR 460 million (USD 543 million) in total to the Federal Republic to finance actions in the context of RWM, of which EUR 181 million (USD 213.69 million) in 2018 (KENFO, 2019a, 2019b).

The federal government may prohibit concrete Fund investment projects by instruction, while the BMF may, in agreement with the BMWi and the BMU, issue the Fund's investment guidelines by means of general administrative regulations (Disposal Fund Act, §5 & §9). The guidelines can include specifications regarding the weight of asset classes, the regional orientation of new investment decisions, and the maximum amount of individual investments. Regarding accepted investment classes, the Fund's investment policies and guidelines must be in accordance with the "investment principles for security assets" laid out in §215 (2) of the German Insurance Supervision Act (Disposal Fund Act, §9). The said part of the Insurance Supervision Act sets out that security assets may only be invested in: a) loan receivables, bonds and profit-sharing rights; b) debt register claims; c) equities; d) participations; e) land and equivalent rights; and e) shares in undertakings for collective investment in transferable securities as defined in Directive 2009/65/EC, and for other investments made in accordance with the principle of risk diversification, where the undertakings are subject to effective public oversight to protect the unit-holders.

In accordance with the above outlined principles, the KENFO fund further prohibited investments in businesses operating nuclear reactors or owning entities that run nuclear reactors, as well as investments in businesses not compliant with the UN Global Compact. The current investment strategy of the fund foresees splitting the capital into three portfolios: 10% is to be invested in fixed interest bonds with a maturity of ten years; 60% is to be invested in liquid assets in form of stocks; and 30% is to be invested in illiquid assets that are not traded in stock markets, e.g. real estate or infrastructure projects (KENFO, 2019a, 2019b).

Access to detailed information regarding the nuclear companies' assets dedicated to their back-end liabilities is limited, as the assets are held and managed by the companies as internal financial provisions. Before the 2016 Reorganisation Act, the only applicable regulations regarding the investment strategies for the companies' provisions held for decommissioning were the general accounting principle of the German Commercial Code (HGB) and the international accounting standards, within the framework of which companies are free to determine the nature of their investments. As of 2017, supplementary financial reporting obligations are introduced to help public authorities assess the operator's provisions. The Transparency Act, in force since January 2017, foresees annual reports by the operators to the BAFA; on this basis, the federal government delivers a report to Parliament every year on the provisions for decommissioning and dismantling costs. Information regarding assets classes or return rates achieved by the dedicated assets was not to be found in the financial reports of the nuclear operators. The WKGT auditors, commissioned by the Federal Republic, have themselves encountered difficulties in collecting relevant data on the companies' assets:

> "… we questioned the extent to which the companies' aggregate assets are suitable for ensuring the financing of future costs. Apart from the information on the annual financial statements, we did not have any in-house information; in particular no internal planning by the companies was available." (WKGT, 2015: p. 78).

Conclusion

Given the number of reactors to be shut down as a result of the nuclear phase-out decision, Germany will face large projects in decommissioning and RWM. The way those are handled will likely be closely followed by the international community. The German system for decommissioning and RWM is based on an approach of segregated responsibilities regarding decommissioning and RWM. The changes imposed by the 2011 decision as a consequence of the Fukushima Daiichi accident have since 2016 resulted in a remarkable split between the shorter-term decommissioning responsibilities and the long-term RWM responsibilities. The former are borne by the nuclear operators, the latter by the Federal Republic, with initial funding through the nuclear operators. This involved the transfer of EUR 24.1 billion (USD 28.45 billion) from the nuclear operators to the nuclear waste fund overseen by the government. This amount is composed of a base amount, corresponding to internal provisions for RWM worth EUR 17.93 billion (USD 21.17 billion) accrued by the companies under the former financing system, as well as a 35.47% surcharge in order to cover potential uncertainties. Through this scheme, the German state ensures that the financing and all juridical and administrative aspects of RWM are handled under the same roof, while still respecting the guidelines set out in the Polluter Pays Principle. Regarding the management of provisions for decommissioning, the nuclear operators remain individually liable.

The storage system for nuclear waste in Germany is rather decentralised, consisting in a multitude of storage facilities and a disposal facility for LL/IL-radioactive waste that is currently under construction and expected to be operational from 2027. The new German approach for a final DGR is based on a three-phase evaluation system. A final DGR is expected to be selected by 2031 and to be operational by 2050.

The 2011 decision to immediately shut down several nuclear reactors resulted in lawsuits against the government and eventually in reimbursements for the nuclear operators for their investments in nuclear reactors between 2010 and 2011 and taxes paid on nuclear fuel until 2016. While the nuclear phase-out is posing challenges both for operators as well as for the electricity system at large, the financing of the back-end of the fuel cycle with a clear-cut separation of private shorter-term liabilities and public longer-term liabilities has provided transparent and stable framework conditions for both public and private stakeholders.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 11

Japan: Country case study

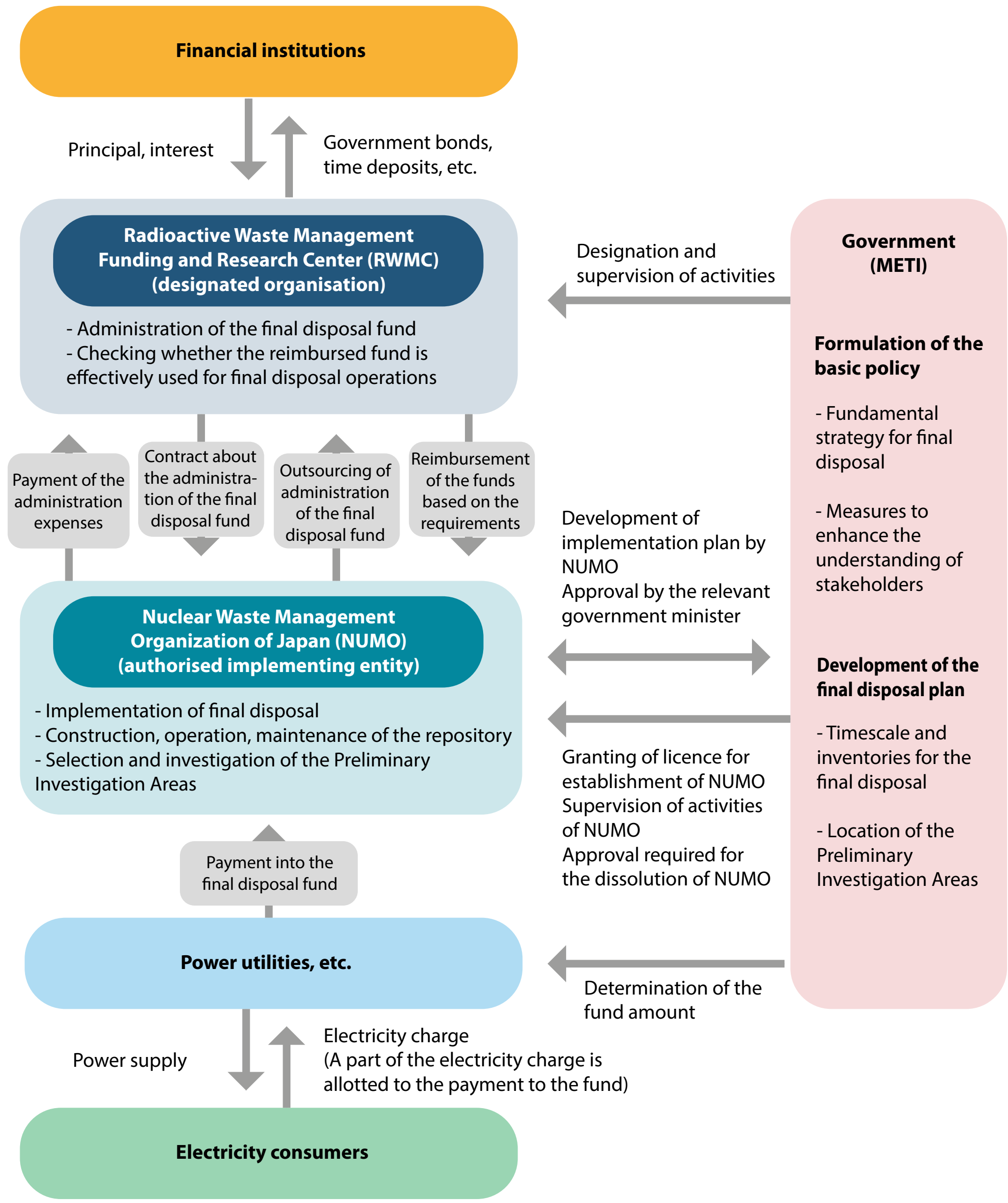
KEY FACTS	
Funding model	Internal funds for decommissioning, external segregated funds for SNF reprocessing and RWM.
Assets	• SNF Reprocessing: USD 13.67 billion (2019) • RWM: USD 10.34 billion (2019)
Liabilities	• Geological disposal: USD 34.09 billion (2019)
Avg. effective real return	• 0.64% (2019)
Discount rate	• 0.4% (2019)
Assumed operational lifetime of nuclear power plants	40 years with possibility for extension to 60 years
Investment rules	RWM (final disposal of HLW) and SNF funds' investments strictly limited to "safe assets", e.g. Japanese Government Bonds.
Evaluation of fund adequacy	Annual recalculation of funding liabilities and according fees to be collected for all funds.
Issues at stake	• Introduction of a complementary funding system dedicated to finance reactors affected by accidents. Currently only applicable to the operator of the Fukushima reactors.

Decommissioning and RWM in Japan

Japan has a relatively recent but well-developed funding system in place to finance future liabilities for decommissioning and RWM, including advanced plans for a future final deep geological repository (DGR). The DGR shall host Japan's HLW at a depth of at least 300 metres (NUMO, 2018). In selecting a final disposal site, the responsible Nuclear Waste Management Organisation of Japan (NUMO) shall follow a three-step procedure, consisting of the selection of a preliminary survey site based on the results of a literature survey on geological disturbances caused by earthquakes or other natural phenomena, a number of tests at that site to determine the stability of the geological stratum, and the final selection of a site where the disposal facilities are to be constructed. Before a decision on the site selection is finalised, the Ministry of Economy, Trade and Industry (METI) is to review the final disposal plan, considering the position of the local government where the site is to be located (NEA, 2017). For the time being, Japan possesses one centralised interim storage facility for HLW at Rokkasho, while SNF is interim-stored at 18 nuclear power plants, as well as at different SNF interim storage facilities throughout Japan (WNA, 2019b).

In the Japanese funding system, nuclear operators are to pay for the totality of the costs for decommissioning, SNF reprocessing and final disposal of radioactive waste. To that end, nuclear operators have to pay respective fees into the funds for SNF reprocessing and final disposal of radioactive waste, while allocating a prior-defined annual sum in internal funds to cover future decommissioning liabilities. Nuclear operators finance the funding streams from their operational profits, meaning that in practice a fee is levied on the electricity bill for the systematic accumulation of funds.

Figure 11.1:
Overview of the funding scheme for RWM in Japan



Source: RWMC, 2019a: p. 7.

In Japan, the funding scheme for decommissioning and RWM consists of three independent funding streams. To cover their costs for decommissioning, nuclear operators have to hold internal funds that are accounted for on their balance sheets and their adequacy are supervised by the METI. The regulations regarding the legal operational lifetimes of nuclear reactors in Japan have recently changed, decreasing the time over which nuclear operators can build up the necessary funds to cover their decommissioning duties from 50 to 40 years. Consequently, the regulators have also adapted the rules for fund collection in order to allow nuclear operators to compensate potential shortfalls that would otherwise arise from earlier shutdown dates. Future liabilities for RWM in Japan are covered by a dedicated external Final Disposal Fund, which is accumulated by NUMO and managed by the Radioactive Waste Management Funding and Research Center (RWMC) under the supervision of the METI (Figure 11.1). Finally, a third funding stream is in place to finance the reprocessing of spent nuclear fuel, as part of Japan's fuel recycling strategy. To that end, an external SNF reprocessing fund under the management of the Nuclear Reprocessing Organization of Japan (NURO) exists.

Currently, there are 37 reactors operable in Japan, of which 17 are in the process of restart approval (WNA, 2019a). Until 2011, Japan generated some 30% of its electricity from its nuclear reactors. This was expected to increase to at least 40% by 2017. Following the Fukushima Daiichi accident, the outlook was adapted and is now for two-thirds of this, from a depleted fleet. In April 2015, the government announced that it wanted base-load sources to return to providing 60% of the power by 2030, with about one-third of this being nuclear (WNA, 2019a). The first two reactors, Sendai 1&2, restarted their operations in the second half of 2015. The International Energy Agency's (IEA) 2015 Long-term Energy Supply and Demand Outlook envisions nuclear power providing 20% to 22% of the country's total electricity output by 2030. Although this target is lower than the policy before the Fukushima Daiichi nuclear accident, it reflects the important role of nuclear power in Japan, for both securing energy supply and limiting carbon emissions over the long term (IEA, 2016).

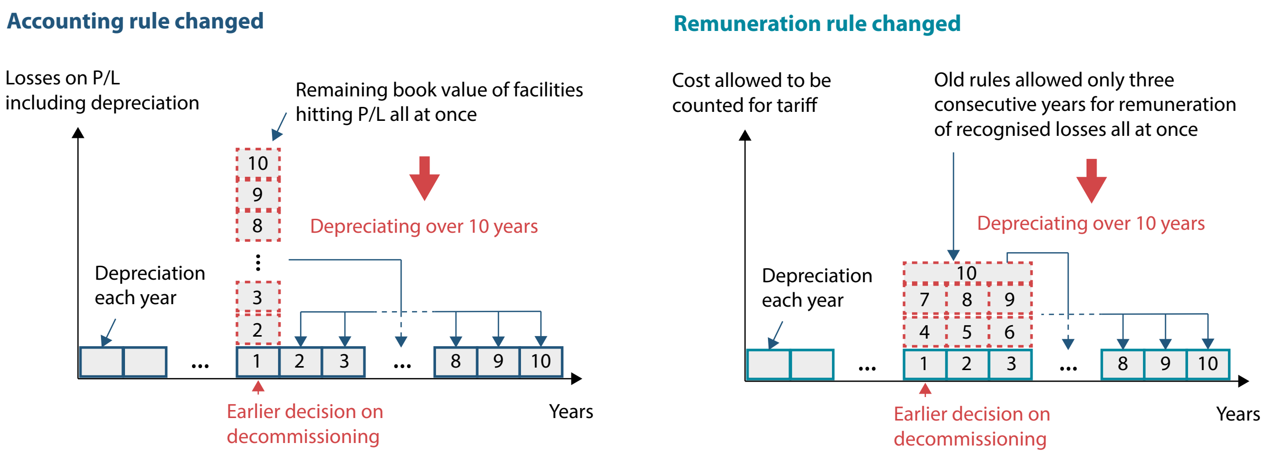
As a consequence of the 2011 Fukushima Daiichi accident, the concerned nuclear operator TEPCO HD is assigned to pay the entirety of the costs for decommissioning of the nuclear power plant's six accident-affected reactors. The Japanese government supports TEPCO HD with different measures such as the introduction of a special funding scheme to finance decommissioning of accident-damaged reactors, and by investing USD 2.17 billion in R&D (METI, 2017e). As part of the special funding scheme for accident-affected reactors, the accident-affected nuclear operators reserve the amount of funds approved by the METI under the management of the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) to implement decommissioning appropriately. The NDF is an entity that is jointly financed by the Japanese government and nuclear operators.

The funding system

The Japanese legislation applicable to the management of radioactive waste resulting from nuclear reactor operation is the 1957-166 Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (Reactor Regulation Act). The Japanese government establishes the basic policies and direction regarding final radioactive waste disposal via its Ministry of Economy, Trade and Industry. In particular, the METI defines the country's final disposal plan, including timing and quantities of waste to be disposed of. Further, it authorises and supervises bodies for the implementation of the final disposal plan and the management of the according funds. The 2000-117 Designated Radioactive Waste Final Disposal Act defines the geological disposal of radioactive waste as the country's final disposal strategy. To apply for a licence to engage in RWM activities, an application may be submitted to the Nuclear Regulation Authority (NRA), as set out in Article 51-2 of the Reactor Regulation Act. The licence authorises the interim storage of radioactive waste and its final disposal in deep geological layers. Regarding HLW, Japan plans to build a DGR under state supervision and has set up several R&D programmes in this direction. NUMO is responsible for the development of Japan's HLW DGR and was established in 2000, supervised by METI (EUJCIC, 2016). It is entrusted with the entire implementation of the final disposal strategy for HLW, including responsibilities ranging from the selection of a DGR and the relevant preliminary investigations, to the post-closure management of the disposal facility.

The funding strategies of Japanese nuclear operators are based on the originally defined lifetimes of nuclear power plants. Due to the introduction of an approval system for the extension of operational lifetimes for nuclear reactors by the 2012 Supplementary Provisions of the Act for Establishment of the Nuclear Regulation Authority, some nuclear operators had to make decisions on the shutdown date of their facilities earlier than expected. Early shutdown has a significant impact on the operators' balance sheets, as the value of the facilities related with nuclear reactors is large and there is a risk of potential depreciation. To encourage operators to consider the possibility of earlier shutdown and decommissioning, the Japanese government has introduced new accounting rules, allowing nuclear operators that decide to shut down their facility earlier than planned to depreciate the remaining book value of the facilities over about ten years. Besides, new remuneration rules allow nuclear operators to have ten consecutive years for remuneration of recognised losses all at once (Figure 11.2) (Shimazu METI, 2016). The introduction of this measure underlines the sensitivity of nuclear operators' balance sheets and potentially market values to changes in the lifetimes of nuclear power plants as well as to the regulatory framework for decommissioning and RWM. The dependence of nuclear operators on stable and sustainable regulatory framework conditions in order to operate in a profitable manner emphasises the need to carefully consider changes in the framework conditions and to co-ordinate those, where possible, with the elementary economic requirements.

Figure 11.2:
Changes introduced in the funding schedule by the measures taken to ensure the earlier collect of funds for decommissioning



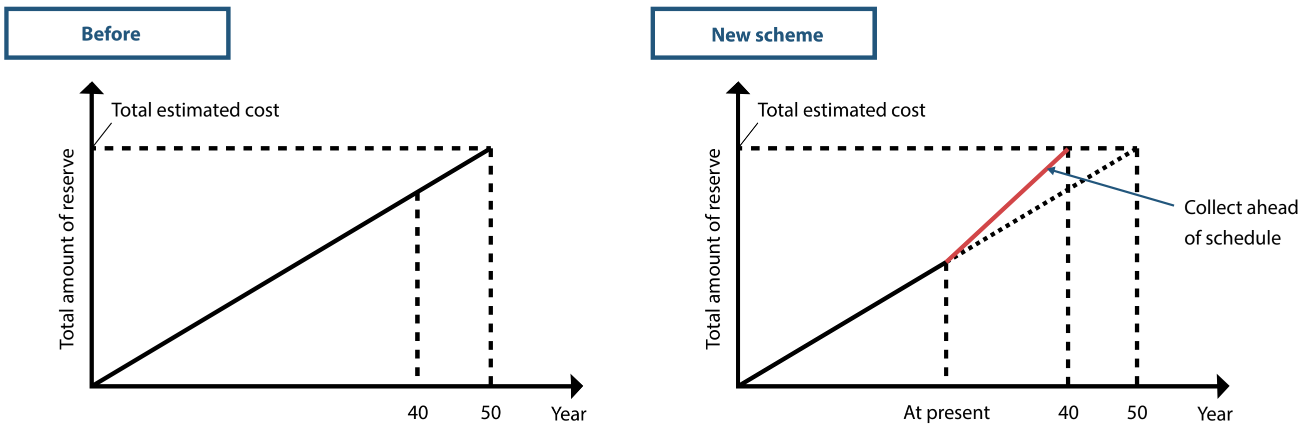
Source: METI, 2017b: p. 25 (Text translated).

Post-Fukushima liberalisation of entry to the electricity retail business

After the Fukushima Daiichi accident, the structures of the Japanese electricity market were changed profoundly. As a result, market barriers for enrolling in the retail electricity business were removed in April 2017. Before, large utilities, most of them also nuclear operators, were able to conserve the profits generated from the retail business. Accordingly, they were able to easily include the cost of decommissioning in the price of electricity. Following the regulatory changes, nuclear operators have to finance future decommissioning costs entirely from the profits earned from the generation of electricity. The full liberalisation of electricity retail sales intensified competition by creating market intersections and facilitating entries from different industries (METI, 2017a). The increased competition on the electricity market potentially aggravates the inclusion of decommissioning costs in the electricity price. As decommissioning costs are to be accumulated of the nuclear operator's current expenses, the development after the regulatory changes appears to require closer monitoring over the next few years.

In response to the accident at the Fukushima Daiichi nuclear power plant, the Reactor Regulation Act was revised by the 2012 Supplementary Provisions of the Act for Establishment of the Nuclear Regulation Authority to introduce new regulations based on lessons learned and on the availability of the latest technical knowledge. In this context, the Japanese government changed the rules for setting aside funds for decommissioning cost. Nuclear operators are now expected to accumulate the funds for decommissioning over 40 years from the start of operation, compared to 50 years before. The Japanese government has hence decided to allow utilities to accumulate assets by including costs, that were initially planned to be collected over the last ten years in the electricity price and to collect funds ahead of schedule (Figure 11.3) (METI, 2017b, free translation).

Figure 11.3:
Changes in the funding schedule caused by the measures taken to ensure the earlier collect of funds for decommissioning



Before the government implemented the reform, the total estimated cost was to be collected over 50 years, and utilities were not allowed to include the cost of the last 10 years in the present price, although some of the reactors might have been shut down at 40 years.

After the reform, utilities are allowed to include the cost that was to be collected in the last 10 years. On the other hand, once the application for a lifetime extension is approved by the Japanese NRA, utilities can extend the pay-back period from 40 years to 60 years.

Source: METI, 2017b: p. 25 (free translation).

Nuclear operators in Japan make annual payments to NUMO, which manages the final disposal of HLW in accordance with the 2000-117 Designated Radioactive Waste Final Disposal Act. The specific fee amount is determined by METI for each year. The NUMO was established in 2000 as an organisation authorised by the 2000 Final Disposal Act, with the remit to implement a project for the geological disposal of HLW. In 2002, NUMO initiated the siting process with open solicitation of volunteer host municipalities to explore the feasibility of constructing a final repository. The funding system to cover final waste disposal was enforced in 2000. Since then, NUMO has levied a fee on the electricity bill for the systematic accumulation of funds for the final disposal of radioactive waste. The Radioactive Waste Management Funding and Research Center (RWMC) is the body designated for the administrative management of the Final Disposal Fund (NEA, 2013).

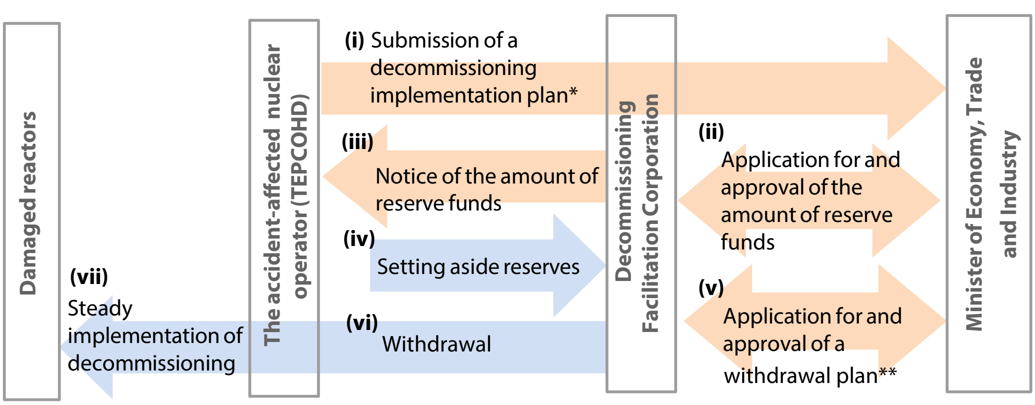
In 2016, NURO was established under an amendment to the 2005-48 Spent Nuclear Fuel Reprocessing Implementation Act. Its mission is to develop a master plan of overall nuclear reprocessing projects and to collect the contributions that are to be paid by utilities (METI, 2016b). The Act obliges nuclear operators to make annual payments to NURO for the implementation of SNF reprocessing. NURO calculates the amount of the annual payments and manages the fund for SNF reprocessing. Before the 2016 revision of the Spent Nuclear Fuel Reprocessing Implementation Act, the RWMC was responsible for the management of the fund for SNF reprocessing. The RWMC handed over the existing fund to the NURO once it was established (METI, 2016b).

A special case is constituted by the decommissioning of reactors that experienced a severe accident, such as Fukushima Daiichi. For the time being, only TEPCO HD corresponds to this case after the additional scheme was established in 2011. The 2011-94 Nuclear Damage Compensation and Decommissioning Facilitation Corporation Act enforces operators of facilities that experienced severe accidents to make additional annual payments to ensure the accumulation of the necessary financial assets to pay for the decommissioning of destroyed reactors. This can cause remarkably higher costs than for the decommissioning of accident-free reactors. The Act on the Nuclear Damage Compensation and Decommissioning Facilitation Corporation was partially revised in 2017. The bill requires accident-affected operators to reserve necessary funds, every fiscal year, to be allocated to the decommissioning of damaged reactors under the management of the NDF. It further requires those operators and the NDF to prepare the "Withdrawal Plan for Reserve Fund for Decommissioning" to ensure the completion of their decommissioning efforts. The plans must receive approval by the METI (METI, 2017a).

The NDF is an organisation established in 2011 that is approved by and 50% financed by the Japanese government. The other half of the NDF's capital is funded by nuclear operators. Initially established to finance accident compensation, the NDF's role was revised by the 2017 revision and its competence was expanded. The NDF was charged with managing the reserve fund for decommissioning costs related to reactors damaged by accidents. The NDF is responsible for determining the amount of reserve funds every year subject to approval from the METI, while the accident-affected nuclear operator is obliged to set aside the determined amount of reserve funds at the corporation (Figure 11.4). The NDF does not directly implement decommissioning. The situation in Japan shows that it is favourable to ensure a certain flexibility of the overall regulatory framework for decommissioning and RWM to leave room for manoeuvre in case of unforeseen events that fundamentally change the framework conditions for decommissioning and RWM. This recalls that long-term assumptions based on permanently stable framework conditions are to be treated with caution, particularly in view of the timeframes that are to be considered in the treatment of nuclear back-end liabilities. In particular, the Fukushima Daiichi accident shows that public-private co-operation is indispensable also with respect to financial liability for cases of nuclear accidents. While nuclear operators must prepare financially to be able to respond fully to all eventualities, certain extreme circumstances, such as nuclear accidents, inevitably bring forth discretionary decisions by public authorities. These decisions, e.g. regarding evacuation, remediation, or compensation of victims, cannot easily be spelled out ahead of time. At the same time, such decisions can affect costs by an order of magnitude or more. Some public involvement in the discretionary part of accident costs can therefore improve the sustainability of financing arrangements without releasing nuclear operators of their fundamental responsibility.

Figure 11.4:

New decommissioning financing arrangement applying to damaged reactors in Japan (currently only applying to TEPCO HD)



* Implementation plan for decommissioning: plan for concrete actions based on the Mid-and-Long-Term Roadmap.
** Withdrawal plan: formulated jointly by the accident-affected operator and Decommissioning Facilitation Corporation. It describes a multi-year funding plan.

Source: METI, 2017a: p. 9.

The cost side

Nuclear operators in Japan are obliged to estimate the amount of annual contributions to be transferred into their decommissioning funds based on an ordinance related with the Electricity Business Act (METI Ordinance 1989-30 Article 2). To do so, operators estimate the total cost of decommissioning and divide the cost in annual rates that they continue to pay throughout the operational lifetime of their facilities. After the estimation of the annual payment amount, this has to be approved by METI. In 2015, METI's Agency of Natural Resource and Energy (ANRE) revised the accounting provisions in the Electricity Business Act. After the revision, nuclear operators can now calculate decommissioning costs in instalments of up to ten years, instead of one-time as before. This enhanced cost recovery provision was meant to encourage the decommissioning of older and smaller units (WNA, 2019a).

The price for final disposal per unit of radioactive waste in Japan is clearly set out in the METI's 2000-398 Designated Radioactive Waste Final Disposal Ordinance. The Nuclear Energy Subcommittee, which is established within METI and composed of various external experts and professionals, determined in 2000 that the total cost for disposing of 40 000 units of HLW will be around USD 27.19 billion. At the same time, the subcommittee designed a function to calculate the annual payments price and concluded that the price for final disposal per unit of HLW should be around USD 333 290. In like manner, it concluded in 2008 that the price for final disposal per unit of transuranic (TRU) waste for geological disposal (some types of long-lived, low heat generating waste from fuel reprocessing and other processes in the nuclear fuel cycle) should be calculated using a similar approach. The total cost for final disposal of TRU waste for geological disposal was calculated to be USD 6.90 billion and the price for final disposal per USD 320 000 in the year 2000. The price for final disposal of HLW and TRU waste for geological disposal is revised every year based on the latest expected cost to implement final disposal.

The 2005-48 Spent Nuclear Fuel Reprocessing Implementation Act sets out that NURO estimates the price per certain unit of SNF based on criteria that are legitimated and approved in an according ordinance by METI. The criteria are rather broad and basically require NURO to set the price at a level to achieve two goals: 1) NURO has to collect adequate resources to allow the implementation of SNF reprocessing in the long term; 2) NURO has to ensure the fairness between operators and 3) the price should have a foreseeability in order not to have a serious negative impact on the economic health of the nuclear operators. NURO-calculated prices must earn the approval of METI and NURO is obliged to annually estimate the appropriate price per certain unit of SNF.

METI periodically reviews the prices to take into account the fluctuation of commodity prices, tax rates and inflation (METI, 2017d). METI estimates a discount rate by calculating the ten-year average of real interest rates on Japanese Government Bonds, resulting in a discount rate of 0.7% in 2017. In this manner, METI tries to manage uncertain costs and METI publicises the details of the calculations on their website to satisfy transparency objectives (METI, 2017d).

Table 11.1:
Scope of the back-end cost estimates in Japan

Reprocessing	*	Research and develop	✓
Siting and pre-construction	✓	Admin	✓
Transportation	✓	Decommissioning ***	✓
Reception charge		Uncertainty margins	✓
Encapsulation	✓	Others	**
Final disposal	✓	Other waste	
Interim storage	✓	Legacy	
On-site SNF storage			

Source: NEA, 2013.

* Separate fund; ** Consumption tax and Monitoring; *** Here, decommissioning does not refer to decommissioning costs of back-end facilities but to nuclear power plant decommissioning – i.e. if 'Decommissioning' is included in this table, the cost calculations include nuclear power plant decommissioning (and the fund will be set to cover costs for SNF/HLW management and nuclear power plant decommissioning).

Assets, investment rules and performance

Nuclear operators in Japan are obliged to accumulate internal funds for decommissioning and the funds have to be accounted for on the companies' balance sheets. NUMO discloses the portfolio of the Final Disposal Fund. The balance of the Final Disposal Fund was USD 10.34 billion at the end of 2019 (RWMC, 2019b, 2019c). According to the information disclosed at the end of 2019, the expected return rate from the fund was 0.64 %. This rather moderate return rate is explained by the fact that Article 79 of the 2000-117 Designated Radioactive Waste Final Disposal Act strictly limits RWMC to invest the assets of the Final Disposal Fund in safe investments such as Japanese Government Bonds. The 2000-117 Designated Radioactive Waste Final Disposal Act (Article 67) allows NUMO to borrow money from third parties if it faces temporary shortfalls. NUMO needs to earn METI's approval in order to borrow in such manner. According to NURO's annual financial report for the full year 2017, the SNF reprocessing fund's assets are mainly composed of two investment forms: a) investment securities (68.8%); and b) deposits (26.1%) (NURO 2017). The 2005-48 Spent Nuclear Fuel Reprocessing Implementation Act (Article 51) allows NURO to borrow money from third parties if it faces temporary shortfalls. NURO needs to earn METI's approval in order to borrow in such manner. The fund balance of the SNF reprocessing fund was USD 13.67 billion in 2019.

Conclusion

The Japanese funding scheme for decommissioning and RWM is sophisticated and well managed. In addition to mandatory funding arrangements for decommissioning and RWM that must be established by the nuclear operators, a SNF reprocessing fund exists in which nuclear operators have to transfer annual amounts defined by governmental authorities. Funding adequacy and respective annual payments are reassessed on a yearly base. The 2011 Fukushima Daiichi accident has led to a number of amendments in Japan's regulatory framework. These include the establishment of a dedicated funding stream for accident-affected reactors that has to be provided by the respective nuclear operator, as well as state-sponsored R&D and supervisory measures. In general, the Fukushima Daiichi accident has underlined the need for public-private co-operation in the case of extreme events such as nuclear accidents. Prudent management and realistic discount rates ensure that in particular the Final Disposal Fund remains adequate even in the current low interest rate environment. Further changes have led to a reduction in the operational lifetimes of nuclear reactors to 40 years with the possibility of prolongation to 60 years. This has led to earlier than expected shutdown dates for some nuclear operators, requiring the Japanese government to adapt the regulatory framework to ensure adequate build-up of funds to cover decommissioning duties.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 12

Korea: Country case study

KEY FACTS	
Funding model	Internal funds for decommissioning, external segregated funds for RWM
Assets (radioactive waste management fund)	• KRW 6 774 billion (USD 6.15 billion) (2018)
Provisions (KEPCO subsidiaries)	• Decommissioning: KRW 13 388 billion (USD 12.17 billion) (2018) • Spent Nuclear Fuel: KRW 1 291 billion (USD 1.17 billion) (2018) • Radioactive Waste Management: KRW 1 685 billion (USD 1.53 billion) (2018)
Liabilities	• KHNP: KRW 19 390 billion
Avg. effective real return	• Radioactive Waste Management Fund: 2.17% (2016)
Discount rate	• KHNP: Decommissioning: 2.94%; RWM and SNF: 4.49% (2012)
Assumed operational lifetime of nuclear power plants	40 years
Investment rules	3.00% rate of return and a shortfall risk below 5.00%
Evaluation of fund adequacy	Recalculation of financial liabilities every two years
Issues at stake	• Nuclear phase-out (cancellation of planned new reactors, cancellation of life extension of incumbent reactors) in a context of a low carbon energy transition.

Decommissioning and RWM in Korea

Korea's financing scheme for decommissioning and RWM is built upon two state-owned companies, the Korea Hydro & Nuclear Power (KHNP) and the Korea Radioactive Waste Agency (KORAD, prevously KRMC). KHNP, a subsidy of KEPCO is the sole operator of nuclear power plants in Korea. KORAD, a not-for-profit corporation, is an umbrella entity created in 2009 to tackle Korean issues surrounding radioactive waste and spent nuclear fuel, in particular through the Radioactive Waste Management Fund (RWMF). While the decomissionning scheme is straightforward and relies on a unified basic strategy, the RWM scheme is original and complex. It is ultimately built on the transfer of legal and financial liabilities from the nuclear waste generator to the KORAD. To put it simply, this occurs when the KORAD physically picks up waste from KHNP. The financial provisions accumulated by the waste generators beforehand are then transferred to the RWMF for the radioactive waste long-term management. However, building facilities for radioactive waste and spent fuel storage or disposal has been challenging and in practice liabilities are being shared between waste generators and the KORAD. For example, as of June 2020, spent nuclear fuel is still being stored at on-site facilities and managed by KHNP. In other words, while the government envisioned a two-pronged scheme with KHNP managing short-term activities and decommissioning and with KORAD managing the long-term activity of radioactive waste and spent fuel, the reality falls in between. Furthermore, this shared responsibility comes with a shared financial liability that adds a level of complexity when ensuring the adequacy of funding for RWM.

In this challenge, Korea can rely on a strong history of nuclear power development with its first nuclear reactor, Kori 1, achieving commercial operation in 1978. Today, Korea has become a world leader in this sector and was the first in 2016 to begin commercial operation of a third-generation nuclear power plant using the new and domestically built light reactor APR1400. As of December 2019, 24 nuclear reactors across four nuclear power plants provide approximatively 25% of the country's electricity and four new nuclear reactors are in construction (Shin Hanul 1 & 2, Shin Kori 5 & 6) (WNA, 2019).

However, the nuclear power sector faced an important political shift in the country in 2017 that was strongly correlated with the 2011 Fukushima Daiichi accident in Japan. Indeed, in 2015, Korea committed to significant cuts in greenhouse gas emissions and the government's 7th Basic Plan for Long-term Electricity Supply and Demand (2015-2029) accordingly promoted the development of renewable and nuclear energy (WNA, 2019). However, in 2017 the newly elected government decided to review the nuclear development policy and prepare the country to exit the nuclear energy era within four decades. It immediately cancelled the anticipated development of four nuclear reactors (Cheonji 1 & 2, Cheonji 3 & 4 or Daejin 1 & 2) and put on hold design work for two others (Shin Hanul 3 & 4) (WNA, 2019). In this context, the present study on the adequacy of funding for decommissioning and radioactive waste management is relevant for Korea to successfully reach its goals.

Recent nuclear developments

In the past decade, Korea has proactively been working to tackle the challenge of decommissioning and radioactive waste management. The Fukushima Daiichi accident in 2011 reinforced the country's focus on developing decommissioning technologies to prepare the upcoming decommissioning of nuclear power plants and to improve global nuclear industry safety. Indeed, if the government decides not to extend nuclear power plants' operating lifetimes as it announced in 2017, half of the current fleet (i.e 12 reactors) will prepare for or enter the decommissioning phase by 2030 (KAERI, 2020). As of January 2020, Korea has already successfully decommissioned the Uranium Conversion Facility dedicated to the development of fuel fabrication technologies for PHWR and is decommissioning two research reactors (KRR-1 and 2). Furthermore, the government's decision to shut down the Kori Unit 1, Korea's first commercial nuclear power plant, and Wolsong 1, Korea's first CANDU 6 unit, also highlight the importance of fostering industrial infrastructures for the safe and effective dismantling and decommissioning (NEA, 2016). KHNP is seizing this opportunity to complete the lifecycle of the nuclear power plant industry and to lead the domestic decommissioning industry. By acquiring the decommissioning technologies required for the shutdown of Kori 1, KHNP aims to secure a track record and seek business opportunities overseas (KHNP, 2018a). Korea's Kori 1 (576 MWe net) and Wolsong 1 (661 MWe net) were shut down respectively in June 2017 after 40 years of service, having had a 10-year licence extension, and in May 2018 after 36 years of service.

Regarding radioactive waste management, Korea distinguishes high-level waste (HLW) from low-and intermediate-level waste (LILW). Concretely, in Korea, HLW consists of SNF while LILW encompasses all other radioactive waste (NEA, 2014; NEA, 2016). As of December 2015, the cumulative amounts of SNF and LILW from nuclear power plants stood at 425 086 bundles and 98 887 drums respectively and reached 81% and 72% of total on-site storage capacities (NEA, 2014; NEA, 2016). In this context, Korea has deployed noticeable efforts to overcome its waste management issues. Regarding LILW, the Wolsong Low and Intermediate-Level Radioactive Waste Disposal Centre (WLDC), a rock-cavern type disposal facility, started operating in 2015. As of March 2017, 6 848 LILW drums (1.2 million liters) of LILW were stored and managed in the storage building and 6 920 drums (1.38 million liters) were disposed in silos (NSSC, 2017, p.43). Several capacity extensions are scheduled, including additional near-surface and underground silo-type locations, in order to reach a total storage capacity of 800 000 drums (160 million liters) (WNA, 2018).

For HLW, the government chose the deep geological repository (DGR) solution (NSSC, 2017: p. 22). Its strategy is detailed in the Basic Plan on High-level Radioactive Waste Management established in 2016. It describes a three-step plan: a) a 12-year study to select the final candidate site; b) construction and operation of an Underground Research Laboratory (URL) at the selected site and c) expansion of the URL into a permanent repository. According to available information, the site for the final disposal facility should be identified by 2020 in order to have it built and operational by 2051 (NEA, 2014; NEA, 2016). In practice, the large bulk of spent fuel in Korea is generated by 24 nuclear power plants and the research reactor HANARO (High-flux Advanced Neutron Application Reactor) which is operated by the Korea Atomic Energy Research Institute (KAERI). Spent fuel generated by nuclear power plants is stored in wet and dry storage facilities (only for PHWRs) on site. Low- and intermediate-level radioactive waste generated from nuclear power plants and HANARO is stored at on-site facilities and partially transported to the WLDC disposal facility after KORAD's on-site inspection. The spent fuel generated from nuclear power plants and HANARO is stored and managed at on-site pools (NSSC, 2017: p. 22). Finally, the radioactive waste generated by the Korea Electric Power Corporation Nuclear Fuel Co., Ltd. (KEPCO NF) during the nuclear fuel fabrication process is stored at the radioactive waste storage facility of KEPCO NF (NSSC, 2017: p. 4).

Decommissioning regulations and requirement

According to the Nuclear Safety Act (NSA), the decommissioning of nuclear reactors is supervised by the Nuclear Safety and Security Commission (NSSC). To decommission, all relevant stakeholders (KAERI, KEPCO NF, KHNP, etc.) must present the NSSC with a valid plan detailing its strategy, schedule and required human and economic resources. The Korean legislation also has stringent standards regarding the management of radioactive materials (hazards, decontamination, treatment, storage, etc.) that takes into account the local population. In practice, local public hearings have to be held to inform and discuss a decommissioning project. A Decommissioning Status Report is required by the NSSC every six months during the project and a final inspection is conducted by the NSSC at the end of the project. Furthermore, the operators must review the plan every ten years (NSSC, 2017).

Policy for radioactive waste and spent fuel management

The Korean government establishes basic policies and directives regarding final radioactive waste disposal via its Ministry of Trade, Industry and Energy (MOTIE). By law, the MOTIE must have a 30-year plan for RWM and review it every 5 years (NLIC, 2018). In particular, the MOTIE proposes policies with regard to nuclear energy production and the utilisation of corresponding resources, in accordance with the recommendations of the Atomic Energy Promotion Commission (AEPC, formerly called Atomic Energy Commission) (NEA, 2009). As of June 2020, the curent basic policy for low-and intermediate-level RWM was adopted in the fourth meeting of the AEPC held on 30 January 2015. The current basic policy for the HLW management was adopted in the 6th meeting of the AEPC held on 25 July 2016. Both plans have the same priorities for RWM: public and environement safety, public trust and transparency and management efficiency. They both further stipulate that the financial liability must be borne by the waste generator according to the polluter's pay principle and that the long-term management must be incurred by the governement.

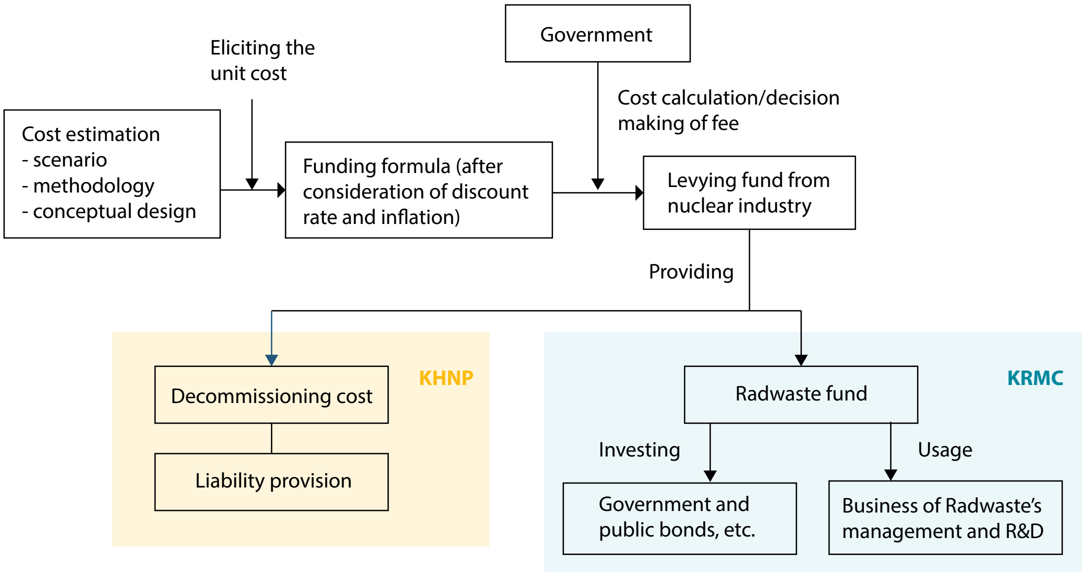
The funding system

The Korean legislation applicable to decommissioning and the RWM resulting from nuclear reactor operation is the 2008 Radioactive Waste Management Act (RWMA). The corresponding funding scheme relies on a public fund, the RWMF and three entities: a) nuclear waste generators, b) the Korea Radioactive Waste Management Company Ltd. (KORAD) and c) MOTIE. The KORAD is a non-profit organisation created in 2009 to resolve Korea's RWM issues, and particularly to forge a national consensus on HLW management. Further, its mission is to build a structure of mutual control and balance by differentiating the producers of radioactive waste from their disposal operators which follows the IAEA recommendations (IEA, 2012; NEA, 2016). According to the RWMA Article 9, the KORAD manages the RWMF and has five operational tasks: a) transportation, storage, treatment and disposal of radioactive waste; b) site selection and radioactive waste management facilities construction, operation and closure; c) collection and analysis of data for radioactive waste management; d) communication and sensitisation of the population on radioactive waste management; e) auxiliary projects, prescribed by Presidential Decree, such as research and development, manpower training, and international co-operation (NLIC, 2018).

Nuclear waste generators historically bore the financial and management responsibilities for both decommissioning and radioactive waste. In practice, KHNP is directly responsible for radioactive waste and spent fuel management such as fuel removal from the reactor and on-site interim storage, prior to the handoff of both the LILW and the SNF to the KORAD for transfer to a disposal facility. As early as 1983, nuclear power plant licensees deposited the cost required for decommissioning and RWM on a yearly basis and accumulated this provision as an in-house liability in accordance with the Electricity Business Act established by the MOTIE. Since 2009, with the Radioactive Waste Management Act enforcement that created the KORAD and the Radioactive Waste Management Fund, separate funds are raised to cover decommissioning and waste activities. In other words, ultimate financial liabilities of nuclear power plant decommissioning and RWM remain unchanged and are borne by nuclear power plant operators and waste generators. However, since 2009, they must accumulate in-house provisions for the former and pay fees transferred to an external dedicated fund, the Radioactive Waste Management Fund (RWMF) that is held and managed by the KORAD, for the latter.

In Korea, decommissioning is the process whereby the unit is shut down at the end of its life, the fuel is removed and the unit is dismantled. Related provisions consist of costs related to spent fuel, costs related to radioactive waste, and costs related to dismantling nuclear plants. KHNP implements a policy under which a unit is dismantled five to ten years after its closure. The cost for decommissioning is estimated by the Cost Determination Committee established by the MOTIE and it is adjusted annually and reviewed bi-annually. It is estimated per nuclear reactor and the provisions start to be filled as soon as the nuclear reactor begins commercial operation. Nuclear power plant operators must allocate this prior-defined annual sum in an internal fund. Finally, the MOTIE is required to issue every two years guidelines relating to the accounting treatment of decommissioning, which KHNP is required to adopt (KHNP, 2018b).

Figure 12.1:
Overall financing system (decommissioning and RWM) in place in Korea



Financial liability for both SNF and LILW management is borne by the waste generator. In practice, a fee on radioactive wastes and SNF is levied on the electricity bill. It is different for SNF from a light water reactor, SNF from a heavy water reactor or LILW (see details in the cost section). The basic units for cost evaluation are the drum for LILW, bundle for PWR spent fuel and assembly for CANDU spent fuel. For LILW, provisions are accumulated by the waste generators and payable whenever radioactive waste is delivered to KORAD. For spent fuels, they are accumulated when a nuclear reactor is loaded with nuclear fuel and paid to KORAD when nuclear fuel is unloaded from the nuclear reactor (NSSC, 2017: p. 77).

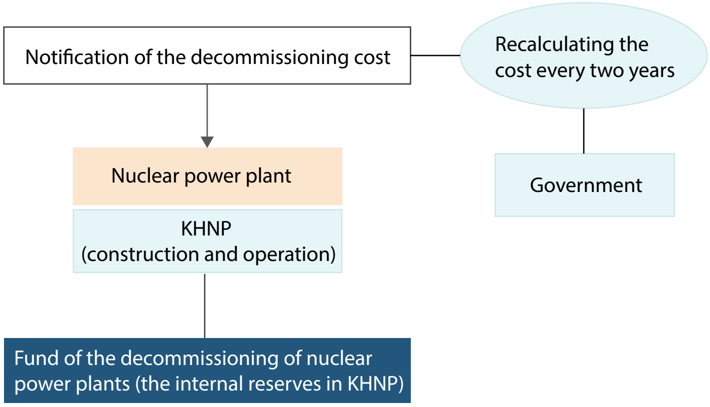
Decommissioning

The decommissioning financing plan must be designed by the nuclear power plant operator and sent to the MOTIE on a yearly basis. It must include information on the status of provisions, the projections and the financing strategies (Cha, 2016). See details in the cost section.

A special case concerns the decommissioning of research facilities such as KRR-1 and -2 and the Uranium Conversion Facility constructed and operated by KAERI. In this situation, the decommissioning was funded by the Korean government. In 1996, KAERI reported its basic plan to the Ministry of Science, ICT and Future Planning (MSIP), received financial support from the government, and began to decommission research reactors in 1997. The decommissioning of the Uranium Conversion Facility operated by KAERI was also funded by the government (NEA, 2014).

To avoid any shortfall, the government is responsible for reviewing every two years both the nuclear power plant's operator (KHNP) assessment cost and the methodology by which the cost liability was established. Moreover, the adequacy of financial resources available versus the assessed cost liability is reviewed every year (NEA, 2016). In any case of shortfall in the value of the fund's available assets during the decommissioning phase, the nuclear power plant's operator is responsible for the additional payments (NEA, 2016).

Figure 12.2:
Mechanism for the adjustment of the fees for decommissioning after every two-year review



Structurally, KHNP is a state-owned company and Korea's sole nuclear operator. Hence the decommissioning related responsibilities lie ultimately with the Korean state and there is no risk of a financial shortfall (NEA, 2016).

Radioactive waste management

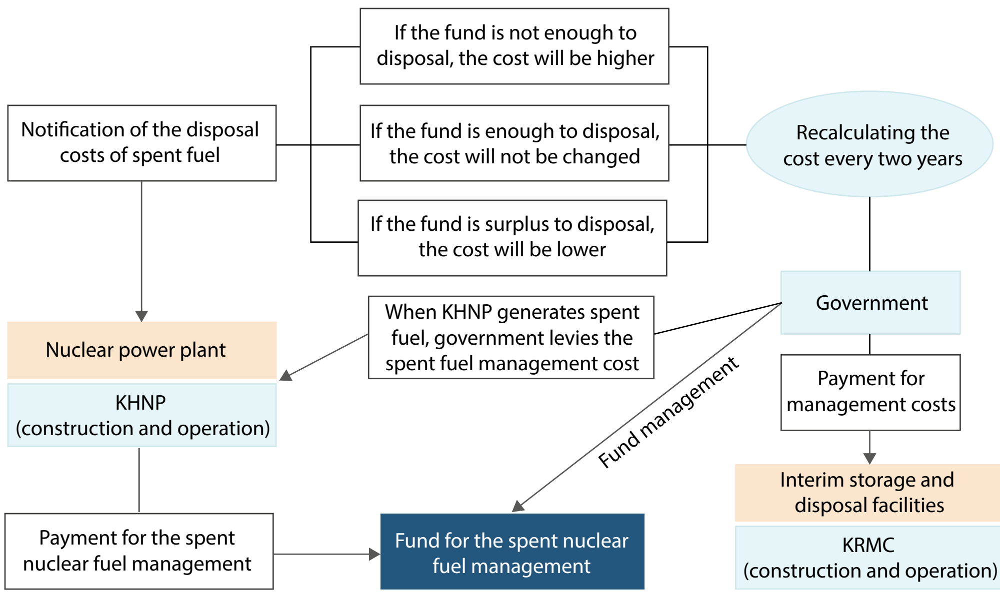
The corresponding funding scheme relies on a public fund, the RWMF and three entities, a) nuclear waste generators, b) the Korea Radioactive Waste Management Company Ltd. (KORAD) and c) MOTIE.

KORAD is financed through the Radioactive Waste Management Fund which gathers provisions from five sources, namely: a) a RWM and SNF fee from waste generators, b) contributions from the MOTIE, c) contributions and donations from non-governmental stakeholders, d) profits from the operations of the Fund and e) other imports prescribed by Presidential Decree (interest on money lent). As of December 2018, the balance of the RWM Fund was of KRW 3 538 billion (USD 3.21 billion) (KORAD).

The RWM Fund can be legally used to finance KORAD's operational and management costs, the RWM Fund management costs and other specific projects related to nuclear energy and prescribed by Presidential Decree (NLIC 2018). As an example, the RWM Fund covers expenses such as the conceptual design of SNF transportation, the analysis of the back-end nuclear fuel cycle, R&D related to SNF disposal, the disposal costs for LLW/ILW, the construction of disposal facilities for LLW/ILW, the operation of disposal facilities for LLW/ILW (part of the operation) and the LLW/ILW disposal-related R&D (NEA, 2013). The vast majority of radioactive waste and spent fuel is still stored on nuclear power plants' sites and provisions for RWM and SNF are accordingly held by both the waste generators and the KORAD (through the RWMF). Thus, to estimate the total Korean provisions for decommissioning and RWM it is necessary to consider both assets of the Radioactive Waste Management Fund and provisions of nuclear waste generators (KHNP, KEPCO NF, etc.).

To ensure the fund's adequacy, the government reassesses the cost of radioactive waste and spent nuclear fuel management every two years and adjusts the fees accordingly.

Figure 12.3:
Mechanism for the adjustment of the fees for RWM after every two-year review



The cost side

The appropriate cost for both decommissioning and RWM is assessed every two years by all relevant authorities including the government, the KORAD, KHNP, etc. (NEA, 2014). To estimate the fees on SNF and radioactive waste and the nuclear power plants' decommissioning cost, the net present value method is applied (NLIC b). According to the information disclosed, discount rates of 4.49% and 2.94% are applied by KHNP to respectively assess SNF and decommissioning liabilities. The KHNP's change to the decommissioning discount rate from 3.55% to 2.94% in 2017 likely aims to reflect the current environment of low interest rates and to take into account expenditure horizons according to various decommissioning plans. At the end of 2016, the RWMF applied a discount rate of 2.17 % (RWMF, 2017: p. 18). It might be helpful to have KHNP and the RWMF entities use identical technical assumptions regarding nominal rates of return and discount rates, which were, as at 2018 still differing to a notable degree (4.49% and 2.17%).

Radioactive waste management

The fee levied on the electricity bill includes the costs of radioactive waste transportation, encapsulation, interim storage and of final disposal (NEA, 2013). For LILW it is KRW 12.19 million (USD 11 076) per drum, for spent fuel from PWR it is KRW 320 million (USD 290 776) per assembly and for spent fuel from PHWR it is KRW 13.2 million (USD 11 994) per bundle. As an example, the liability for radioactive waste and SNF management for 2017 is set out in the table below.

Table 12.1

Radioactive Waste Management Fund's revenues from fees on radioactive waste and SNF in 2017

		Quantity of waste	Cost per nit (KRW million)	Total (KRW million)
Spent nuclear fuel	Light water reactor	1 022 assemblies	320 (USD 290 776)	**326 850** (USD 297 million)
	Heavy water reactor	21 600 bundles	13.2 (USD 11 994)	**285 163** (USD 259 million)
Low- and intermediate-level radioactive waste		8 652 drums	12.2 (USD 11 076)	**105 464** (USD 96 million)
Total				**717 477** (USD 652 million)

Source: RWMF, 2017.

For SNF only, a surplus has also been settled to take into account costs related to wastes that were produced prior to the Radioactive Waste Management Act's enforcement. A total of KRW 4 529 billion (USD 4.12 billion) will be paid by SNF generators over 15 years from 2014 to 2029. In 2017, the surplus equals KRW 250 237 million (USD 227.38 million) and added to the above total, makes the global financial liability for RWM in 2017 reach KRW 967 714 million (USD 879.34 million).

Besides KHNP, also KEPCO NF and KAERI have accumulated financial provisions for radioactive waste and spent fuel management. KAERI has several facilities related to spent fuel and radioactive waste management, including HANARO, the Post Irradiation Examination Facility (PIEF), radioactive waste treatment and storage facilities, and one combustible waste treatment facility. As of June 2017, two totals of KRW 108.01 billion (USD 98.14 million) and of KRW 5.9 billion (USD 5.36 million) were earmarked respectively by KEPCO NF and KAERI for RWM (NSSC, 2017).

Decommissioning

To secure stable resources for the decommissioning and the safe management of decommissioning waste, nuclear power plant operators have been depositing expenses for decommissioning of nuclear power plants in provisions, in accordance with the 2008 RWMA. Operators are required to accumulate money for decommissioning and to manage it financially in accordance with set accounting standards. An annual financing plan must be designed and sent to the public authorities, including information on the status of provisions, the projections and the financing strategies (Cha, 2016).

The methodology to assess the decommissioning costs relies on an engineering tool and represents a standard Korean decommissioning cost, for both PWR and PHWR technologies. For example, the decommissioning provision for Wolsong Unit 1 is of KRW 642 billion (USD 583 million) when the estimated decommissioning costs was of KRW 607.97 billion (USD 552 million) (SEC, 2018). For this reactor, the overall process is expected to last 15.5 years but should be of 13 years for others (safety management for 5 years, dismantling for 6 years, and site restoration for 2 years). A 2017 assessment of the decommissioning cost made by KAERI led to the average value of KRW 751.5 billion (USD 682.87 million) per reactor, where KRW 462 billion (USD 420 million) and KRW 289 billion (USD 263 million) would be respectively allocated to demolition and radioactive material management costs. Considering all 26 existing reactors and with no operating lifetime extension, the same report estimates that the total overnight cost for decommissioning would be KRW 19 539 billion (USD 17.76 billion) by 2061. Over time, the global annual expenses for decommissioning is expected to sharply increase in the coming decades and to reach an annual average of KRW 581 billion (USD 527.9 million) for the 2030-2040 period before decreasing to a lower plateau at approximatively KRW 360 billion (USD 327.12 million) from 2040 to 2060. The residual cost of decommissioning would then vary between KRW 200 billion (USD 181.73 million) and zero until the end of the century (KAERI, 2018: p. 9).

Assets, investment rules and performance

KHNP records liabilities for decommissioning and disposal of spent nuclear fuel and management of low- and intermediate-level radioactive waste in two different funds. For both of them, corresponding provisions are determined at the present value of the expected future cash flows (SEC, 2019). As of 31 December 2018, the present value of total discounted nuclear liabilities of KHNP was estimated at KRW 16 364 billion (USD 14.87 billion), of which KRW 16 359 billion (USD 14.87 billion) were covered by provisions, resulting in a coverage ratio of 99.9%. Of these accrued provisions at the end of 2018, KRW 13 388 billion (USD 12.165 billion) were for decommissioning costs of nuclear plants and KRW 2 971 billion (USD 2.699 billion) for RWM and spent fuel management costs.

Due to the change in 2017 in the decommissioning discount rate from 3.55% to 2.94%, the coverage ratio at the end of 2017 was of 81% in spite of a drop in the inflation rate to 1.21% from 1.40% (KHNP, 2018b; SEC, 2019). At that time, the total accrued provisions were of KRW 13 049 billion (USD 11.86 billion) divided in KRW 10 196 billion (USD 9.26 billion) and KRW 2 853 billion (USD 2.59 billion) respectively for decommissioning and RWM and spent fuel management. Regarding cost liability of radioactive waste and spent fuel, the discount rate of 4.49% and inflation rate of 2.93% are applied (SEC, 2019).

As of 2018 the total assets of the RWM Fund were worth KRW 6 774 billion (USD 6.15 billion) respectively divided into KRW 4 424 billion (USD 4.02 billion) of current assets and KRW 2 351 billion (USD 2.14 billion) of non-current assets. The non-current assets of the RWM Fund are invested at 98% in medium and long-term funds and the rest in short-terms funds. The medium and long-term funds are composed of six investment forms: a) Korean government bonds (69%), b) oversees stocks (10%), c) alternative investments (8%), d) domestic stocks (5%), e) deposits (4%) and f) oversees government bonds (2%) (RWMF, 2019). The high share of long-term low-risk investments contrasts to some extent with the tendency observed in other OECD countries to allow for greater diversification with the double objective of increasing returns and managing financial risk.

According to the information disclosed, the standard return rate of the fund's assets was of 2.17% at the end of 2016 (RWMF, 2017: p. 18) and the shortfall risk was of 1.61% in 2019 (RWMF, 2019: p. 5). The objectives are to reach approximatively a 3.00% rate of return and to maintain a shortfall risk below 5.00% (RWMF, 2019: p. 1).

Conclusion

The Korean decommissioning scheme is straightforward. Liabilities are borne by the nuclear operator that pays and manages the process from the beginning to the end under the supervision of the NSSC and the MOTIE. The adequacy between financial resources available and the estimated cost liability is assessed each year. Current accrued provisions match discount future liabilities at 99.9% and seem coherent with total decommissioning overnight cost estimates. However, the 2017 change in discounting rates used for assessing the current value of future decommissioning liabilities led to a 25% increase in KHNP's liabilities and points towards a need to adapt the Korean nuclear back-end financing scheme. However, the fact that the government is legally required to own, directly or indirectly, at least 51% of KHNP's issued capital stock ultimately ensures the robustness of the overall system. At the same time, in combination with the complexity of KHNP's accounting rules for nuclear provisions, which are not constituted as dedicated assets, this arrangement reduces the ability to fully assess the adequacy of currently constituted provisions. Greater simplicity and transparency would increase sustainability.

The RWM scheme involves a transfer of responsibilities from the nuclear waste generator to the KORAD. As a consequence, it is important that estimates of RWM future costs are realistic and comprehensive in order to avoid the transfer of residual or unforeseen financial responsibilities ultimately falling on the taxpayers. In this context, it would be beneficial if KHNP and KORAD used identical technical assumptions regarding nominal rates of return and discount rates, which, as late as 2018, were still differing notably. Moreover, the RWMF's investment portfolio displays a high share of domestic bonds, which contrasts with other OECD countries that promote diversification to lower financial risks. Overall, with KHNP and KORAD both being state-owned companies the financing system for the RWM is robust and provides a fair degree of clarity and foreseeability.

The Korean government wishes to make KHNP a strong competitor in the global industry for nuclear power plant decommissioning. Currently, important know-how is being accumulated with the current decommissioning of the KRR-2 and 1 research reactors and the soon-to-be approved decommissioning of the commercial reactors Kori 1 and Wolsong 1. Furthermore, new policy intentions to begin to exit nuclear power generation during the next decade and thus to not extend operating periods of existing units beyond their designed lifetime implies that 12 nuclear reactors will enter the decommissioning phase by 2030. This drastically complicates the previous government's plan for a 10-year operating lifetime extension for all nuclear reactors and sets an important challenge for KHNP. Thus a number of challenges will require that decision-makers in government and industry maintain some degree of adaptability in the regulatory framework to ensure fully the adequacy of financing for decommissioning and RWM over the long term.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 13

Spain: Country case study

KEY FACTS	
Funding model	External joint earmarked fund without legal personality, under direct public control
Assets	• USD 7.09 billion
Liabilities	• USD 13.37 billion
Avg. effective real return	• 3.16% (2015-2018)
Discount rate	• 1.5%
Assumed operational lifetime of nuclear power plants	Approximately 45.7 years, on average[1]
Investment rules	Investments inter alia allowed in marketable fixed-income or equity securities, domestic and foreign state debt, mortgage-market securities, derivative instruments, deposits at financial institutions, and real estate.
Evaluation of fund adequacy	A diversity of annual and semi-annual status update reports on funding adequacy must be provided by the Empresa Nacional de Residuos Radiactivos, S.A., S.M.E. (Enresa), as established in the Spanish regulation.
Issues at stake	• State-centralised system under the management of a single state-owned company, Enresa, allows for a fair degree of clarity and foreseeability. • Large degree of state responsibility. Law 25/1964, of April 29th, on nuclear energy, establishes that radioactive waste management, dismantling and decommissioning of nuclear facilities is an essential public service under the responsibility of the state. Enresa is the public company entrusted with the provision and management of this service. Enresa takes responsibility for the decommissioning of a nuclear facility after its final shutdown, upon approval of the Ministerial Order that grants the dismantling license and transfers such a license to Enresa. On the other hand, Law 25/1964 establishes that the State will take title of the radioactive waste after it has been permanently disposed of safely in appropriate facilities.

1. This figure is in accordance with the schedule for the orderly final shutdown of the Spanish nuclear power plants, as established in the Protocol of intentions between nuclear power plant owners and Enresa signed in March 2019 (Enresa, 2019), which is based in the provisions of the draft Spanish National Integrated Energy and Climate Plan 2021-2030 (PNIEC, 2019).

Decommissioning and RWM in Spain

The primary instruments that constitute the legal and regulatory framework on decommissioning and radioactive waste management in Spain are the following:

(a) Law 25/1964 of April 29th on nuclear energy;[2]

(b) Law 15/1980 of April 22nd establishing the Nuclear Safety Council[3]. Amended by Law 33/2007;[4]

(c) 6th Additional Provision of Law 54/1997, declared in force by Law 24/2013,[5] on the Fund for the financing of the activities included in the General Radioactive Waste Plan;

(d) Royal Decree 1836/1999 of December 3rd approving the regulation on nuclear and radioactive facilities;[6]

(e) Royal Decree 102/2014 of February 21st on the safe and responsible management of spent fuel and radioactive waste.[7]

Law 25/1964, on nuclear energy, establishes that radioactive waste management, dismantling and decommissioning of nuclear facilities is an essential public service under the responsibility of the state. In 1984, Royal Decree 1522/1984 authorised the constitution of the Empresa Nacional de Residuos Radiactivos, S.A. (Enresa), as the company responsible for the dismantling and decommissioning of nuclear facilities and for RWM in Spain. It is a state-owned company whose shareholders are the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Ciemat, 80%) attached to the Ministry of Science and Innovation, and the Sociedad Española de Participaciones Industriales (SEPI, 20%) of the Ministry of Finance, both of them governmental institutions. The tutelage of Enresa corresponds to the Ministry for the Ecological Transition and the Demographic Challenge (Miterd or "the Ministry"), through the Secretary of State for Energy, who carries out the strategic direction and the monitoring and control of its actions and plans (Law 25/1964, art. 38 bis).

The General Radioactive Waste Plan (GRWP) is the reference framework for the national strategies on dismantling, decommissioning and management of spent nuclear fuel (SNF) and other radioactive waste (RW) in Spain. The GRWP is intended to address the strategies, necessary actions and technical solutions to be developed in the short, medium and long terms, aimed at ensuring the adequate management of RW and SNF, the dismantling and decommissioning of nuclear facilities, and associated activities, including the economic and financial measures required to carry them out. Article 6 of Royal Decree 102/2014 prescribes the contents of the GRWP.

The GRWP determines the main activities to be carried out by Enresa, as established in article 9.3 of Royal Decree 102/2014, including, among others:

a) treating and conditioning SNF and other RW, without prejudice to the responsibilities of the waste producers or the licence holders who have been entrusted with such a responsibility;

b) searching for sites, designing, constructing and operating facilities for the storage and disposal of SNF and other RW;

c) developing systems to ensure the safe management of SNF and other RW in the storage and disposal facilities;

d) establishing systems for the collection, transfer and transport of SNF and other RW;

e) managing the national inventory of SNF and other RW;

f) adopting safety measures for the transport of SNF and other RW, pursuant to the provisions of specific regulations on the transport of dangerous goods, as it may be determined by the competent authorities;

2. Law 25/1964, of 29 April, on nuclear energy.
3. Law 15/1980, of 22 April, establishing the Nuclear Safety Council.
4. Law 33/2007, of 7 November, amending law 15/1980, of 22 April, establishing the Nuclear Safety Council.
5. Law 54/1997, of 27 November, on the Electricity Sector and Law 24/2013, of 26 December, on the Electricity Sector.
6. Royal Decree 1836/1999, of 3 December, approving the Regulation on nuclear and radioactive installations.
7. Royal Decree 102/2014, of 21 February, for the responsible and safe management of spent nuclear fuel and radioactive waste.

g) managing the operations regarding the dismantling and decommisioining of nuclear and, where appropriate, radioactive facilities;
h) establishing training plans, and research and development plans, to cover the needs of the GRWP;
i) performing the necessary technical, economic and financial analyses, taking into account the deferred costs to establish the corresponding economic needs;
j) managing the Fund for the financing of the activities included in the GRWP.

Royal Decree 102/2014 also establishes that Enresa shall submit, every four years or upon request of the Ministry for the Ecological Transition and the Demographic Challenge, a revision of the GRWP. The Ministry may then decide to carry out the approval proceedings and, if so, it will submit a proposal for the approval of the government, following a strategic environmental assessment procedure. Within this environmental assessment procedure, the general public and the relevant stakeholders are consulted. Furthermore, according to Law 25/1964 (art. 38 bis, 2), as part of the approval proceedings the autonomous communities are heard and the Nuclear Safety Council (CSN) has to provide a report. The whole process, until the plan is approved by the Council of Ministers, may take about two years. Following the approval of the plan, it will be reported to the Spanish Parliament (Cortes Generales).

The first GRWP was approved in 1987. The 6th version, approved in June 2006 (GRWP, 2006), is still in force today, and the forecast data it contains are periodically updated by Enresa (RD 102/2014, art. 10). In March 2020, Enresa submitted to the Ministry a draft 7th General Radioactive Waste Plan (GRWP, 2020) that has to go through the different proceeding stages before it may be approved, including the strategic environmental assessment procedure.

Nuclear power plant lifetime

Currently, there are seven nuclear reactors in Spain, operating in five different sites, which were commissioned between 1983 and 1988 and represent about 20% of national electricity generation. Current exploitation licenses for the operating reactor fleet in Spain are due to expire between 2020 and 2024, the 2019-20 period having been the deadline to apply for the renewal of the exploitation licenses of six out of seven units.

In February 2019, a draft Spanish Integrated National Energy and Climate Plan 2021-2030 (PNIEC, 2019[8]) submitted by the Spanish Government to the European Commission, envisaged that the nuclear phase-out should be completed by 2035 at the latest, although only four out of seven units would be closed by 2030. Based on the provisions of this draft plan, a protocol of intentions between the nuclear power plant owners and Enresa was signed in March 2019, establishing the schedule for the orderly final shutdown of the Spanish nuclear power plants. By means of this protocol of intentions, the nuclear power plant owners agreed on dates for the cease of operations of their nuclear power plants. Consequently, according to this schedule, the planned average operating lifetime of the seven reactors currently in operation shall be 45.7 years.

The applications for renewal of the exploitation licenses of the nuclear units, to be submitted to the Ministry by the nuclear power plant license holders, shall take into account the agreed phase-out schedule.

National strategy on waste management

In Spain, RW is classified as follows:

(a) Low- and intermediate-level and short-lived waste (LILW). Waste mainly consisting of β and γ emitting radionuclides with a half-life below 30 years and very low and limited concentrations of longer-lived radionuclides. This category also includes the sub-category very low-level waste (VLLW).

8. A new version of this draft Plan has been published by the Spanish Government in January 2020. At the time of editing the present report, this version is in public hearing, as a part of the strategic environmental assessment procedure: www.miteco.gob.es/es/cambio-climatico/participacion-publica/eae-pniec.aspx.

(b) Special waste (SW). This category includes materials that have been activated in reactor (such as reactor internals or reactor instrumentation), components of nuclear fuel assemblies and neutron sources.

(c) High-level waste (HLW). This category includes waste that contains significant concentrations of α, β and γ emitting radionuclides that generates heat due to nuclear disintegration. The category includes SNF declared as a waste, and vitrified waste from reprocessing activities carried out in the past.

LILW is currently disposed of in the centralised near-surface solid RW disposal facility of El Cabril, located in Sierra Albarrana (Córdoba), in operation since 1992. SW and HLW, due to its high level of radiation, cannot be managed at this facility.

The management strategy for HLW is based on a combination of wet and dry storage at each nuclear power plant site. HLW, mainly spent nuclear fuel, is stored on site in the nuclear power plant pool and additionally, in most cases, in a dry interim storage facility on site, next to the nuclear power plant buildings, called Almacén Temporal Individualizado (ATI). Currently, the nuclear power plants of José Cabrera (under decommissioning), Santa María de Garoña (in cease of operations situation since 6 July 2013, waiting for the decommissioning license), Ascó, Trillo and Almaraz have an ATI already licensed and in operation. At the time of editing the present report, another ATI is under licensing proceedings, at the Cofrentes nuclear power plant site.

The 6th GRWP set the strategy to store the SNF and any other HLW, as well as the SW, in a single centralised long-term interim storage facility called Almacén Temporal Centralizado (ATC). The ATC would host this waste for 60 years, and it would also store any other LILW that cannot be disposed of at the El Cabril facility, until a permanent disposal solution for all HLW/SW is made available (GRWP, 2006). This strategy for the temporary management of HLW/SW is still kept within the reference scenario included in the draft 7th GRWP, for the purpose of planning and calculations (GRWP, 2020). Nevertheless, the environmental documentation accompanying the draft 7th GRWP considers different options for the long-term interim storage of HLW/SW, basically a single site or several sites for the storage facilities. During the processing of the plan it shall be defined whether the strategy of a single centralised facility is maintained, as in the current 6th GRWP.

With regard to the final disposal of HLW/SW, Spain has adopted a strategy based on the construction of a deep geological disposal facility (Almacenamiento Geológico Profundo – AGP). It is broadly accepted at the technical level that, at this time, deep geological disposal represents the safest and most sustainable option as the end point of the management of HLW, as stated in the preamble of Directive 2011/70/Euratom, establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste. As a matter of fact, the bulk of Enresa R&D efforts in recent years have been devoted to this purpose.

Financial responsibilities for the back-end

The Spanish state takes over a large degree of responsibility in the decommissioning of nuclear facilities and RWM scheme. As already mentioned, radioactive waste management, dismantling and decommissioning of nuclear facilities is an essential public service under the responsibility of the state. The public company entrusted with the provision and management of this service is Enresa, whose activities are governed by Royal Decree 102/2014, and its financing system is set in the 6th additional provision of Law 54/1997. Enresa assumes responsibility for the management of RW once it is handed over to Enresa, and it takes responsibility for the dismantling and decommissioning of a nuclear facility after its final shutdown, upon approval of the Ministerial Order that grants the dismantling license and transfers such a license to Enresa.

Regarding the financing of the decommissioning activities and RWM costs, Spain works on the basis of the Polluter Pays Principle (EC, 2018).

Nuclear power plant license holders are indeed financially liable to cover all costs related to the decommissioning and RWM of their plants. On the one hand, nuclear power plant license holders are directly responsible for RWM operations such as fuel removal from the reactor and on-site interim pool storage, prior to the handoff of the SNF to Enresa for transfer to an interim storage facility. On the other hand, in order to finance GRWP-relevant decommissioning and RWM activities to be carried out by Enresa, nuclear power plant license holders must pay fees into a dedicated fund, the Fund for the financing of the activities included in the General Radioactive Waste Plan ("GRWP Fund", or "the Fund"), which is held and managed by Enresa. The supervision and control of the transitory investments concerning the financial management of the Fund correspond to an interministerial Monitoring and Control Committee that is attached to Miterd, as established in the 6th additional provision of Law 54/1997. Such fees must be satisfied by the nuclear power plant license holders throughout the entire operational lifetime of their reactors. They are also liable to pay extra fees in case they opt, on their own will, for an early final shutdown of their plants.

After a legal amendment in force since 2010, most of the income of the Fund comes from the fees to be paid by the nuclear power plant license holders, levied per gross nuclear kWh generated, with a fixed unit rate in the range of 8.25-9.75 USD/MWh in 2019. As of 1 January 2020, the tariff has been increased by +19.3%, upon approval of Royal Decree 750/2019 which modifies the unit rate of the fees to be paid by operating nuclear power plants[9].

The funding system

Spain has a well-structured centralised funding scheme in place to finance the decommissioning of its nuclear facilities and RWM costs. The Spanish funding scheme is two-pronged: (1) any pre-decommissioning activities are under the direct operational responsibility of the license holders, and (2) long-term activities such as radioactive waste management or dismantling and decommissioning of nuclear power plants are managed by the public company Enresa.

In Spain there is a single external joint fund to cover the costs for the management of RW (including SNF) and the decommissioning of nuclear facilities: the Fund for the financing of the activities included in the GRWP.

The Fund, which is regulated by the 6th additional provision of Law 54/1997, is held and managed by Enresa, and its purpose is to finance the activities included in the GRWP, the government plan that sets out the reference framework for national strategies on dismantling, decommissioning and management of SNF and RW.

Fund scope

The Fund must cover the cost of all the activities included in the GRWP, i.e. relevant expenditure incurred for dismantling and decommissioning of nuclear facilities, disposing of decommissioning waste, safely handling and disposing of HLW (including SNF), SW and LILW, as well as all relevant expenses relating to the technical tasks and support services required to undertake those activities, including structural costs and R&D activities. Further, the Fund must pay allocations to municipalities located close to nuclear power plant sites where SNF is interim-stored, to nuclear power plant sites being dismantled, or nearby RW storage and disposal facilities. The assets held in the Fund are strictly earmarked for, and therefore limited to, their use in GRWP activities.

More precisely, the Fund covers, among others, the following GRWP-related activities and concepts (GRWP 2020):

a) Management of LILW, from the handoff to Enresa until its final disposal, including support services, ecological taxes and allocations to municipalities close to centralised LILW storage and disposal facilities (i.e. El Cabril radioactive waste disposal facility).

b) Management of HLW, including SNF, and SW, from the handoff to Enresa through interim temporary storage, until its final disposal at the DGR, including support services, ecological

9. Royal Decree 750/2019, of 27 December, amending the fixed unitary fee relating to the non-fiscal public allowance used to fund the services provided by Empresa Nacional de Residuos Radiactivos, S.A., S.M.E., (Enresa) to nuclear power plants in operation.

taxes and allocations to municipalities located close to nuclear power plant sites where SNF is interim-stored, or nearby other HLW/SW interim storage facilities.

c) Dismantling and decommissioning of nuclear facilities (activities under Enresa responsibility): dismantling and decommissioning of nuclear power plants, dismantling and decommissioning of nuclear facilities of the fuel cycle (nuclear fuel assembly manufacturing plant at Juzbado, Salamanca), including the decommissioning and restoration of legacy uranium mines and milling facilities.

d) Management of other RW such as radioactive lightning rods or special radioactive sources, RW from radioactive facilities, operations after particular events or incidents, and provision of support in case of emergencies.

e) Support for Enresa R&D projects and activities.

f) Support for Enresa's structure: high-level management, international affairs, technical, administrative and any other horizontal activities, including the required support to Enresa Headquarters in Madrid.

The Fund also covers the pre-decommissioning activities to be carried out by the nuclear power plant license holder during the first years after the final shutdown of the plant, until the approval of the Ministerial Order that grants the dismantling license. In addition, this Ministerial Order transfers the dismantling license to Enresa, which becomes the license holder of the facility. In contrast, shutdown activities, including the management of SNF stored in the nuclear power plant pool during this period, are not covered by the Fund and remain under the direct financial responsibility of the nuclear power plant license holder.

As already mentioned, RWM and SNF management costs are only covered by the Fund once Enresa takes over responsibility for the radioactive waste. In particular, the Fund covers the loading operation of SNF into dry storage casks and their transfer to the ATI, in addition to the cost of the casks themselves and the cost of any equipment and systems required to manage the casks (e.g. typically, the replacement of the crane at the nuclear power plant fuel building).

Furthermore, article 38 bis of Law 25/1964 establishes that the state shall take over the ownership of RW once it has been definitively disposed of in a final disposal facility. In addition, the state is responsible for undertaking whatever surveillance may be required following the decommissioning of a nuclear facility.

This particularly clear assumption of state responsibility, emphasised by a firm and transparent regulation, makes the Spanish system rather unique compared to other OECD countries: while nuclear power plant license holders in Spain are held financially responsible for the costs of decommissioning and RWM, the management of those activities, especially over the long term, falls exclusively within the competence of the state. This policy gives Spain an advantage: the ability to closely align legislative projects with long-term decommissioning and RWM strategies. Overall, the comprehensive management of all aspects of decommissioning and RWM allows for a high degree of coherence and traceability throughout the funding and management scheme. In return, this arrangement requires that cost estimates consider realistic and comprehensive future costs in order to avoid transferring residual or unforeseen financial responsibilities to the state, and thus ultimately to the taxpayers.

Fund management responsibility

The Fund is held and managed by Enresa as an external joint earmarked fund without legal personality, under direct public control. However, the supervision and control of the transitory investments concerning the financial management of the Fund correspond to an interministerial Monitoring and Control Committee that is attached to Miterd through the Secretary of State for Energy (RD 102/2014, art. 8).

Enresa is also responsible for monitoring and ensuring that the financial provisions are adequate to cover future liabilities, but does not hold a regulatory power to adjust the level of the unit rates of the fees that go into the Fund. Such a prerogative is the exclusive remit of the government, whose decisions are nonetheless informed by Enresa-provided expertise.

Fund build-up mechanisms

To finance the costs of the activities under the GRWP, Enresa relies on fees to the license holders of nuclear facilities and other radioactive waste producers, direct payments for RWM services, and yields on the transitory financial investments of the Fund. Enresa determines the amounts that are payable to the Fund and annually reports to the Spanish government which, in turn, can adjust the unit rates by regulatory means, if necessary.

There are four types of revenue sources to the Fund, as established in the 6th additional provision of Law 54/1997 and its amendments:

1) *Fees relating to the electricity tariff*. It is a tax on tolls applied to electricity transmission and it currently represents a small amount of income, as the tax rate is only 0.001% of the total monthly receipts for this concept. These fees were the main funding source before 2005. Nowadays they are mainly used to cover, among others, decommissioning and RWM (including SNF) costs of nuclear power plants permanently shut down before 1 January, 2010, as well as any costs related to dismantling and closure tasks carried out as a consequence of the activity of legacy uranium mines and milling facilities before 4 July, 1984.

2) *Fees to nuclear power plant license holders levied per kWh of nuclear electricity generated*. Introduced partially in 2005 and totally in 2009, these fees finance all dismantling, decommissioning and RWM costs of nuclear power plants (other than the ones already considered in the previous paragraph), including the management of radioactive waste and SNF from nuclear power plant operation – regardless of the date of generation. These fees must be satisfied on a monthly basis by the nuclear power plant license holders, throughout the operational lifetime of their reactors. The sums to be paid result from multiplying the monthly gross nuclear electricity generated, measured in kWh, by a specific value for each facility, which is obtained from multiplying the fixed unit rate of 8.36 USD/MWh – 9.98 USD/MWh as of 1 January 2020 – by a corrector coefficient in accordance with the reactor type and the gross electrical power level of the nuclear power plant (6th additional provision of Law 54/1997; Royal Decree 750/2019).

   Should the nuclear power plant license holder opt, on his own will, for an early final shutdown or cease of operations of his plant, the taxable base shall be equal to the financing shortfall in the Fund, if any, existing at the time of cease of operations of the facility, and the resulting fee shall have to be satisfied by the license holder during the three years after cessation. In this case, the amount of the fee to be paid shall be determined by Miterd, on the base of an economic study carried out by Enresa.

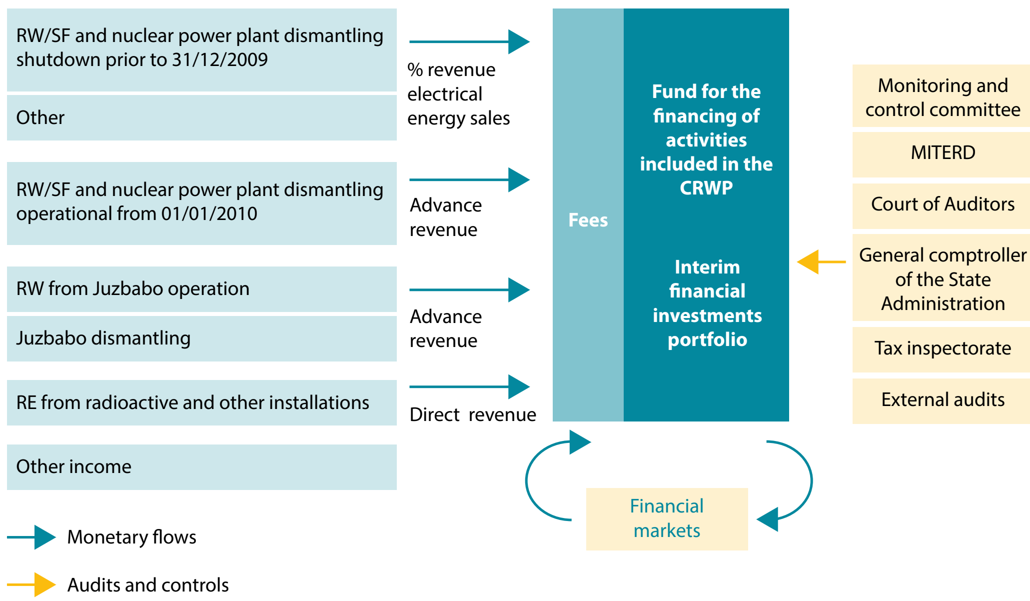
3) *Fees to the license holder of the nuclear fuel assembly manufacturing plant at Juzbado, Salamanca*. Introduced in 2009, these fees finance the provision of services for the management of RW arising from the operation of the nuclear fuel assembly manufacturing plant located at Juzbado, as well as the dismantling and decommissioning of this facility. These fees must be satisfied by the license holder of the plant at the end of each natural year, throughout its operational lifetime. The sums to be paid result from multiplying the annual amount of nuclear fuel assemblies manufactured, measured in metric tonnes, by a fixed unit rate of 1 811.25 USD/tonne (6th additional provision of Law 54/1997).

   The methodology applied for the calculation of the fixed unit rate in this case is similar to that used for the nuclear reactors: an updated future cost of dismantling, decommissioning and RWM is estimated and divided by the expected future production of the manufacturing plant, resulting in a unit cost.

4) *Fees to the license holders of other radioactive facilities*. Also introduced in 2009, these fees finance the provision of services for the management of RW produced by any other radioactive facilities not considered in previous paragraphs: medical, research, industry and agricultural installations, and other small RW producers. These fees are directly satisfied by the license holder at the time when the service is provided, and their amount depend on the type and quantity of RW handed off to Enresa for management and disposal, in accordance with the fixed unit rates established in the 6th additional provision of Law 54/1997.

The transition from fees relating to the electricity tariff to fees per kWh of gross nuclear electricity generated was progressively done since 2005, and finalised in 2009, long before the approval of the Euratom Directive on waste management. The accordingly amended 6th additional provision of Law 54/1997 sets out that, as of 1 January 2010, all relevant costs for dismantling, decommissioning and RWM are to be paid for by the license holders of operating nuclear power plants, while only a minimal fraction is to arise from the fees relating to the electricity tariff. This policy reform led to a significant increase in the Fund annual income – from USD 146 million to USD 536 million per year between 2005 and 2010. In 2018, each nuclear power plant paid Enresa fees proportional to its total gross electricity output, which ranged from USD 8.25/MWh to USD 9.75/MWh (Enresa, 2018). In 2019, a +19.3% increase of the fixed unit rate component of these fees was subsequently approved by the government, through Royal Decree 750/2019. Currently, these fees represent about 99% of the Fund income, so the nuclear power plant license holders, who are the most significant RW generators, are also the main contributors to the Fund.

Figure 13.1:
Synthesis of the financial inflows to the Fund for the financing of the activities included in the General Radioactive Waste Plan



Source: Enresa.

Fund adjustment mechanisms

Fees in the form of taxes are legally set by the state, self-assessed by nuclear power plant license holders, and collected by the Spanish Tax Agency. Funds are then transferred to Enresa from the Treasury. To factor in the specificities of each nuclear power plant, two corrective factors are included in the calculation of the fees, accounting for the future generation of LILW, HLW/SNF, and the dismantling and decommissioning costs of the facilities (6th additional provision of Law 54/1997; Royal Decree 750/2019).

The 6th additional provision of Law 54/1997 establishes that the fixed unit rates used to determine the fees can be revised by the government by means of a Royal Decree, on the base of an updated economic and financial study on the cost of the activities included in the GRWP, to be prepared by Enresa. The unit rates currently in force are those established by Law 11/2009[10], with the exception of

10. Law 11/2009, of 26 October, regulating listed public limited real estate investment companies.

the unit rates regarding other radioactive facilities, modified by Law 2/2011[11], and the tariff relative to the fees to operating nuclear power plants, modified through Royal Decree 750/2019.

Furthermore, any future costs corresponding to nuclear power plants or nuclear fuel manufacturing facilities that, after their respective cease of operations, had not been foreseen during the period of operation of the facilities, shall be covered by additional fees collected from the tax on the electricity tariff. On the other hand, if a nuclear power plant license holder opts, on his own will, for an early final shutdown or cease of operations of his plant, any remaining shortfall in the Fund shall have to be satisfied by him during the three years after cessation (6th additional provision of Law 54/1997).

The cost side

Process and responsibilities

In Spain, cost estimations are carried out by the Planning and Technical Departments of Enresa. As a part of the periodical revision of the GRWP, Enresa is required to submit to the Ministry a revised proposal of the economic and financial projections and requirements that are necessary to carry out the activities included in the GRWP (RD 102/2014, art. 10).

Methodology

The cost estimates are computed either on the basis of extrapolation of current data, e.g. for LILW management, R&D and structural costs; on the experience of other countries with similar activities, or on in-house estimates based on the specific studies performed, e.g. for costs regarding the centralised interim storage facility, HLW/SNF disposal, or nuclear power plant decommissioning and dismantling. Decommissioning and related RWM cost data are determined through a bottom-up approach for all nuclear power plants. In most cases, costs were estimated using a blend of different methodologies and databases, depending on the nature of the costs and the own experience of Enresa (e.g. the operation of the El Cabril centralised disposal facility, or the decommissioning of José Cabrera nuclear power plant).

The cost estimates for all the activities included in the GRWP are reviewed and updated at least once a year. It is evident that these estimates are complex for a number of reasons, such as the absence of any similar facility in the world in the case of the DGR, or the difficulty to establish standard costs for the dismantling and decommissioning of nuclear power plants. Enresa includes in the calculations slack variables that allow it to predict extra costs, where appropriate. However, this deterministic calculation model is not capable of quantifying possible risks in the actions derived from unforeseen events. It is therefore necessary, and in this line Enresa is working nowadays, to introduce probabilistic models in the estimation of costs. Basically, these models will allow, by means of a correct and adequate definition of the variables involved in assessing and quantifying those risks, to simultaneously compare its results with the ones obtained by deterministic calculation.

The future costs are evaluated based on the strategies foreseen in the GRWP and considering a time horizon that, according to current hypotheses, extends to the year 2100. At present, the assumptions underlying the calculations of the costs are compiled in the reference scenario set out in the draft 7th GRWP (GRWP, 2020):

a) cease of operations of the nuclear power plants in accordance with the schedule for the orderly final shutdown of the Spanish nuclear power plants, as established in the Protocol of intentions between nuclear power plant owners and Enresa signed in March 2019 (Enresa, 2019), which is based in the provisions of the draft Spanish National Integrated Energy and Climate Plan 2021-2030 (PNIEC, 2019);

b) open nuclear fuel cycle, i.e. SNF reprocessing is not considered;

11. Law 2/2011, of 4 March, on sustainable economy.

c) commissioning of a centralised interim storage facility for HLW/SNF in the year 2028, that would host RW for 60 years and would also store any other LILW that cannot be disposed of at the El Cabril facility; and

d) immediate and complete dismantling strategy for all light water reactors. The nuclear power plant site preparation activities would be started at least three years before the date scheduled for the cease of operations. The grant of the dismantling license and the transfer of such a licence to Enresa, which will become the license holder of the facility, and the start of the dismantling works, are foreseen at least three years after the cease of operations of the nuclear power plant. The estimated time duration of the dismantling works, including restoration, is ten years. Following the decommissioning of the facility, the time duration of the site surveillance period is ten years[12].

In Spain, GRWP-related cost estimates are discounted. The 5th GRWP, valid between 1999 and 2006, was initially based on a discount rate of 2.5%. However, this rate was later downscaled to 1.5% in order to better comply with the market environment (WU, 2007). In the current 6th GRWP, the discount rate of 1.5% was maintained and it is still used.

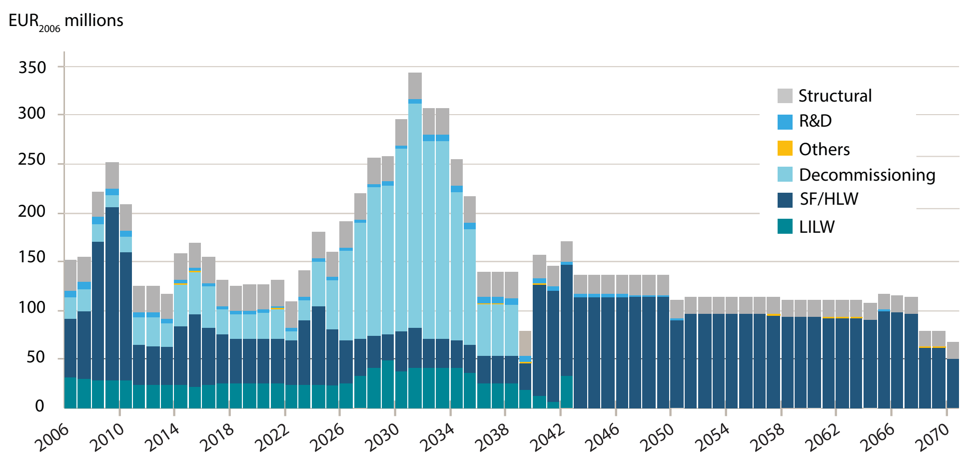
To provide a sense of scale, the "Economic and Financial Study" carried out by Enresa in June 2018 estimated that the undiscounted sum of the future expenses, as well as those already incurred since 1985, was USD 24.6 billion, while the remaining expenses as of 1 January 2019, amounted to USD 19.3 billion. According to the estimates of Enresa, the present value of these remaining costs, discounted with a rate of 1.5%, was USD 13.37 billion.

Assets, investment rules and performance

In the 6th GRWP, enacted in 2006, the present value of the future liabilities in the period between 2011-2070 was estimated at USD 11.12 billion (GRWP, 2006). The above-mentioned study by Enresa, of June 2018, which updated the cost estimations of the activities included in the 6th GRWP, assessed that the present value of the future liabilities in the period 2019-2100 was USD 13.37 billion. On the other hand, as of 31 December 2018, the balance of the Fund was USD 7.09 billion.

Of the estimated future liabilities, around 58% represented RWM activities, while around 25% were attributed to dismantling and decommissioning duties. Another 17% were allocated to structural and R&D costs. This underlines the important magnitude of the costs foreseen for RWM, which is arguably the area affected by the largest amount of uncertainty as it will be the major cost driver over the long term (Figure 13.2).

Figure 13.2:
Distribution of GRWP-related costs per year and item in EUR millions (2006 calculation). 1 EUR = 1.25 USD



Source: GRWP, 2006: p. 164.

12. The time durations mentioned in this paragraph are just assumptions for planning purposes. There is not any reference to these values in the Spanish regulation.

At the end of 2013, the assets in the Fund were invested in non-speculative activities in financial markets with a targeted rate of return of 3% to 4% (IEA, 2015). The average return rate on the invested assets of the Fund was 3.13% in 2015, 3.15% in 2016, 3.28% in 2017, and 3.07% in 2018, leading to an average return rate of 3.16% from 2015 to 2018 (Enresa, 2018). As a point of comparison, the minimum target return of the Fund is the Spanish cost of living plus a minimum real yield that is currently 1.5% (EC, 2018).

Fund asset management rules

The Monitoring and Control Committee is responsible for establishing investment criteria and general principles for the management of the Fund. Additionally, in its asset constitution and management strategy, Enresa is committed to comply with the principles of security, profitability, and liquidity enshrined by Royal Decree 102/2014. Article 7 of this Royal Decree also defines the categories of assets the Fund can be composed of. These are:

a) marketable fixed-income or equity securities listed on an officially recognised and regular trading organised market open to the public or at least to financial institutions, state debt, mortgage-market securities and other financial assets and instruments;
b) derivative instruments for the structuring, transformation or hedging of investment transactions in the financial investment portfolio;
c) deposits at financial institutions, creditors' rights and loans that must be formally executed in a public document or by policy before a Notary Public;
d) real estate;
e) foreign securities listed on foreign exchanges or in organised markets; and
f) any other investment instrument or asset that the Monitoring and Control Committee deems appropriate and which complies with the financial management principles of the Fund.

More recently, the Monitoring and Control Committee has enforced the following restrictions on the investment options of the Fund, which come on top of those established by Royal Decree 102/2014 (EC, 2018):

a) 100% may be invested in fixed-income securities;
b) up to 20% can be invested in index-linked products with 100% guaranteed principal;
c) no equity or real estate investments are permitted;
d) long-term investments must be investment grade;
e) currency risk must be hedged; and
f) a maximum of 20% of the Fund can be invested in assets which have to be recorded at market value for accounting purposes.

Current asset portfolios and management strategy

In the Fund, Enresa holds financial assets that can be classified as follows (EC, 2018; Enresa, 2018):

a) loans and receivables, including financial assets that have no commercial origin, or originate from the sale of assets;
b) investments maintained up to maturity, including debt securities with fixed maturity dates;
c) other financial instruments at fair value through profit or loss, including hybrid financial assets like structured bonds; and
d) derivatives, in a small amount and used for hedging purposes only.

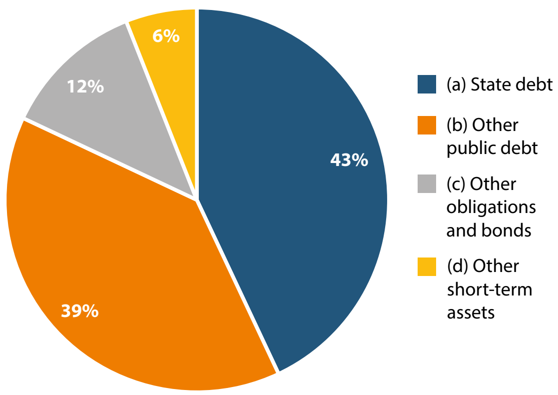
The investment portfolio of Enresa as a whole is managed with the objective of optimising the financing model for RWM in Spain as initially provided in the 6th GRWP, which determines a long-term time frame and envisages neither partial divestments nor profitability targets in real terms. The valuation criteria of the securities portfolio of the Fund, with the exception of assets at fair value through profit and loss, is the amortised cost with financial accrual of interest – and not market value – because amortised cost is the criterion that best allows for the optimisation of the model (Enresa, 2016).

Regarding the categorisation of the investment portfolio, as seen on Figure 13.3, the company distinguishes four classes of assets (Enresa, 2018):

a) state debt, including Spanish public debt, e.g. Spanish treasury bonds;
b) other public debt, including financial assets issued by Spanish government agencies, supranational bodies, and the public debt of other countries;
c) other obligations and bonds, including a diverse range of financial assets from different issuers; and
d) other short-term assets, including, among others, financial assets and deposits issued by financial institutions.

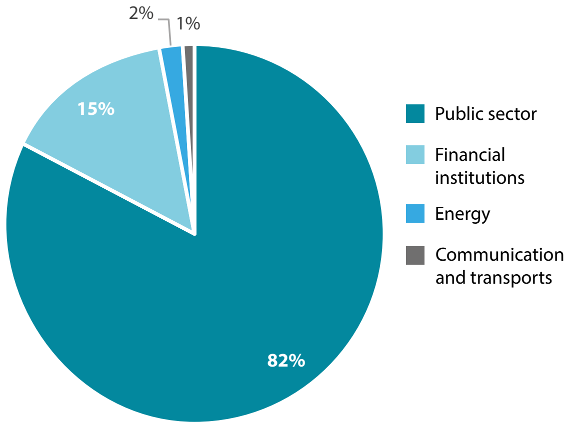
Enresa also provides another sector-based breakdown of the investment portfolio (Figure 13.4).

Figure 13.3:
Investment portfolio of Enresa by asset class in 2018



Source: Based on Enresa, 2018: p. 93.

Figure 13.4:
Investment portfolio of Enresa by sector in 2018



Source: Based on Enresa, 2018: p. 94.

Funding adequacy review mechanisms

Enresa is responsible for ensuring that the funding is consistent with the estimates of future liabilities. Therefore, Enresa regularly monitors the adequacy of the financial reserves set aside for decommissioning and radioactive waste management. The decommissioning and RWM cost estimates proposed by Enresa have to be updated every year and reported to Miterd.

In accordance with art. 10 of Royal Decree 102/2014, the Ministry is responsible for the strategic management, monitoring and control of the actions and plans of Enresa, both technical and economic, through the Secretary of State for Energy. To this end, Enresa has to submit to the Ministry:

a) during the month following each calendar quarter, a budget monitoring report for that quarter;
b) during the first six months of every year: (1) a report that includes the technical and economic aspects related to the activities of the previous year, and the degree of compliance with the corresponding budget, and (2) an updated economic and financial study of the cost of the activities included in the GRWP, including the adequacy of the existing financial mechanisms to that cost; and
c) before 30 November of each year, a technical and economic justification of the annual budget corresponding to the following year, and its forecast for the next four years, according to the provisions of the updated economic and financial study on the cost of the activities of the GRWP.

Additionally, Enresa publishes audited financial statements each year, which are made public. As Enresa is a public sector company, the Spanish state can carry out its control via the Ministry for Economy, the General Comptroller in the Ministry of Finance, and the Court of Auditors, i.e. the independent supreme governmental accounting body (WU, 2007).

On the other hand, art. 8 of Royal Decree 102/2014 states that the Monitoring and Control Committee has to prepare reports every six months on the status of the Fund and its investments, including a rating of its management, with appropriate observations. Such reports are submitted to Miterd and to other Ministries in charge of Finance and Science and Innovation.

Recent progress on funding adequacy

In February 2019, the draft Spanish Integrated National Energy and Climate Plan 2021-2030 (PNIEC, 2019) submitted by the Spanish Government to the European Commission, envisaged that the nuclear phase-out should be completed by 2035 at the latest. Based on the provisions of this draft Plan, a Protocol of intentions between nuclear power plant owners and Enresa was signed in March 2019 (Enresa, 2019), establishing the schedule for the orderly final shutdown of the Spanish nuclear power plants. By means of this Protocol of intentions, the nuclear power plant owners agreed on dates for the cease of operations of their nuclear power plants, which implies that the planned average operating lifetime of the seven reactors currently in operation shall be 45.7 years.

This agreement has a very positive impact on the estimated income of the Fund. In fact, previous revenue estimations of Enresa were based on a reference scenario that considered an average nuclear power plant operating lifetime of 40 years, according to the 6^{th} GRWP. Besides, the fees per kWh of gross nuclear electricity generated by nuclear power plants have to be satisfied by the license holders throughout the whole operational lifetime of their reactors. Consequently, the collection period of these fees shall now be extended by, on average, 5.7 years per reactor, thus significantly increasing the total income of the Fund.

Additionally, in December 2019, the Spanish government approved Royal Decree 750/2019, which modifies the unit rate of the fees to be paid by operating nuclear power plants. The objective of this regulation is to increase the level of back-end fees collected from nuclear power plant generation, increasing by +19.3%, as of 1 January 2020, the fixed unit rate component used to calculate the final fee to be paid to Enresa by nuclear power plant license holders. The Spanish government highlighted that this corrective action was necessary to allow the country to remain on track fulfilling its long-term funding adequacy targets, as this unit rate had not been revised since 2010, and needed to be adjusted to recent variations in the future cost estimates of Enresa.

The revision of this unit rate also highlights the importance of institutional co-ordination in the public management of nuclear liabilities. Indeed, as Enresa does not hold a regulatory power to revise the unit rates, which can only be modified by governmental Royal Decree, the future adequacy of the Fund to cost forecasts will depend on the timeliness with which the cost deviations spotted by Enresa in its economic and financial updates are translated into actual funding system adjustments. Systematising and streamlining functional synergies between relevant governmental bodies thus appears to be a rewarding area for policy improvement, in view of decisions whose technicality and sizeable financial implications demand effectual feedback between public institutions.

To complete this list of recent developments seeking to improve the funding adequacy for decommissioning and RWM in Spain, it is necessary to mention that in March 2020 Enresa submitted to the Ministry a draft 7^{th} General Radioactive Waste Plan (GRWP, 2020) which, at the time of editing the present report, still has to go through the different preceding stages before it may be approved, including a strategic environmental assessment procedure. The whole process may take about two years before the Plan is approved by the Council of Ministers.

The draft 7^{th} GRWP is based on an updated reference scenario that takes into account, among others, an immediate and complete dismantling strategy for all light water reactors, and the nuclear power plant cease of operations schedule agreed in the Protocol of intentions between nuclear power plant owners and Enresa. Thus, this draft Plan should provide the basis for a number of key strategic decisions on decommissionong and RWM and, consequently, it should allow for a more precise estimation of some of the costs of the activities included in the GRWP.

Conclusion

Spain has a well-structured, centralised funding system in place to finance the decommissioning of its nuclear facilities and the radioactive waste management costs. The Spanish funding system is two-pronged: (1) any pre-decommissioning activities are under the direct operational responsibility of the license holders, and (2) long-term activities such as radioactive waste management or dismantling and decommissioning of nuclear power plants are managed by the public company Enresa. Both activities are funded from an Enresa-managed Fund which is primarily supported by nuclear power plant license holders.

The Spanish state takes on a large degree of responsibility in the decommissioning of nuclear facilities and RWM. In Spain, radioactive waste management, dismantling and decommissioning of nuclear facilities are thus considered an essential public service under the responsibility of the state. This make it possible to manage and finance these activities under a single system, while keeping nuclear power plant license holders responsible for assuming their own relevant liabilities, notably in case of cost overruns. This provides a strong backbone to the overall financing system, as well as a fair degree of clarity and foreseeability. However, due to the transfer of back-end management responsibilities to the state, it is important that estimates of future costs are realistic and comprehensive in order to avoid transferring residual or unforeseen financial responsibilities to the state, and thus ultimately to the taxpayers.

Moreover, the approval, in due time, of the 7th GRWP will represent a major step forward for the nuclear sector in Spain. Indeed, the forthcoming 7th GRWP is likely to remove key uncertainties about the future of the Spanish nuclear fleet, to rebalance funding streams for decommissioning and RWM, and to provide license holders and Enresa with a clarified decommissioning and RWM schedule and governance vision for the medium and long-term.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 14

Sweden: Country case study

KEY FACTS	
Funding model	External joint fund: decommissioning & RWM in one fund ("Nuclear Waste Fund") that is managed by public authority.
Assets (12.2018)	• USD 7.59 billion
Liabilities (2019)	• USD 11.9 billion (undiscounted sum of future expected costs) **NB: All monetary amounts are provided in USD. The average 2018 exchange rate used for conversion is 8.7 SEK/USD.**
Avg. effective real return (2014-2018)	• 2.74%
Discount rate	Discount rates with adjustments for risks for different assets classes (notably an ultimate forward rate of 4.2%), depending on maturity.
Assumed operational lifetime of nuclear power plants	50 years (+ at least 6 years of remaining operational time)
Investment rules	Recently broadened to allow equity as well as treasury bills, government bonds (nominal and index-linked), and specific mortgage-backed bonds.
Evaluation of fund adequacy	Assets monitored in and yearly reports. Fund adequacy and decommissioning/RWM cost estimates reviewed every three years.
Issues at stake	• Operators recently closed facilities earlier than scheduled due to lack of profitability. Potential risk for negative feedback between lacking profitability and funding streams' sufficiency, because of early shutdowns. • Recent transfer of responsibility for supervision of the Fund from Radiation Safety Authority to National Debt Office could indicate broader acceptance of governmental responsibility in D & RWM. • Advanced DGR project and operation of central interim storage facilities. • If there are remaining assets in the Fund when the programme is completed, the means are to be refunded to Fund contributors.

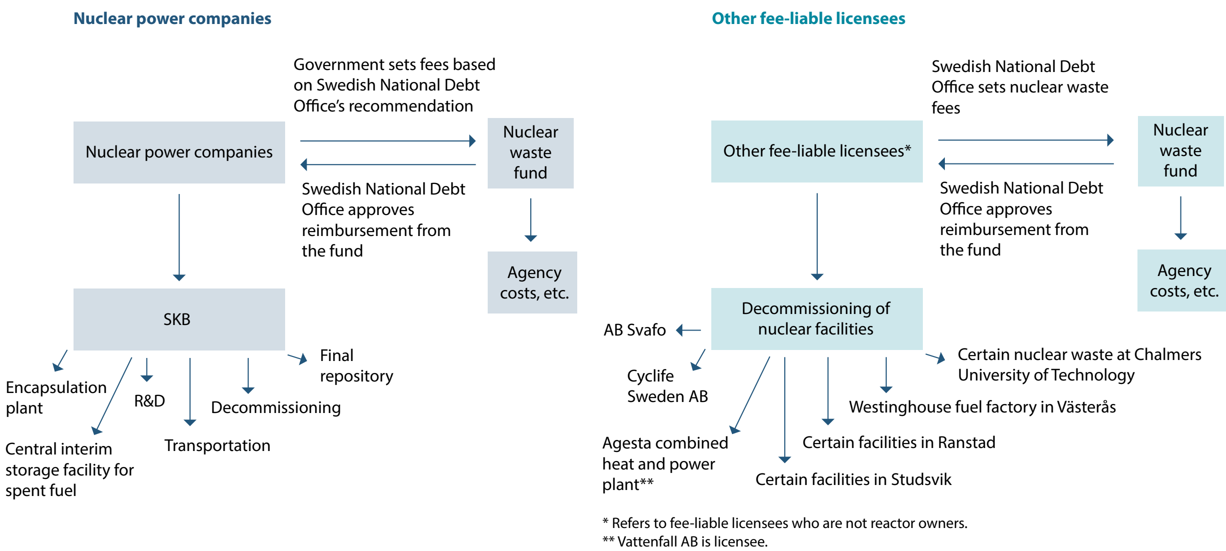
Decommissioning and RWM in Sweden

Sweden has a sophisticated, advanced and well-organised infrastructure for managing its decommissioning and radioactive wastes, backed by solid funding mechanisms (i.e. an independent external Nuclear Waste Fund overseen by the government) and running on a sound practice of regularly re-assessing cost estimates and updating decisions on nuclear waste fees.

Recent changes in the Financing Act (Act [2006:647] on Financing of Nuclear Residual Products) have broadened the investment opportunities for the Swedish Nuclear Waste Fund. In the new legislation, the possibility for the Fund to invest in risky assets are reflected in the new definition of the risk margin, one of the two guarantees that a license holder must provide. The risk margin must cover uncertainties related to liabilities, as well as the uncertainties related to the assets, i.e. the expected return of the Fund. The overall objectives of the financing system to uphold the Polluter Pays Principle (PPP) and protect future taxpayers are strengthened with this change in legislation.

In 2018, the Swedish Nuclear Waste Fund saw somewhat lower real returns. It is impossible to say to which extent the recent changes regarding the investment rules have played a role here. However, the long-term effect of these changes appears adequate to escape from an investment profile limited to assets for which the low interest rate market environment has not been ideal in the last years. Further, while the Fund remains an autonomous entity, the recent transfer of the primary responsibility for its administrative operation to the Swedish National Debt Office (SNDO) might be a concrete way to strengthen the government's role as the ultimate guarantor in the Swedish financing system for decommissioning and RWM – or might at least signal the state's willingness to enforce more direct control in this regard.

Figure 14.1:
Swedish fund management models for nuclear power plant operators and other fee-liable licensees since 1 September 2018



Source: Nuclear Waste Fund's website 2019 (http://www.karnavfallsfonden.se/informationinenglish/thefinancingsystem.4.697303b91648b46fd8d21cd.html). **It should be noted that decommissioning is operated directly by licence holders.**

Nuclear power plant lifetime

Currently, eight nuclear power reactors are in operation in Sweden, making up for around 40% of the Swedish electricity supply and running since the late 1970s or early 1980s. Two reactors, R2 and R1 were shut down at the end of 2019 and 2020 respectively. This followed six shutdown of nuclear reactors in previous years including two research reactors. While operating licenses for nuclear power plants in Sweden are not limited in time, they are subject to a periodic review by the Swedish Radiation Safety Authority (SSM) (WNA, 2019). The six remaining units have made large investments in the refurbishment and safety upgrades required to continue their operations beyond 2020 (IEA, 2019). In 1980, Sweden decided to phase out nuclear energy by 2010, under the condition that adequate alternatives exist by then to maintain the energy supply. The implementation of this policy was largely deferred and finally abandoned in 2010. Instead, the further operation and the replacement of up to ten reactors with new units was allowed and reaffirmed, along with other nuclear policy orientations outlined below, in a multi-party Framework Agreement signed in 2016 (WNA, 2019). Accordingly, the long-term policy environment for nuclear energy in Sweden is rather positive.

For the time being, nuclear power plant operators must base their decommissioning and RWM cost estimates on a total of 50 years of operating time and a remaining operating time of 6 years, while the operators even expect real lifetimes for their reactors of up to 60 years (Swedish Government, 2017a; Ström, 2018; WNA, 2019). However, different operators have recently taken the decision to shut down some of their nuclear reactors earlier than scheduled citing economic considerations. In 2015, it was decided to stop the operation of four reactors by 2020 – two have already been taken down. Operators said it was difficult to be profitable in a context of comparatively high taxes on produced energy and a falling price overall for electricity. This reveals the difficult equilibrium between funding foreseeability and changes in the economic environment, although funding obligations remain in place and fees must still be paid into the Fund within a three-year period even in case electronuclear production is terminated – in addition to which operators must also provide two types of financial guarantees to the Fund. It appears that maintaining favourable – or at least sustainable – economic conditions for the operation of nuclear power plants throughout their assumed lifetimes is appropriate and conducive to the fulfilment of cost liabilities for decommissioning and RWM, regardless of policy orientations on nuclear energy. Even if a phasing-out is envisaged, it indeed seems favourable to hold the framework conditions steady and at a level where nuclear power plants can operate in a profitable manner over the assumed lifetime, for the sake of securing funding for decommissioning and RWM liabilities.

On this topic, in 2016, Sweden's key political parties signed a multi-party Framework Agreement on Energy Policy, which presented important clarifications to nuclear energy policy. First, it dispelled any prospect of a ban on existing reactors, provided they meet safety and regulatory requirements. Second, it allowed new constructions at existing nuclear sites, up to a maximum of ten reactors, and provided the government does not directly or indirectly subsidise it. Third the "nuclear tax" was to be, and has been, suppressed as of January 2018. This tax on installed nuclear thermal capacity was first introduced in the late 1990s, in replacement of an earlier tax on generation that applied to both nuclear and hydropower since the 1980s, and had increased over time to equal around USD 8/MWh in 2015. It constituted about one-third of the operating costs of nuclear power and, in combination with low wholesale electricity prices in the Nordic market area, severely hampered the economics and competitiveness of nuclear energy with respect to other generating options, according to the IEA (2019). More broadly, the 2016 Framework Agreement also stated that permission should be given to replace current reactors as they reach the end of their economic lifetime; and that the SNDO should examine the need for changes to the operating periods in the Fund. Furthermore, while it stated that Sweden's electricity supply shall come 100% from renewable sources by 2040, it did not specify whether – or how many – nuclear reactors should be shut down. The agreement nonetheless reaffirmed that the cost of RWM shall still be covered by those who generated it, and that the Swedish state will not pay for decommissioning or final radioactive waste disposal.

Waste management

A pioneering project regarding a deep geologic repository (DGR) for SNF is going through its final stage of authorisation by the government, which may take a final decision in the early 2020s following a positive review by the Swedish Radiation Safety Authority (SSM) in 2018. Next to its planned DGR, Sweden already possesses a functional central interim storage facility for SNF, the "Clab", in which used fuel from all Swedish nuclear power plants is centralised and stored in rock vaults about 30 metres below ground. Sweden also has a final repository for short-lived RW, "SFR", in which low- and medium-level radioactive waste is stored at about 50 metres below the Baltic Sea's bed. Both repositories have been operating since the 1980s. Possessing two centralised storage facilities for radioactive materials and a proper sea transporting system for wastes, the Swedish repository system is well advanced and will be completed by the DGR's commissioning.

Financial responsibilities for back-end

In Sweden, license holders in nuclear facilities bear full financial responsibility for the back-end programme and have to pay fees into a segregated Nuclear Waste Fund ("the Fund"), whose levels are set by the government based on a recommendation by the SNDO. The Nuclear Waste Fund is to provide funding for decommissioning and RWM, as well as for the treatment of SNF, legacy waste management, and regulatory oversight expenses through a single entity (Ström, 2018). In September 2018, a government decision resulted in a redistribution of responsibilities regarding the Swedish RWM financing system. Responsibilities formerly carried out by the SSM were taken over by the SNDO. Following this transfer, the SNDO is now responsible for supervising the nuclear operators' liabilities and the adequacy of the financing system, including the (re)evaluation of due fees and periodical cost estimates (Figure 14.1) (SNDO, 2018). The SNDO is also the regulator for the financing system. This change in responsibilities could be construed as a concrete measure to strengthen the state's role as the ultimate grantor in the financing system for decommissioning and RWM – or might at least signal the state's willingness to enforce more direct control in this regard.

To fulfil their back-end obligations, license holders (reactor companies) have to pay a dedicated fee and pledge financial guarantees. The expenses for the disposal of SNF and radioactive waste must be covered by revenues arising from the production of energy that has resulted in the expenses, while the long-term liability for the handling and disposal of SNF and radioactive waste is treated as a non-delegable state responsibility. This means that the Swedish state bears the ultimate responsibility for the long-term and safe management of SNF and radioactive waste. While the Swedish state can delegate the financial obligations to nuclear operators in the first place, its responsibility includes an ultimate financial liability: if it turns out a reactor owner cannot pay, and that the Fund's assets and guarantees are insufficient, the state and thereby the taxpayers must provide the necessary additional funds (NWF, 2017b; IEA, 2019). In the current arrangement, reactor companies – not their parent companies – have the primary financial liability for their activities. The state must bear any further liability that may arise if the guarantees for which the reactor companies are responsible are valued too low (SNAO, 2017). The financing system is designed with the objective of minimising this risk.

Under this premise, the recent change in legislation, which reallocated responsibilities for the financial supervision of decommissioning and RWM to the SNDO rather than the SSM appears coherent. It must however be noted that, in practice, this transfer in itself makes no difference with the previous funding arrangement. Indeed, the reallocation of responsibilities from the SSM to the SNDO does not entail the inclusion of the Fund's assets and liabilities into the Swedish Central Government's budget and debts. The Fund is an independent government agency with its own balance sheet and no staff. It is only overseen by a board appointed by the government (IEA, 2019). On behalf of the board, the Swedish Legal, Financial and Administrative Services Agency (*Kammarkollegiet*) handles the administration and asset management of the Fund – a part of said management is also operated by external managers. The Fund remains segregated from the rest of the public sector and, while each nuclear licensee holds a share in it, Fund assets are only earmarked for specific parts of the decommissioning and RWM programme as regulated in the Financing Act.

The funding system

The funding system to cover the costs of decommissioning and RWM in Sweden was established in its current form in 1996. It aims to protect Swedish taxpayers from inheriting the financial burden of future decommissioning and RWM activities. Therefore, the Nuclear Waste Fund, i.e. an external fund structure with a specific subsection for each nuclear licensee, exists to cover all decommissioning and RWM costs, including SNF management and legacy reactors and radioactive waste. In addition to the fees accumulated in the Fund each license holder must provide two guarantees. The guarantee for the credit risk amount covers the credit risk in decided, but not yet paid, fees. The guarantee for the risk margin covers, as mentioned above, uncertainties related to liabilities, (future costs of the programme), as well as the uncertainties related to the assets (the expected return of the Fund).

Purpose and scope of the Fund

In Sweden, nuclear license holders bear full financial responsibility for the back-end programme and have to pay fees into a segregated Nuclear Waste Fund, whose levels are set by the government. The Fund must cover decommissioning, RWM, SNF treatment, legacy waste management, and regulatory oversight expenses incurred in relation to all the above-mentioned activities, through a single entity (Ström, 2018). The fees do not cover the financing of the management and disposal of operational waste, which are to be paid for directly by the licensees (NEA, 2016). Within the Fund, the collected fees are earmarked for each payer and may only be used to cover the costs attributable to that particular payer (NEA, 2016b). In case of earmarked assets remaining in the Fund once all liabilities of a specific contributor are settled, a reimbursement of the arrearage to the payer is foreseen (SNDO, 2018). This measure appears particularly important in order maintain mutual trust between nuclear operators and public authorities, thereby avoiding a biased and therefore non-viable future solution which would be predicated upon available funds rather than technological and safety necessities, i.e. avoiding a solution designed to cost a sum X only because funding amounts to sum X.

Fund build-up mechanisms

The Fund is financed by fee-based contributions from reactor operators. All operators that hold a permit to conduct nuclear activities or are currently operating a nuclear reactor are fee-liable. This includes also those license holders that have run a nuclear reactor in the past, as well as those companies directly engaged in nuclear activities by any other measure, e.g. as a contractor or producer of nuclear material (Swedish Government, 1984; NEA, 2016). Funding takes place through 1) a "nuclear waste fee", and 2) financial guarantees to the government (see below).

Fee-liable licensees that operate a nuclear reactor must pay a nuclear waste fee (1) in form of a levy on each kWh of electricity produced, which is individually set for each permit holder based on calculations regarding future costs for decommissioning and RWM caused by the operator's activities. For reactor operators, fees are set every three years by the government, based on estimates provided by the industry and assessed by the SNDO. For reactor operators that no longer produce electricity, a yearly fee amount is set in a similar way. The level of contribution to the Nuclear Waste Fund has been increased to an average of 4.6 USD/MWh of electricity produced, taking into account more recent cost estimates and an operating lifetime of 50 years for the existing nuclear power plants. For the 2018-20 period, the government has decided an average fee level of 5.7 USD/MWh (IEA, 2019), in line with a proposal from SSM that was then responsible for proposing fee levels. For those fee-liable licensees who are not reactor operators, a yearly fee amount is set directly by the National Debt Office (SNDO, 2018).

Financial guarantees

In addition to paying a fee on nuclear energy generation to the Nuclear Waste Fund, nuclear licensees must provide two types of financial guarantees to the Nuclear Waste Fund. These guarantees provide some security that future decommissioning and RWM costs will be met as and when required (EC, 2018). They correspond to the amounts and the types of acceptable guarantees determined annually by the Swedish government, on the basis of recommendations by the SNDO for nuclear power plant operators. For other fee-liable licensees, the guarantees are determined directly by the SNDO. The guarantees are managed by the SNDO and consist of a "financing amount" and a "supplementary amount". The financing amount is to cover the gap between the current level of funding and the estimated liabilities, assuming that no further nuclear waste fees are paid in. It covers the credit risk in the fees not yet paid to the Fund. For 2015–17, the total financing amount guarantee to be provided by the three reactor owners Forsmark, OKG, Ringhals and Barsebäck was set by the Swedish government at USD 3.36 billion. This guarantee is based on discounted costs (Holmberg et al., 2014). Previously the supplementary amount was meant to increase the likelihood that the funds will be sufficient to finance all remaining costs. This type of guarantee is solely determined by the Swedish government and calculated by the financial regulator SNDO as the 90th percentile of the probability distribution of possible costs (Ström, 2018). It is pledged exclusively by the three reactor owner companies. It is only to be used if the financing amount guarantee is not sufficient. In 2016, the total supplementary amount guarantee to be provided by the reactor owner companies was set by the Swedish government at USD 1.74 billion (Holmberg et al., 2014; NEA, 2016; NWF, 2016a; SNDO, 2019).

Recent developments

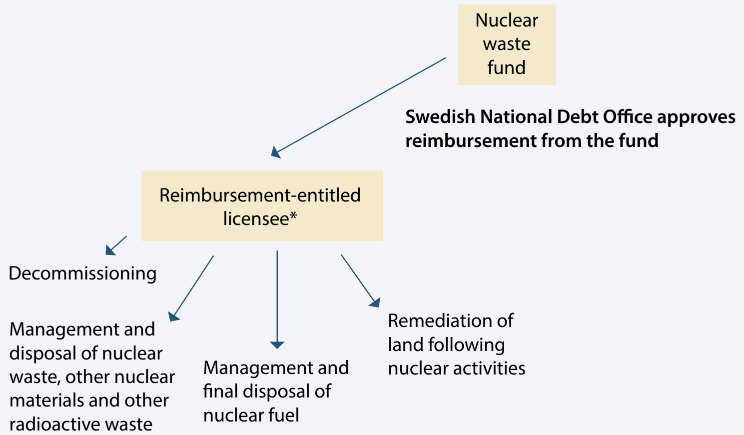
Recently, the Swedish Parliament has changed the Financing Act, and from 2018 it is the responsibility of the SNDO to calculate the supplementary amount (now termed the "risk margin"). The definition of the risk margin has changed. Previously, it only included uncertainties related to the financing system's liabilities. As of 2018, the risk margin must also cover uncertainties about the financing system's asset side, e.g. the uncertainties associated with future nuclear fee payments or the expected return of the Fund. Methods for calculating risks in the Swedish back-end financing system are being reviewed accordingly and are open to change.

To meet the enhanced demands on calculation of the risk margin the Debt Office is on its way to develop a model that can be used to (1) calculate the risk margin with respect to the uncertainties in the value of the Fund's assets, in the present value of the future nuclear waste fees, and in the liabilities of the whole back-end programme; and (2) to make analyses that can be used as a basis for the Fund's strategic asset allocation decisions. The system has to meet the requirements in the revised legislation as well as the needs for modelling the risks associated with cash flows, which can be compared with the risks in a large infrastructure project with high complexity and long duration. In 2019, the SNDO had initiated the development of such a model. The first version is to be used in drawing up the next proposal for fee and guarantee amounts to the Swedish government, which is due in September 2020.

Financing of legacy radioactive waste

As of 1989, a special fee was levied on the nuclear power utilities according to the 1988 Studsvik Act. This "Studsvik fee" was collected in the same funding system as the nuclear waste fee, but put in a dedicated fund (NEA, 2013). This fee was supposed to cover expenses to finance the decommissioning of research reactors and other costs for the early Swedish nuclear power programme. This included the management of waste from older experimental facilities (notably SNF), from medical uses, and from other non-nuclear power plant activities. The nuclear power plant operators created a specific company in the 1990s, AB SVAFO, which is responsible for decommissioning old research and development facilities and for managing and disposing of legacy wastes in dedicated disposal facilities operated by SKB (NEA, 2013). Current waste in this regard arises in particular from the research facilities at Studsvik, at the Agesta reactor and at the uranium mine in Ranstad (NEA, 2013; SNCNW, 2017). As of January 2018, the Studsvik fee ceased to exist, leaving the funds already accumulated and earmarked for the treatment of legacy waste without a perennial source of funding. With a 2018 market value amounting to USD 115 million, the Studsvik funds are now solely disbursed to cover the costs arising from the treatment of legacy waste (Figure 14.2) (NWF, 2018).

Figure 14.2:
Swedish fund management model to finance the costs of legacy facilities and waste (NB. Formerly financed through the "Studsvik fee")



* Refers to licensees for facilities covered by the Studsvik Act. At present these are AB SVAFO, Studsvik Nuclear AB, Vattenfall AB (Agesta), Randstad miljöriskområdet, Uppsala University and Cyclife Sweden AB.

Source: Nuclear Waste Fund website (http://www.karnavfallsfonden.se/informationinenglish/thefinancingsystem.4.697303b91648b46fd8d21cd.html).

The cost side

Process and responsibilities

Nuclear reactor operators shall prepare a cost estimate for the management and disposal of nuclear residual products every three years and deliver it to the financial regulator, the SNDO. The nuclear operators have assigned SKB, an entity they jointly founded and own, to prepare these cost estimates (SKB, 2019).

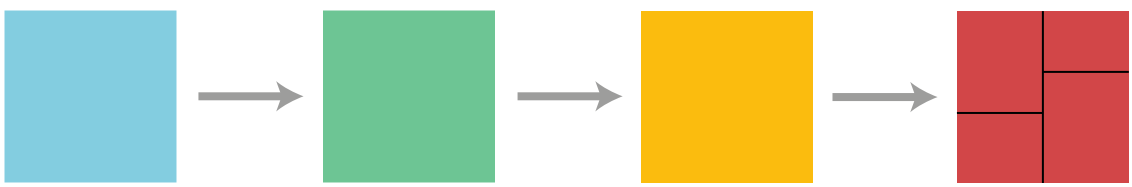
Scope

It must be noted that the scope of cost estimates for decommissioning includes costs for the removal of the reactor building, the turbine halls, and non-radioactive structures above ground level, as well as the disposal or recycling of non-radioactive waste. Further, it includes final site surveys, de-licensing of the site, landscaping and contaminated ground remediation (NEA, 2016). It does not consider measures like defueling, or any kind of on-site storage, e.g. of fuel or radioactive waste from decommissioning. Those costs have to be directly born as operative costs by the reactor operators.

Methodology

SKB's calculations for the 2021-2022 period were carried out in multiple steps starting from a base cost estimate made by the industry using Monte Carlo projections (EC, 2018), and including measures to deal with uncertainty in its calculations (Figure 14.3).

Figure 14.3:
Methodology for risk assessment used by SKB



Source: SKB, 2019: p. 32.

SKB's calculations begin with the establishment of a reference scenario, based on the nuclear operator's best estimate for the lifetime of newest reactors, i.e. 60 years, or the respective expected lifetime for older nuclear power plants. In addition to costs relating to RWM and SNF, the calculation for the reference scenario includes the costs for decommissioning and dismantling nuclear power plants. The reference scenario is calculated based on a deterministic method, i.e. conditions are stipulated and locked. The calculation is based on a functional description for each facility, including layout drawings, equipment lists, and staffing forecasts (SKB, 2017).

In a second step, SKB establishes a calculation model for the scenario requested in the Financing Act (the available calculation details are based on the former version of the Financing Act, which assumes a now discarded lifetime of 40, instead of the newly defined 50 years). In accordance with the Financing Act, the calculations of the SKB result in the estimation of two cost classes: the "remaining basic costs"; and the "basis for the financing amount", which stems from this basic cost. While the basic costs represent an estimation of future liabilities, the basis for the financing amount is used to calculate the guarantees to be provided to insure the funding gap between fund assets and future liabilities. The supplementary amount serves as a basis for the guarantees that have to be provided to insure unforeseen events. The scenario in accordance with the Financing Act also factors in future real price changes, in particular through a number of conversion factors referred to as "external economic factors" (EEF). For each EEF, a forecast is made for the future real price trend, based on regression analysis. Costs are then adjusted for the real cost trend from the time of calculation until the cost outcome. The EEFs retained for calculations consist of a small number of macroeconomic variables, which entails a significant degree of aggregation. They include unit labour costs (i.e. payrolls adjusted for productivity in the service and construction sectors), as well as real prices for machinery, construction material, copper, bentonite, energy, and real exchange rates of SEK compared to USD (SKB, 2017).

Cost uncertainties

To meet the statutory requirements on the consideration of uncertainty, SKB uses a probabilistic calculation method, the "successive principle", to calculate uncertainties to be included in the cost estimate, especially in regard to the supplementary amount's level. The method is used to plan and calculate costs for projects and has been developed specifically to identify, analyse and evaluate uncertainties. The successive calculation involves a scheme implying that variations, deviations or other uncertainties that are of a general or overall nature are dealt with separately. The cost impacts of these uncertainties with different outcomes are then added together based on a chosen statistical method (Monte Carlo simulation) in order to produce the total effect expressed as a probability distribution over different cost levels (SKB, 2017).

The identification and selection of cost uncertainties to be considered in SKB's uncertainty analysis is done in a systematic manner, with the purpose of facilitating the work and reducing the risk of overlooking essential uncertainties. To that end, six areas are identified as potential sources of uncertainty: 1) society, including legislation, regulation, and political issues; 2) economics, e.g. costs of labour and material, and currency exchange risks; 3) implementation, regarding time schedule strategies and nuclear power plant decommissioning strategies; 4) organisation, including implementation of future (de)commissioning projects; 5) technology; and 6) calculation, including the risk of incorrect assessments (SKB, 2017).

Discounting

Future liabilities in the Swedish decommissioning and RWM financing system are estimated using discount rates with adjustments for risks for each asset class, depending on maturity. The nominal discount rate curve consists of a risk-free discount rate curve plus a fixed risk premium of 0.75 percentage points (for all maturities based on a set of assumptions, see Table 14.1). The risk-free discount rate curve is calculated according to the Swedish Financial Supervisory Authority's regulations for occupational pension insurance companies in the way that follows. First, risk-free zero-coupon spot rates are calculated from market swap rates for maturities 1-10, 12, 15 and 20 years minus 0.35 percentage points, with a floor rate of zero. Then, the zero-coupon spot rates are used to calculate implied forward rates for all maturities between 1-20 years, with equal forward rates for maturities of 11 and 12 years, 13-15 years and 16-20 years. The risk-free discount rate curve of spot rates is then calculated from the following forward rates:

- for maturities 1-10 years: the implied forward rates;
- for maturities 11-20 years: weighted average of implied forward rates and the ultimate forward rate (UFR) for occupational pension insurance companies (4.2% in 2019). The weight for the UFR is calculated as (the actual time to maturity in years - 10) divided by 11. A recent study by the European Commission (EC, 2018) yet noted that, reflecting significant falls in long-term interest rates at all maturity points in recent years (and lower expectations for future interest rates), the UFR is set to decrease in future, and hence, all else remaining equal, the present value of the liability can mechanically be expected to continue increasing;
- for maturities over 20 years: the UFR.

The expected inflation curve is calculated in a similar way based on data from the Swedish Break-Even Inflation curve and from the Swedish Riskbank's inflation targets, depending on maturity. The real discount rate curve, which is used to discount the real costs from to present (base year) value, is finally calculated with the Fisher equation.

Table 14.1:
Calculation of risk premium on risk-free discount curve in the Swedish financing system

Asset class	Risk premium (% points)	Share of fund	Contribution to the fund's risk premium (% points)
Sovereign fixed income	0.00	40%	0.00
Covered bonds	0.50	40%	0.20
Equity	2.75	20%	0.55
Total portfolio	0.75	100%	0.75

Source: Adapted from EC, 2018: p. 132, additional data provided by SNDO.

Assets, investment rules and performance

SKB estimated the sums of future liabilities at USD 10.9 billion in 2017 and USD 11.9 billion in 2019 for the base case liability. The assets in the Fund amounted to USD 7.2 billion in March 2017 and USD 7.59 billion in December 2018. According to the European Commission, in 2017, Sweden's funded level was around 65%; the country also had the shortest liability duration among EU Member Countries, i.e. at 19 years (EC, 2018; SNDO, 2019). To provide a more holistic picture of expected future costs, fund levels and expected fees, the SNDO adopts the following balance sheet approach (Figure 14.4).

Figure 14.4:
Balance sheet modelling of assets/liabilities adequacy in Sweden's funding system as by 31 December 2016

	Assets	Liabilities
On balance sheet items ("first line of defense")	Market value of Nuclear Waste Fund USD 7.46 billion	Net present value of future disbursements USD 11.2 billion
	Fee assets (i.e. gap to be covered by future fees) USD 3.76 billion	
Off balance sheet items ("second line of defense")	Credit risk amount USD 3.36 billion	
	Risk Margin* USD 1.74 billion	

* The risk margin is calculated in accordance with legislation in place in 2016.

Source: SNDO, 2019.

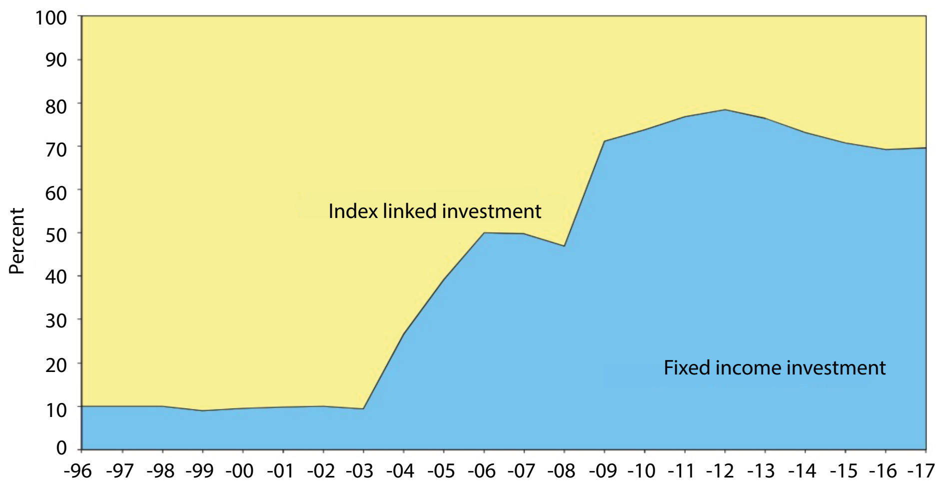
Fund asset management rules

The assets in the Nuclear Waste Fund are to be managed in a prudent way to ensure a good return and satisfactory liquidity. In practice, this means that the assets shall be managed with a strong focus on the final purpose of the Fund, i.e. fully paying for nuclear liabilities. The Board of the Fund annually establishes and reviews an investment policy to provide rules for the investment of the Fund's assets. The policy stipulates how different risks are to be controlled and limited and how the results of fund management are to be reported (NWF, 2017 [website]). Under the investment rules applied until 2016, the NWF's options for influencing the rate of return were limited to the choice of the investments' duration, the choice between fixed-income and index-linked investments, the choice between treasury and covered bonds, the choice of individual securities within each category and timing of purchases and sales, and the increase of return by means of repurchase transactions repos (NWF, 2017b).

Historical management of the Fund

Until 2003, the proportion of index-linked investments in the Fund was around 90%, responding to the long periods of high inflation Sweden had experienced. Since then, this share has steadily declined. At the end of 2016, the proportion of index-linked investments reached 30%. The decline of investment in index-linked assets reflects the change of conditions. With the Riksbank's inflation target, introduced in 1993, the inflation rate sharply declined. After 2000, real market rates fell quickly, leading to a drastic increase of the market value of the Fund's assets. The fund's board decided to partially realise the profits and thereby reduce the proportion of index-linked investments (Figure 14.5).

Figure 14.5:
Evolution of the distribution of index-linked/fixed-income investments within the NWF (NB. Before 2018 change in investment rules for the Fund)



Source: NWF, 2017b: p. 10.

In 2009, a restriction in favour of treasury bonds was abolished and the Fund was given the option of investing in covered bonds. This led to a strong shift from fixed-income treasury bonds to covered bonds, given the higher return at only slightly higher risk of covered bonds compared to fixed-income treasury bonds. At the end of 2016, the proportion of covered mortgage bonds was about 52% of the portfolio. Previously the basis for active management in the Fund was the standard portfolio, conforming to the Board of Governors' decision regarding the distribution between index-linked and fixed-income investments (NWF, 2016a). In 2017, the standard portfolio consists of 70% investments with a nominal rate of return and 30% investments with a real or index-linked rate of return (percentages refer to the market value of the capital in the Fund) (NWF, 2017 [website]).

Broadening of Fund investment rules in 2018

During 2013, SSM, in consultation with the Nuclear Waste Fund and the SNDO, submitted a report to the government with proposals for changes in the financing system. In 2017, an Asset Management Ordinance (2017: p. 1180) introduced a new regulatory framework for the Fund's investment mandate, mainly entailing a broadening of the Fund's investment options towards corporate bonds and equities, subject to certain restrictions (NWF, 2018). As of 2018, the Fund can thereby invest a maximum of 40% of its assets in different listed securities. Hence, the 2017 Asset Management Ordinance has given more flexibility and leeway to the NWF (NWF, 2017a, 2018).

Further, the general requirements on asset management were clarified to emphasise the cautious manner in which the fund assets shall be managed. This is intended to ensure the sufficiency of fund assets to meet the expected need for disbursements, a suitable level of risk, and a satisfactory level of liquidity. Accordingly, the Fund designed and initiated a new asset management strategy in 2018, which is further detailed in the next section. Besides, the Swedish government also adopted and implemented guidelines for environmental and ethical considerations in the Fund's investments (NWF, 2018).

Current asset portfolios and management strategy

Due to the recent changes in the investment rules for the Fund as per the new Asset Management Act and Asset Management Ordinance (2017: p. 1180) that entered into effect on 20 December 2017, the asset composition of the Fund is likely to be volatile in the near future. Indeed, in 2018, the Nuclear Waste Fund formulated and initiated a new asset management strategy. Asset management is now divided into two portfolios:

a) *a base portfolio* with Swedish treasury and mortgage bonds, i.e. asset classes that all licensees' (and others') paid-in funds may be invested in without restriction. This portfolio contains the same authorised asset classes as those to which the Nuclear Waste Fund was restricted up to 20 December 2017, that is: a) a sight deposit account at the National Debt Office, with nominal return based on the repo rate; b) short-term deposits at a fixed interest rate at the SNDO with an investment period that can vary between one month and one year; c) investments on the market in treasury bills, fixed-income bonds and index-linked bonds issued by the National Debt Office; and d) mortgage bonds issued in accordance with the Covered Bonds Issuance Act (2003: 1223). The base portfolio thereby constitutes a continuation of the former total portfolio approach to the management of the Fund;

b) a new *long-term portfolio* with corporate bonds and equities, i.e. riskier asset classes compared with those in the base portfolio, in which the Fund is allowed to invest from 20 December 2017. This portfolio was built up starting June 2018 with initial investments in corporate bonds in Swedish kronor and in Swedish equities. Investment options are restricted by Section 9 of the Asset Management Ordinance (2017: p. 1180). Funds may only be invested in liquid financial assets that consist of a) Swedish and global equities; b) derivatives, but not to create leverage in the portfolio; c) shares in mutual funds invested in the kinds of financial instruments stipulated above; and d) sight deposits at the SNDO. Exposure to global corporate bonds and global equities is achieved by investing in fund shares in a specially selected mutual fund that meets the requirements of the Nuclear Waste Fund. Section 19 of the same Ordinance also states that the degree of exposure to one or several companies in a designated corporate group may not together exceed 20% of the Fund's value.

The transition to the new investment model with two investment portfolios, begun in June 2018, will proceed gradually. The same method used in the management of mutual funds is also used to keep track of each payer's share of the funds in each portfolio. The new division into two portfolios has made it possible to offer the different reactor owners and other fee-liable licensees in Sweden an asset management strategy adapted to the particular reactor owner's investment horizon. At the end of 2018, the NWF's investments were reported to consist, inter alia, of 24% treasury bonds, 43% covered bonds, 30% index-linked investments, 3% equities, 2% corporate bonds, and 3% deposits in an account with National Debt Office (NWF, 2018).

Recent Fund performance

In 2016, the Fund's nominal return was 5.8% and its real return 4.1% (NWF, 2016b). The nominal return in 2018 amounted to 1.5%, compared to an inflation rate of 2.00%. As an annual average, the real return over 2014-2018 is 2.66%, while it amounts to 4.5% over the whole lifetime (i.e. 1996-2018) of the Fund (NWF, 2018). Hence, the Fund's performance was recently strongly mitigated by the inflation effect. The rather poor performance compared to the inflation rate is considered to be due to the general economic environment characterised by very low interest rates. Further, the implementation of the recent changes in the Fund's investment policy, which are precisely supposed to respond to an investment environment of low returns on capital, necessarily entails a greater level of risk. Due to these changes, the Fund's rate of return is expected to be more volatile than in the past (NWF, 2018).

Funding adequacy review mechanisms

All cost estimates are submitted to the SNDO for review. The industry's cost estimates undergo a three-year assessment cycle that consists of several steps: 1) the publication of the cost estimates by SKB in a report; 2) a review and recommendations by the SNDO; 3) the circulation of the initial review to stakeholders for comment; 4) a final review and recommendations to the government by the SNDO (Aström and Carroll, 2017; SKB, 2017). If needed, the SNDO can order a license holder to submit a cost estimate earlier than three years or to submit an additional cost estimate. This can provide the basis for a fee proposal by the SNDO over periods shorter than three years (NEA, 2016).

For each reactor licensee, the SNDO then prepares a proposal regarding nuclear waste fees that licensees must pay over the next three years. The proposal is itself based on proposals provided by the industry, which are analysed by SNDO-related experts. The proposal takes previous payments and specified additional costs into account. Once completed, it is presented to the government that has the responsibility to set the final fees and guarantees the licensees will be charged with (NEA, 2016).

The re-evaluation of costs and assets adequacy takes place every three years under the responsibility of the SNDO, with inputs from the Nuclear Waste Fund (NEA, 2016). Additionally, the Fund publishes a yearly report on the status of the financing system (Aström and Carroll, 2017). The three-year periodicity of the Swedish financing system for the nuclear back-end ensures that the system is predictable and robust. Changes in estimated costs and revenues are identified every third year and the system is balanced by means of decisions on fee levels and financial guarantees for the subsequent period (SNAO, 2017; Ström, 2018). Nuclear operators and other fee-liable licensees are fully responsible for all of their decommissioning and RWM costs, even if the assets are insufficient to cover future expenses. Guarantees are to be provided by licensees and can be used to cover the costs in case of fund inadequacy (NEA, 2016). Even if the fees paid in by a reactor owner or another fee-liable licensee should not suffice to cover its costs, fees paid in by another reactor owner may not be used to make up the difference (NWF, 2017b).

Conclusion

The Swedish system for decommissioning and RWM is sophisticated and well managed, backed by solid funding mechanisms (i.e. an independent external Nuclear Waste Fund overseen by the government) and running on a soundly regular practice of re-assessing cost estimates and updating decisions on nuclear waste fees.

An advanced centralised storage scheme for nuclear waste exists, represented by a central interim storage facility for spent nuclear fuel and a final repository for short-lived radioactive waste, both operating since the 1980s. In addition, a DGR project is in its final stage of authorisation by the government. Funding adequacy and cost estimates are reassessed every three years, ensuring sufficient and timely endowment of the Nuclear Waste Fund.

Recent changes regarding the investment rules of the fund have led to somewhat lower real returns in 2018, while the long-term effect of these changes appears adequate to escape from an investment profile limited to assets, for which the low interest rate market environment has not been ideal over the last years. Further, while the Fund remains an autonomous entity, recent changes in the Financing Act (Act [2006:647] on Financing of Nuclear Residual Products) have broadened the investment opportunities for the Fund. The government decided to redistribute responsibilities regarding the Swedish RWM financing system. Responsibilities formerly carried out by the SSM were taken over by the SNDO. Under the new legislation, the possibility for the Fund to invest in risky assets was reflected in the new definition of the risk margin, one of the two guarantees that a license holder must provide. The risk margin must cover uncertainties related to liabilities, as well as the uncertainties related to the assets, i.e. the expected return of the Fund. The SNDO has the responsibility to calculate the risk margin. This might be a concrete way to strengthen the government's role as the ultimate guarantor in the Swedish financing system for decommissioning and RWM – or it might at least signal the state's willingness to enforce more direct control in this regard.

Finally, the late decision by certain Swedish utilities to shut down their nuclear facilities earlier than scheduled due to a lack of profitability calls for increased vigilance from public authorities, as early shutdowns demand a reconsideration of cost and financial projections, especially if the latter were initially based on longer lifetime assumptions.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 15

Switzerland: Country case study

KEY FACTS	
Funding model	Two external segregated funds – decommissioning & RWM in separate funds supervised by Federal Council.
Assets	• Decommissioning Fund: USD 2.4 billion • RWM Fund: USD 5.1 billion
Liabilities	• Decommissioning: USD 3.8 billion • RWM: USD 13.3 billion **NB: All monetary amounts are in USD. However, as the average 2018 exchange rate is essentially 1:1, numbers are identical to the original national amounts provided in Swiss Francs.**
Avg. effective real return	• Decommissioning Fund: 3.78% (1985-2018) • RWM Fund: 2.94% (2002-2018)
Discount rate	3.5% (until 31 December 2019) / 2.1% (from 1 January 2020)
Inflation rate	1.5 % (until 31 December 2019) / 0.5% (from 1 January 2020)
Assumed operational lifetime of nuclear power plants	50 years
Investment rules	Ban on investments in Swiss companies buying/selling nuclear electricity and in all companies that contribute to the funds or have ownership of more than 20% of a company contributing to them.
Evaluation of fund adequacy	Fund assets and operator's provisions are reviewed in yearly reports. Fund adequacy and cost estimates are reviewed and updated every five years.
Issues at stake	• In January 2015, a revision of the Swiss Federal Ordinance on the Decommissioning Fund and the Waste Disposal Fund (SEFV) came into effect. This contained a reduction in the investment rate of return used in the mathematical model from 5% to 3.5% and in the rate of inflation from 3% to 1.5%. In addition, a safety margin of 30% of the costs was introduced.

Issues at stake	• For the cost study 2016 a new calculation method was applied. For every cost element, reference costs, costs of risk mitigation, inaccuracies, and risks are considered. As project managers may tend to be too optimistic in predicting the costs of a project, a general safety margin is taken into account as well. • Due to improved uncertainty implications in the calculation method applied for the cost study 2016, the safety margin of 30% of the costs will be abolished in a new revision of the Federal Ordinance on the Decommissioning Fund and the Waste Disposal Fund. In addition, the contributions will be based on an assumed investment rate of return of 2.1%. Instead of the inflation rate based on the Swiss Consumer Price Index, the inflation rate based on the Swiss Construction Price Index is applied for the definition of the contributions into the funds. Currently a price increase of 1.5% is assumed, while the newly introduced price increase is 0.5%. This leads to a reduction of the real expected rate of return and to higher contributions for the owners of the nuclear power plants. These new conditions will enter into force from January 2020. There is strong allocation of financial liability to the industry. Nuclear operators are collectively financially responsible in case one operator is unable to fulfil its liabilities. • The state intervenes financially only in case of a shortfall in several protective financial measures and in accordance with a Federal Assembly decision.

Decommissioning and RWM in Switzerland

Switzerland possesses a fairly developed infrastructure for the management of its decommissioning and radioactive waste, based on comprehensive cost estimates and sophisticated reassessment mechanisms. Radioactive waste in Switzerland is mainly stored at the Zwischenlager Würenlingen (ZWILAG) ZZL, the Swiss centralised interim storage facility for vitrified waste, spent nuclear fuel and other radioactive waste. The ZWILAG is an entity that is jointly owned by the four Swiss nuclear power plant operators and is responsible for running the ZWILAG ZZL storage facility. Next to the ZWILAG ZZL, all Swiss nuclear power plants have on-site installations for the conditioning and storage of their own operational waste, while radioactive waste from medical operations and research is mainly stored at and operated by the Paul Scherrer research Institute, located in proximity to the ZWILAG (NEA, 2013a; NEA, 2016).

Since 1972, the national co-operative for disposal of radioactive waste (NAGRA), a joint initiative financed by the nuclear power plant operators and the Swiss Confederation, has been working to find a long-term storage solution in Switzerland. A site selection process began in 2008, followed in 2016 by the pre-selection of three potential locations for the construction of a central DGR for low-level and high-level waste (HLW). Nagra will further investigate the potential locations and expects to hand in an application for a general license at the responsible Federal Department of the Environment, Transport, Energy and Communications (DETEC) by the end of 2024. A decision by the government, including a potential referendum, is expected by 2031. A repository for low- and intermediate-level waste (LLW and ILW) might accordingly be operational by 2050, followed by a repository for HLW by 2060 (WNA, 2019). Despite a promising process, the DGR does not seem to be in imminent reach, given the remaining administrative hurdles and the insecurities involved in a potential decision by referendum.

In order to finance costs arising from decommissioning and RWM in Switzerland, reactor owners have to pay annual fees into two segregated and external funds, which are submitted by the administrative commissions called the “Stilllegungsfonds für Kernanlagen und Entsorgungsfonds für Kernkraftwerke” (STENFO) to DETEC. STENFO sets the fees to be paid by the nuclear operators. The funds are supposed to ensure funding in their respective field of responsibility. The Decommissioning Fund is responsible for securing the financing of decommissioning and dismantling costs, including the costs of conditioning, transport and disposal of resulting radioactive waste. The Waste Disposal Fund is responsible for ensuring the financing of all activities associated with the management of operational waste and SNF after the end of the operational lifetime of the reactors. These activities include packaging, transport, and conditioning of SNF for direct disposal, interim storage and the construction, operation, and closure of repositories. The funds possess legal personality and are supervised by the Confederation. Therefore, the Federal Council appoints the members of STENFO's administrative commission and the auditing company and specifies the methodology for the cost estimates. DETEC takes a decision concerning the estimated amount of the costs for decommissioning and waste disposal that have to be covered by the final contributions to the funds. The federal administerial court has verified DETEC's responsibility in this matter. Also, the DETEC defines in the Federal Ordinance on the Decommissioning Fund and the Waste Disposal Fund (SEFV) the expected rate of return and the expected inflation rate as parameters applying to define the contributions. The DETEC just defines rough guidelines for the investment policy, while STENFO defines the asset allocation of the funds (Bundesrat, 2016; Bundesrat, 2018a; UVEK, 2016).

In Switzerland, nuclear power plant operators bear all risk associated with the financing and the management of decommissioning and radioactive waste, independently of the content of the funds (Swissnuclear, 2018a). The Nuclear Energy Act establishes a regulatory framework that allocates responsibilities in a clear and cascading way (Figure 15.1). In the very unlikely case of ultimate failure of all funding mechanisms, the Confederation can take on financial responsibility for any remaining decommissioning and RWM liabilities, following a decision by the Federal Assembly. However, the state's liability is a tool of last resort in the Swiss legislation regarding decommissioning and RWM. The allocation of financial liability is strongly allocated to the nuclear power plant operators. Particularly interesting in this regard is the possibility of advances granted from the fund's assets if a contributor's means are insufficient to pay his liabilities. Such advances have to be repaid to the fund, including interest. In case of a persistent failure of an individual contributor to honour his liability, a collective responsibility applies under which all other contributors are required make proportional extra payments.

Figure 15.1:
Cascading chain of financial responsibilities for the funding of Swiss nuclear back-end as provided by the 2003 Nuclear Energy Act

LEVELS OF FINANCIAL RESPONSIBILITY		
	1	***Funds and claims of facility owners/contributors (2003 NEAct, Art. 77 and 78)*** • Decommissioning and Waste Funds provide funding. • The owners of nuclear facilities contribute to the funds. • Contributors have a claim equal to the amount they paid, increased by return on capital, net of expenses.
	2	***Owners of facilities/contributors (2003 NEAct, Art. 79)*** • If a contributor's claim does not cover the costs, the missing amount is paid by the contributor by his own means.
	3	***Benefits from funds (USL, Art. 79 (2))*** • If the contributor's own means are insufficient, the Fund covers the balance of the costs by devoting all available resources.
	4	***Reimbursement by the owner of the installation/entitlement (2003 NEAct, Art. 80)*** • The beneficiary is obliged to repay the difference to the Fund, including interest.
	5	***Additional payments from other contributors and beneficiaries (Art. 80, para. 2 LENu)*** • If the beneficiary cannot repay the difference, the other contributors are required to cover the difference with additional payments proportional to their contribution.
	6	***Participation of the Confederation (USL, Art. 80 (4))*** • If covering the difference represents an unbearable economic burden for the operators liable for the additional payments, the Federal Assembly shall decide on the Confederation's participation.

Source: Translated from STENFO, 2018b: p. 5.

Currently, five nuclear reactors are operating in Switzerland, delivering up to 35% of the country's electricity. The lifetimes of nuclear power plants are not generally limited in Switzerland, as long as a safe operation in line with all requirements is certified by the Swiss Federal Nuclear Safety Inspectorate (ENSI). The government decided in 2011 in its Energy Strategy 2050 to phase out nuclear, despite an ongoing project by nuclear operators to install up to three new reactors. The decision was subsequently confirmed in different chambers and finally adopted in 2017 through a referendum on the Energy Strategy 2050, leading to the abolishment of all expansion plans for nuclear energy in Switzerland. The new energy strategy foresees a gradual phasing-out of nuclear energy in favour of hydro energy and renewables. The five existing nuclear reactors will be allowed to run without a prior indicated lifetime reduction, as long as the ENSI considers them to be safe. Yet, the operator BWR shut down the Mühleberg reactor in late 2019 (WNA, 2019). For the time being, nuclear power plant operators must base their decommissioning and RWM cost estimates on a total of 50 years of operational time, while some of the operators expect real lifetimes for their reactors of up to 60 years (WNA, 2019; Bundesrat, 2016).

A revision by the Federal Council of the SEFV, which regulates the funding particularities, their supervision and the standards for the cost estimates, provides, among other things, for the abolishment of the currently required 30% uncertainty margin that is added to the cost estimates and eliminates the possibility for reimbursements of assets that exceed the funding ceiling on a yearly basis. Further, it is envisaged to reduce the expected return of the assets from the current 3.5% to 2.1%. Instead of the inflation rate based on the Swiss CPI the inflation rate based on the Swiss Building Price Index is applied for the definition of the contributions into the funds. Currently a price increase of 1.5% is assumed, while the newly introduced price increase is 0.5%. This leads to a reduction of the real expected net rate of return and to higher contributions for the owners of the nuclear power plants into the funds. The measures are justified by the Federal Council with an improvement of the methodology used for the cost estimates, which directly considers uncertainties, while a more conservative investment strategy that has been imposed on the funds in 2017 is expected to result in lower return rates. Also, developments in the asset markets and the building costs are taken into account.

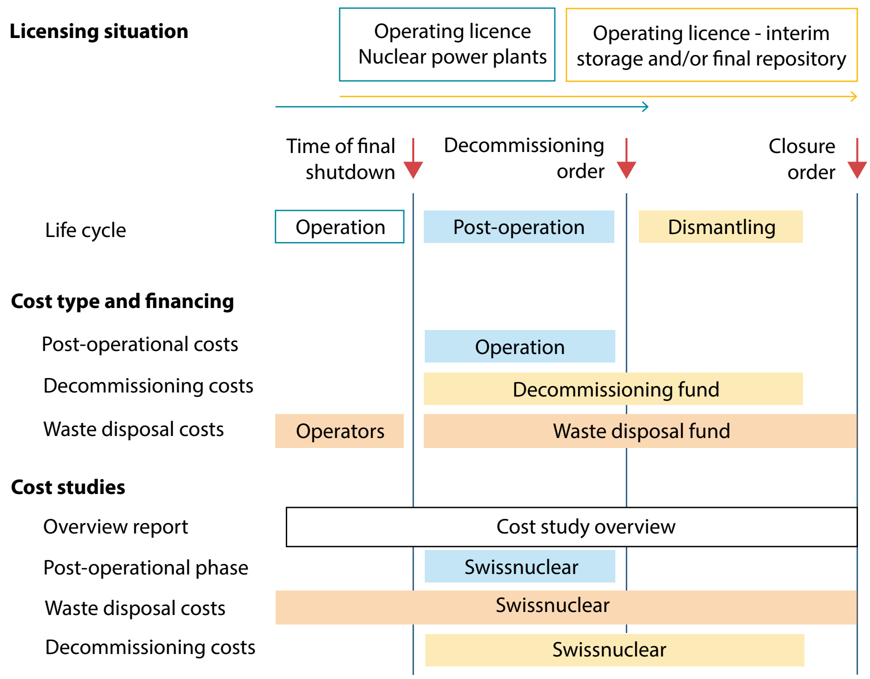
While the owners of the nuclear power plants appreciated the abolishment of the uncertainty margin, they were against the abolition of the possibility of reimbursements of fund assets in case of over-performance as well as the lowered investment rate of return to be applied in the cost estimates. Further, a plan by the Federal Council to reduce the relative number of industry representatives in the respective commissions of the funds caused the owners to oppose the revised SEFV (Swissnuclear, 2018c). The revision of the SEFV entered into force in 2020.

The funding system

The funding system in place to cover the costs of decommissioning and RWM in Switzerland is based on the approach that owners of nuclear reactors are liable for the financing and management of costs arising from decommissioning and nuclear waste. The costs of decommissioning nuclear power plants as well as those occurring after decommissioning for the disposal of the radioactive waste are covered by two segregated and external funds: one to cover decommissioning costs, the other to cover waste disposal costs. Waste disposal costs arising during the operation of the reactors are to be paid directly by the operators, including costs arising during a three to five-year post-operational phase following a reactor's shutdown. The post-operational phase is defined as the period between the shutdown of a facility and the moment at which no fuel elements are left at the site and the legally bounding decommissioning order is available (Swissnuclear, 2016). The funds are financed through fees that are paid by all owners of nuclear facilities used to produce energy or for the interim storage of nuclear waste and SNF. Only nuclear power plant operators pay into the funds. The federal government collects fees from medicine, industry and research but does not pay into the funds (Bundesrat, 2016). The fee amounts for each nuclear operator are set by the administrative commission of STENFO. The fee amounts submitted by the administrative commission of STENFO are based on the evaluation of cost estimates established in the name of the industry by Swissnuclear every five years, taking prescribed discount and inflation rates into account. The fees are to be paid annually, meaning the annual revenues of the funds come from the nuclear operators' contributions and the return gained from the funds' assets.

The entitlement of each owner to the funds is equivalent to the amount paid in, including capital earnings minus costs. Until the revision of the SEFV that entered in force in 2020, concerned parties were entitled to a reimbursement under certain conditions in case of over-financing of the funds. Before the shutdown of a reactor, an owner could file an application for reimbursement to both funds if the target value for funding with respect to the owner's entitlement was exceeded at the end of two consecutive years. After the shutdown, reimbursements of surpluses could be applied for if the real value of the funds exceeds the target value by more than 10%, at least at the end of two years (Bundesrat, 2016; STENFO, 2017a). The owners of the nuclear power plants are obliged to pay their contributions until the end of decommissioning. However, it is possible that the costs rise after decommissioning. This is why in the revised SEFV there will not be any reimbursements of surpluses until all decommissioning and radioactive waste management activities have been carried out and the costs for these have been covered. The surplus shall be refunded within a year after calculation of the closing statement. This asymmetry with respect to duties and rights has been pointed out by the operators as the system is based on a robust methodology with regularly updated cost estimates and a cautiously designed risk and uncertainty model.

Figure 15.2:
Organisation of funding-related responsibilities in Switzerland



The cost side

The cost estimates are mainly represented by all-inclusive cost studies produced and updated every five years under the direction of the STENFO. The frequency of cost studies might be increased due to the final shutdown of a nuclear installation or, if unforeseeable circumstances lead to a significant change in costs, the SEFV stipulates that the contributions have to be reassessed. The nuclear operators have assigned Swissnuclear to elaborate cost estimations for each nuclear installation. The cost estimates provided by Swissnuclear, based on probabilistic methods to take into account the probability distributions of the input variables, are subsequently reviewed by STENFO with the assistance of independent experts and, regarding safety-related aspects, by the Swiss Nuclear Safety Authority (ENSI) (NEA, 2016). Once the cost studies are reviewed by STENFO, they are reviewed and validated by the DETEC. In accordance with the legislative requirements, the estimates have to be based on an assumed lifetime of 50 years for the nuclear reactors (Swissnuclear, 2011; NEA, 2016). The scope of the costs as calculated with the latest 2016 cost study includes costs and cost items regarding decommissioning costs and RWM costs. Those encompass for decommissioning costs:

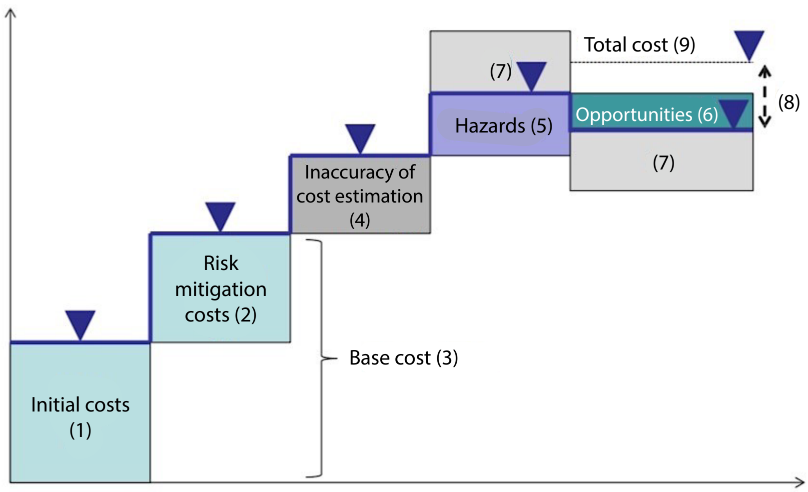
a) technical preparations for decommissioning;
b) containment, maintenance and monitoring of the facility;
c) decontamination or disassembly and fragmentation of radioactive and contaminated parts;
d) transport and management of radioactive waste associated with decommissioning;
e) demolition of all technical installations and buildings, and the setting up of the non-radioactive waste landfill;
f) site decontamination;
g) project planning, development, direction and monitoring;
h) radiation and occupational accident protection measures;
i) authorisation, monitoring, insurance and administration costs.

Regarding RWM, the costs incorporate:

a) transport and disposal of radioactive waste from operation;
b) transport, reprocessing and disposal of SNF;
c) a 50-year observation phase of a DGR;
d) project planning, development and direction, construction, operation, maintenance, repair and overhaul;
e) decommissioning and monitoring of RWM facilities;
f) radiation and occupational accident protection measures;
g) authorisation, monitoring, insurance and administration costs.

The requirements and methodology for the cost estimates are continuously updated and developed in view of technological and scientific developments. In 2016, the requirements for the cost estimates as set by the administrative commission of STENFO foresaw for the first time the gradual aggregation of a number of cost elements as laid out in Figure 15.3.

Figure 15.3:
Swiss cost estimation methodology as prescribed by the STENFO's administrative commission



(7) Costs of ignored hazards and opportunities
(8) Optimism bias

Source: Cron, 2017: p. 11.

First, the initial costs were estimated, including all expenditures predicted to arise in the context of the planning, permission, execution and the finalisation of decommissioning and RWM (1). This explicitly included all costs that might arise for administrative and management duties in this regard, e.g. the commissioning of land and costs of administrative processes. The initial costs were calculated based on expected amounts of needed materials, current price levels and experience gathered in the area. In a second step, risk mitigation costs were added to the initial costs, considering already implemented or planned risk reduction measures (2). Together with the initial costs, the risk mitigation costs represented the base costs (3). The base costs were then to be supplemented with surcharges for considerations regarding the inaccuracy of the cost estimates (4). While older cost estimates in Switzerland were based on confidence intervals, the 2016 cost estimate included uncertainties through the use of surcharges calculated "bottom-up" for each matter of expense in the calculation. However, this estimation did not include considerations regarding external factors like inflation or changes in the policy environment. Further, hazardous costs were included in the estimation, regarding predictable sources of insecurity like substantial changes in the policy or technological environment or delays (5). With the assistance of experts, those costs were calculated based on a "top-down" quantitative risk analysis, assuming the probabilities for each potential risk to occur. The same methodology was applied to consider and calculate opportunities, whose costs were deducted from the cost estimate (6). In a next step, the potential costs of highly unlikely events with disastrous effects were assumed, but not included in the final calculation (7). Finally, a security surcharge was added (8), considering weaknesses in the planning and forecasts caused by too much optimism, resulting in the total estimated costs (9) (Swissnuclear, 2016: pp. 22-25). The results of the 2016 cost study estimation process are summarised in Table 15.1.

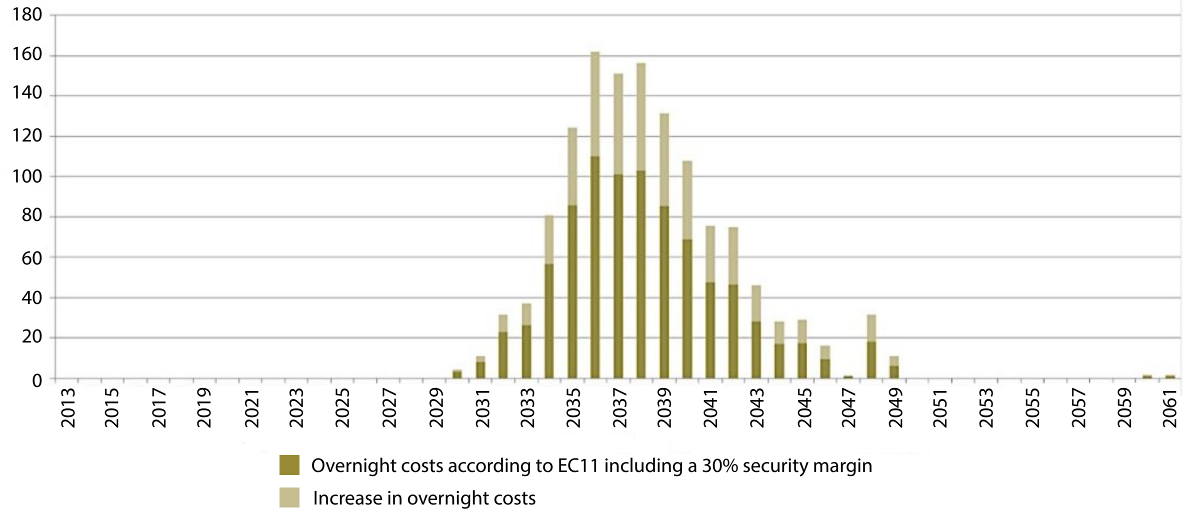
Table 15.1:
Results of the cost estimation in the 2016 cost study (USD billion)

	Waste disposal	Decommissioning	Post-operation	Total
Accrued costs until 2015	5 590	19	0	5 608
Future costs as of 2016				
Initial costs	10 197	2 622	1 406	14 225
Risk mitigation costs	370	67	22	460
Base costs	10 567	2 689	1 428	14 685
Inaccuracy of cost estimation	1 877	301	26	2 204
Risks	1 373	491	271	2 135
Opportunities	-230	-94	-23	-346
Security surcharge	-	-	-	-
Surcharge on future base costs	3 020	698	275	3 993
Total costs	**19 176**	**3 406**	**1 703**	**24 286**
Consideration of DGR-opportunities	-815	0	0	-815
Total costs under consideration of DGR-opportunities (weighted 50%)	**18 362**	**3 406**	**1 703**	**23 471**

Source: Swissnuclear, 2016: p. 28.

In order to define the fees due for each reactor owner, based on the remaining liabilities as assumed in the total costs estimate, the decommissioning and RWM costs were assumed to price levels at the date of calculation, resulting in the so-called "overnight costs". The overnight costs were subsequently extrapolated, using an inflation rate set at 1.5% to assume the costs at the date of disbursement. Subsequently, a 30% uncertainty margin was added in accordance with the SEFV (STENFO, 2019c). The costs assumed at the date of disbursement were then discounted, using a rate of 3.5%, equalling the targeted return rates of the funds, to reach a targeted value of funding for the date of the final shutdown of a facility. The targeted funding value was then used to calculate the fees that have to be paid by each reactor owner, in order to ensure sufficient funding at the shutdown date (Swissnuclear, 2018c). The 30% uncertainty margin on the overnight costs applied to the base costs in order to ensure adequate considerations of uncertainties in the cost estimates (Figure 15.4). With the revised methodology introduced in the 2016 cost study, the Federal Council considered that uncertainties were already sufficiently taken into account in the basic calculation model, and therefore foresaw the abolishment of the 30% uncertainty margin (Bundesrat, 2018b).

Figure 15.4:
Impact of the 30% uncertainty margin in the magnitude and time distribution of the overnight decommissioning costs for the Gösgen nuclear power plant (based on 2011 cost estimates)



Source: STENFO, 2017: p. 4.

Assets, investment rules and performance

As of the 31 December 2018, the total value of future liabilities was estimated at USD 24.6 billion, of which USD 15.7 billion are to be covered by the two funds (2016 price-level) (Table 15.2). The total cost for decommissioning was estimated at USD 3.78 billion, of which USD2.4 billion were already covered by the Decommissioning Fund, leaving a gap of USD 1.4 billion to be financed. The total costs for RWM were estimated at USD 20.8 billion, of which USD 7.6 billion are to be covered directly through the nuclear operators (during the nuclear power plant operation). Next to the operational costs, USD 13.2 billion were estimated for RWM, of which the Swiss Confederation responsible for medicine, industry and research nuclear waste has to cover USD 1.3 billion, while USD 5.1 billion are already covered by the Waste Disposal Fund. This leaves a funding gap of USD 6.8 billion to be financed over the remaining lifetime of the nuclear power plants (STENFO, 2019a).

Since 1 January 2015 (SEFV, revised Annex 1), an investment return of 3.5% (after deducting the costs of asset management including bank charges and sales taxes) and a rate of inflation of 1.5% are envisaged for the funds, which corresponds to a real return of 2% per year. The effective real returns for the Decommissioning Fund are 3.78% per year (1 January 1985 to 31 December 2018) and 2.94% per year for the Waste Disposal Fund (1st Quarter 2002 to 31 December 2018). In 2018, the return on investments was -4.22% (compared to +9.37% in 2017) for the Decommissioning Fund and -4.20% (compared to +9.51% in 2017) (STENFO, 2019b). The negative return on the funds' portfolio in 2018, like the high positive return in 2017, is due to the general performance of the capital markets.

Table 15.2:
Results of the Swiss 2016 cost study (2016 price-level) as adopted by the DETEC – Fund levels as of 31 December 2018

<table>
<tr><th colspan="6">Total costs USD 24.581 billion</th></tr>
<tr><td colspan="2" rowspan="3">Decommissioning Costs
USD 3.779 billion</td><td colspan="4">Waste management costs
USD 20.802 billion</td></tr>
<tr><td colspan="2">Waste disposal</td><td colspan="2">Operational costs</td></tr>
<tr><td colspan="2">USD 13.3 billion
(of which USD 1.3 billion at the charge of the government)</td><td colspan="2">USD 7.5 billion
(to be financed by the nuclear operators)</td></tr>
<tr><td>Level of funding</td><td>Still to be funded</td><td>Level of Funding</td><td>Still to be funded</td><td>Already paid</td><td>Still to be paid</td></tr>
<tr><td>USD 2.4 billion</td><td>USD 1.4 billion</td><td>USD 5.1 billion</td><td>USD 6.8 billion</td><td>USD 5.9 billion</td><td>USD 1.6 billion</td></tr>
</table>

Source: STENFO, 2019a.

As described, the SEFV sets restrictions regarding the range of potential investments that can be made by the two funds (Art. 16). It prescribes that investments are forbidden in companies directly contributing to the funds, or with more than 20% ownership in companies contributing to the funds. Further, it is prohibited to invest in Swiss companies that deliver, acquire, or resell electricity from nuclear power plants. However, these restrictions do not apply to collective investment funds, such as investments in indexes or in investment products. In 2017, STENFO redefined the investment strategy in accordance with the general objectives in Article 15 of the SEFV: the security of the funds' assets is to be guaranteed, the funds are to produce an appropriate return and sufficient liquidity is to be ensured for each nuclear installation (Table 15.3). In addition to the unified fund investment strategy, individual investment strategies can be applied to assets dedicated to specific entities, in order to ensure adequate liquidity. Such strategies are currently applied within the Decommissioning Fund (STENFO, 2016a).

Table 15.3:
Unified fund investment strategies used for both STENFO funds until 2017 and as of 2018

Asset classes	Policy/neutral position	
	Until 2017	As of 2018
Cash	0%	0%
Bonds (CHF)	25%	20%
Bonds FX (hedged)	15%	NA
State bonds for curr. (hedged)	NA	15%
Corp. bonds for. curr. (hedged)	NA	15%
Equities	40%	30%
Real estate	10%	NA
Real estate (Switzerland)	NA	7%
Real estate foreign (hedged)	NA	8%
Alternative investments	10%	5%
Foreign currency component	40%	32%

Source: STENFO, 2017g.

Conclusion

The Swiss system for decommissioning and RWM is transparent and well managed. The fairly advanced infrastructure dedicated to the storage of nuclear waste is based on two centralised interim storage facilities for nuclear waste, one for nuclear waste operated by the nuclear reactor owners and one for medicine, industry and research nuclear waste operated by the federal government. A long-term project envisaging the construction of a central DGR to store all Swiss nuclear waste is close to the licensing stage, following the identification of three potential sites. Current plans foresee such a DGR would be in operation by 2050 at the earliest. The assets of the two external and segregated funds, as well as the operators' provisions are reviewed in yearly reports, while the cost estimates are reconsidered every five years. The regular updates of the cost estimates based on a robust methodology taking most recent data and information as well as learnings into account enable up-to-date assessments of future liabilities and ensures sufficient and on-time provision of resources through the funds. The liability for costs arising in relation to decommissioning and RWM are strongly allocated to the private industry in Switzerland, following a cascading liability scheme, while the Swiss Confederation is participating financially in the exploration of a DGR, being responsible for nuclear waste from medicine, industry and research.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 16

United Kingdom: Country case study

KEY FACTS	
Funding model	• Current reactor fleet: External segregated fund • Legacy reactors/sites: State funding • New build reactors: External segregated or Fleet funds
Assets	• NLF (current fleet): USD 13.24 billion (2018) • Legacy reactors: Public funding • New build reactors: NA funds not yet established
Liabilities	• Current reactor fleet: USD 28.57 billion (2018) • Legacy liabilities (public): USD 185 billion (2017) • New build reactors: USD 10.42 billion (2016) once constructed
Avg. effective real return	• Current reactor fleet (NLF): 1.6% (2018) • Legacy liabilities: N/A • New build reactors: NA funds not yet established
Discount rate	• Current reactor fleet: 2.5% • Legacy reactors: -1.34% (short-term); 1.96% (mid-term); 0.11% (long term) • New build reactors: 1.5% real (above Retail Price Index) (fixed for the years 0 to 33); this discount rate has only been used for Hinkley Point C and may not reflect the rate used for other new nuclear.
Assumed operational lifetime of nuclear power plants	40 years (indicative) to 60 years
Investment rules	• Current reactor fleet: Mainly invested in government bonds (about 80%) and a mixed assets portfolio composed of UK pooled funds and equities (about 20%). • Legacy reactors: Provisions in the Nuclear Decommissioning Authority's (NDA) accounts. • New build reactors: Gradually decreasing risk profile over time, allowing for diversified investments in the early stage.
Evaluation of fund adequacy	• Current reactor fleet: Decommissioning plans to be submitted every 5 years, or 3 years prior to station closure • Legacy reactors: Continuous surveillance by the NDA • New build reactors: Annual and five-year reports to the Secretary of State in regard of the Funded Decommissioning Program.

Decommissioning and RWM in the United Kingdom

The United Kingdom has a diversified funding scheme in place to cover costs from decommissioning and RWM, which is complemented by a differentiated waste storage system. The policy for the management of radioactive waste in the UK is devolved to the Scottish, Welsh and Northern Irish governments, while the UK government is responsible for the policy in England (NEA, 2011). While the general strategy is to implement interim storage and eventual disposal of HLW in a DGR yet to be built, the Scottish government has developed its own policy.

Since 2008, the general UK DGR strategy has been based on a voluntary site selection process, under the condition that the geological conditions are favourable. Despite a failed site selection process in 2013 and limited prospects for voluntary host-locations, the DGR is expected to be operational around 2045 (NDA, 2019). The storage of ILW would begin with the operation of the DGR, while SNF and HLW disposal is expected to take place between 2075 and 2140 (WNN, 2015).

The Scottish scheme foresees the long-term management of HLW in near-surface facilities, located close to the radioactive waste production site, as well as the long-term interim storage of HLW (NEA, 2011).

Currently, HL radioactive waste in the UK is predominantly interim-stored at the Sellafield nuclear site, while most ILW remains stored on site. LLW is disposed of in engineered concrete vaults at the UK's centralised LLW repository in Cumbria. In 2016, the first UK SNF dry storage facility at Sizewell-B was completed. As of 2019 there were 18 operating interim storage sites in the UK. The future strategy for SNF management envisages disposal in a Geological Disposal Facility (GDF). However while the option of reprocessing is retained spent fuel is not classified as waste.

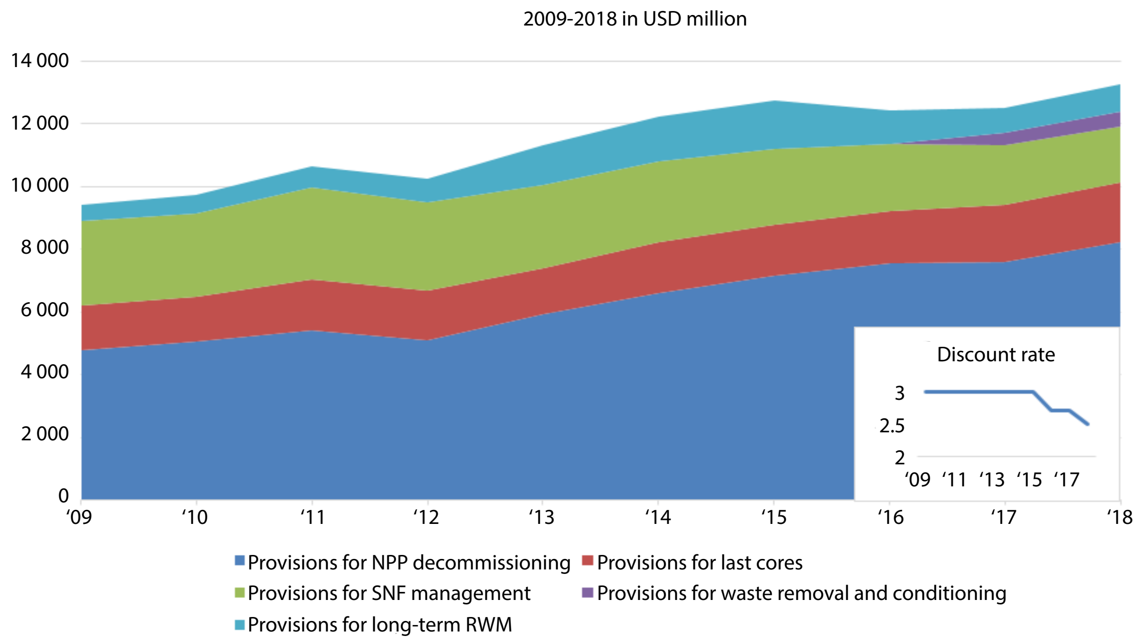
The funding system in the UK consists of three coexisting branches, depending on the type of liabilities: a) one for the newer reactors ("2nd generation Advanced Gas Cooled Reactors and Sizewell-B"), that are currently owned and operated by EDF Energy; b) one for the older reactors ("1st generation Magnox Reactors") and other older facilities ("legacy facilities"), ex BNFL sites e.g. Sellafield and ex UK Atomic Energy Authority sites, now owned by the NDA, a cross-border non-departmental public body that is financed by the Department for Business, Energy, and Industrial Strategy (BEIS); and c) one to be applied for any nuclear reactor to be constructed in the United Kingdom subsequent to the 2008 Energy Act.

a) Newer reactors ("2nd generation"): The provisions to finance the costs for decommissioning and RWM costs in relation with the currently operated EDF Energy-owned reactors were initially set up by the public nuclear operators, the Central Electricity Generating Board, prior to its privatisation in 1990. The successor operators Nuclear Electric and Scottish Nuclear remained in public ownership and were merged to form British Energy (BE). BE was subsequently privatised and set up the Nuclear Generation Decommissioning Fund in 1996. Financial provisions for uncontracted spent fuel management and waste management costs were held in BE accounts. Financial restructuring in 2003 lead to the creation of the Nuclear Liabilities Fund (NLF), which held defined BE liabilities and consolidated provisions for decommissioning and spent fuel and waste management. BE was subsequently acquired by EDF in 2009.

Due to the risk of insufficiency of funds transferred to the NLF, partly a result of the transition of provisions from the public to the private hands, a shared liability model was agreed to fund costs arising from decommissioning and RWM of the currently operating reactor fleet. Accordingly, the NLF will finance the liabilities for the management of SNF from the Sizewell-B reactor, as well as the decommissioning costs and the radioactive waste management costs for EDF Energy's existing nuclear power plants. The government is to fund the costs in relation to the NLF's duties to the extent that they exceed the assets of the NLF.

EDF Energy is responsible for financing the management of SNF, and associated radioactive waste, from fuel loaded to its reactors after 2005, (except for those at the Sizewell-B site). This is discharged through fixed price contracts with the NDA (formerly BNFL). Sizewell-B fuel, an uncontracted liability, decommissioning and post-closure waste management liability are held by EDF Energy, provisioned by the NLF. To this end, EDF Energy both effects quarterly payments to the NLF and holds internal provisions of its own (Figure 16.1). These liabilities are offset against equal and matching assets from the NLF, the government undertaking and historic liabilities funding agreements.

Figure 16.1:
EDF Energy's back-end provisions and applied discount rates (2009-2018)



Source: EDF (2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

b) Older reactors ("1st generation"): Future decommissioning costs for older reactors now owned by the NDA and other "legacy liabilities" fall entirely to the government. Those include, among others, research sites used during the development of the nuclear industry, SNF reprocessing facilities and fuel fabrication plants, as well as the Magnox fleet reactors ("1st generation reactors"). Many of these installations are located at the Sellafield site, where a majority of the UK's legacy waste is stored. The costs of the decommissioning of these 1st generation reactors are reported as provisions in the NDA's accounts and funded by the BEIS (NDA, 2019). Due to uncertainty regarding the exact nature and state of the stored waste at the Sellafield site, it is likely to be a project occupying the UK for at least the next 100 years (NDA, 2016). There is no segregated cash fund for decommissioning NDA sites, as the NDA's operations are directly funded by the government. A proportion of the funding is offset by the revenue from commercial activities carried out by the NDA, mainly SNF management and to a much lesser extent RWM contracts (NDA, 2019).

c) New Build Nuclear reactor post 2008: Following the 2008 Energy Act, the national policy sets out that the operators of new reactors in the UK must set aside funds during their operation to cover the full costs for decommissioning the installation and cleaning up the site (including waste management and waste disposal, for example costs for the interim storage and final disposal in a future DGR) after the nuclear power plant has ceased generation. To this end, nuclear operators are required to submit a Funded Decommissioning Programme (FDP), to be approved by the BEIS Secretary of State, before the construction of a new reactor is approved (BEIS, 2011a). For Hinkley Point C (HPC), just prior to the reactor reaching first criticality, the operator will need to progressively accumulate funds in a secure and independent external fund.

The government expects that the ownership of ILW and SNF will be transferred to it at dates to be agreed on as part of the FDP (BEIS, 2011a). The Waste Transfer Pricing methodology requires the government to set a fixed unit price for the disposal of ILW and SNF. It is expected that the operators' provision will be based on a conservative evidence-based estimate of cost which will include a significant risk premium and will also increase with inflation. The new scheme so far only applies to the new reactor currently under construction at HPC.

Currently, 15 reactors are being operated in the UK, generating around 20% of its electricity supply. However, four of those reactors are planned to be shut down in 2023, with another four in 2024 (WNA, 2019). There are no prescribed lifetimes for nuclear reactors in the UK. Lifetime extensions are considered, primarily against safety considerations supported by a commercial case, by the owners in the context of a Periodic Safety Review undertaken by the licensee, typically every 10 years, as a condition of the Site License, regulated by the Office of Nuclear Regulation. The Nuclear Liabilities Funding Agreement, established as part of a liabilities restructuring in 2005, requires that lifetime extensions area approved by BEIS. All commercial nuclear reactors currently operating in the UK are managed and owned by EDF Energy, a subsidiary of the French EDF (majority-owned by the French government), which foresees lifetimes of up to 60 years for some of its reactors (WNA, 2019), specifically new build.

The generally supportive policy framework for nuclear energy in the UK is reflected by the ongoing construction of a new reactor, HPC, under the main supervision of EDF Energy, and plans for other new reactors. Construction of HPC commenced in 2016 and the reactor is expected to be operational in 2026. It is the first reactor to be constructed in the UK for more than 20 years.

FDP guidance expects a decommissioning plan of sufficient detail to demonstrate that the operator has a realistic, clearly defined and achievable plan for dealing with all of the waste streams that will be produced by its power stations, for remediating the site after use, and to ensure that each element of the work can be costed accurately. Yet, the guidance does not precisely prescribe how operators should calculate their estimates (BEIS, 2011a).

Regarding the current reactor fleet, EDF Energy must submit a lifetime Decommissioning Plan (DP) to the NDA every five years, or three years prior to station closure, setting out its strategy and the cost estimate for the decommissioning of each of its power stations. The DPs must be assessed and approved by the NDA as the agent of the Secretary of State.

Regarding the legacy sites, the NDA's Programme Control Procedures Manual (PCP-M) specifies the requirements for programme and project controls across the NDA portfolio. It contains specific requirements to be adopted by all Site Licence Companies (SLC) for baseline production and management, sanctioning, change control, reporting, risk management and opportunity realisation. The NDA is responsible for monitoring, surveillance and audit of the SLCs' compliance, in all material respects, with this PCP-M, including cost estimation practices (NDA PCP-M rev 3 Mar 2019).

For nuclear reactors built after 2008, nuclear operators must submit to the government cost estimates for decommissioning and RWM activities, in the form of a Decommissioning and Waste Management Plan (DWMP) that includes details of all steps to be taken and associated costs (Middleton, 2016). Additionally, annual and five-year reports have to be transmitted to the Secretary of State by the operators of new reactors regarding their FDP, aiming to ensure that the operator continues to make prudent provisions for its decommissioning and RWM liabilities.

The funding system

As described above, the funding system for decommissioning and RWM costs in the United Kingdom consists of three main pillars. The following chapters will therefore treat each of the three funding systems seperately, while generic information is provided at the beginning of a chapter if applicable.

a) Newer reactors ("2nd generation"): The funding system in place to cover costs arising from decommissioning and RWM of the second generation reactor fleet, today owned and operated by EDF Energy, is mainly constructed around the Nuclear Liabilities Fund.

The assets of the NLF are to cover certain costs of decommissioning and RWM from the currently operating reactor fleet. The assets within the fund are earmarked and the government is responsible for meeting the relevant costs and liabilities if the NLF does not have sufficient assets to discharge these liabilities (NLF, 2018). Conversely, if the NLF is in surplus after settling all liabilities, the balance is to be paid back to the government (NEA, 2016; NEA, 2013).

EDF Energy has to finance the management of SNF and associated radioactive waste resulting from the operation of the reactors after 2005, except for SNF management costs at the Sizewell-B site. The EDF financial responsibility for this SNF ceases once transferred to the Sizewell-B storage site.

To honour its financial liabilities, EDF Energy contributes to the NLF under several forms, including: i) a contribution of USD 214 000 adjusted to retail price index per tonne of uranium loaded in the Sizewell-B plant since 2005; ii) a quarterly, reactor-based contribution of USD 4.28 million (2003 price-level), over the lifetime of the respective reactor; and iii) an annual contribution of about USD 1.42 million for the NLF's administration costs (NLF, 2018; EDF, 2018). As of 2018, the total current liability for newer reactors is estimated at USD 28.57 billion.

The NLF is segregated from the Treasury and the NDA. It is a Scottish Public Purpose Trust, administered by five Trustees, two selected by EDF Energy and three by the Secretary of State, who are also Directors of the Fund. The NLF's Board has outsourced the management of the investment portfolio, the custodial services, and the day-to-day accounting to external agencies on a contractual base. This rather complex funding arrangement shows the complicated transfer of responsibilities for decommissioning and RWM from a public nuclear energy system into a privatised one, revealing the importance of consequent allocation and earmarking of respective funds. The inalienability of dedicated assets has to be ensured in order for a funding system for HLW and SNF to be sustainable over long durations and through policy changes. In this regard, a transfer of assets from the private to the public side appears to promise an improvement in the stability of framework conditions.

b) Older reactors ("1st generation"): The future decommissioning costs for the UK's legacy sites fall entirely to the government. They are reported as a provision in the accounts of the NDA, which is responsible for the long-term management of the country's historic and committed nuclear liabilities, and financed by the BEIS (NDA, 2109). There is no segregated cash fund for decommissioning NDA sites, as the NDA's operations are directly funded by the government (NEA, 2013). A proportion of funding is also offset by revenues from the NDA's commercial activities. The NDA's annual spending limits are set by the Parliament. In 2018, the annual spending limits for the NDA were set at USD 4.58 billion (NDA, 2019).

c) New build nuclear reactor post 2008: Following the 2008 Energy Act, a new funding scheme was introduced, applicable to all reactors subsequently constructed. It stipulates that plant operators are required to submit a FDP, for approval by the BEIS Secretary of State, before the construction of a new reactor is authorised (NEA, 2013). An FDP must contain detailed and costed plans for decommissioning, waste management and disposal, as well as agreed arrangements to ensure that sufficient assets will be available to meet these costs.

Alongside the FDP, the government will enter into a waste transfer contract with the operator regarding the terms on which it will take title to and liability for the operator's ILW and SNF after plant decommissioning for disposal into a geological repository. To enable greater certainty over DGR costs, the final Waste Transfer Price (WTP) will be set after a deferral period, about 30 years after the reactor starts operation and not earlier. The government will set a cap on the level of the WTP at the outset, to provide operators and investors with certainty over the maximum WTP they will be expected to pay for the provision of a waste disposal service (BEIS, 2011b).

During the deferral period the government will provide the operator with an expected price to enable the operator to make prudent provision for their liability. The WTP, when fixed, will be set at a level over and above the estimated costs and will include an increase with inflation, a risk premium and a separate risk fee to reflect the small residual risk that actual costs may be higher than the cap (WNN, 2015).

An operator may decide to create a single fund, or establish separate funds, for its decommissioning (including waste management costs), and its waste disposal costs. A fund may be set up for each new nuclear power station or for a fleet of stations where they are under the same ownership. Where a fund is set up for a fleet of stations, separate and transparent accounting of the liabilities and the apportionment of assets for each site will be necessary (BEIS, 2011a). The FDP funds are to cover the following back-end costs: i) the treatment, storage, transportation and disposal of hazardous material generated during the operation of a nuclear installation on the site; (and only after the site has ceased generation); ii) the decommissioning of any relevant nuclear installation and the cleaning-up of the site; iii) activities preparatory to the matters mentioned in this list; iv) the construction and maintenance of interim stores for ILW and SNF that are not initially constructed as part of the installation; and v) any preparatory activity for the decommissioning of a relevant nuclear installation and the cleaning-up of the site (BEIS, 2011a).

Any remaining activities must be paid for by the operator as operational expenditure. This concerns principally: i) packaging and disposal of LLW from operations, including transport; ii) conditioning and packaging of operational ILW; iii) operation of SNF ponds during the operational life of the nuclear power plant; iv) management and disposal of non-radioactive waste from operations; and v) infrastructure costs for maintenance of site licence requirements (BEIS, 2011a).

The FDP should specify a target value for the fund, which is expected to include a prudent risk-based contingency that the fund would be expected to reassess periodically (BEIS, 2011a). An FDP fund is expected to have been created before reactor core is taken critical, with the initial contribution when the reactor is first taken critical and annual contributions made thereafter (Middleton, 2016; BEIS, 2011a).

The cost side

In the UK, nuclear liability estimates are required to be developed and based on both discounted and undiscounted cost estimates (NEA, 2016). The related programme of work for all nuclear back-end activities in the UK is forecasted to be complete by 2137, while the estimated costs for a DGR amounted to USD 14.7 billion in 2018 (undiscounted price levels) (NDA, 2019).

a) Newer reactors ("2nd generation"): At the end of 2018, EDF Energy applied a real discount rate of 2.5% to its nuclear liabilities in relation to the currently operating reactor fleet in the UK. The discount rate was calculated using an average series of data for a sample of UK Government gilts over the longest available duration, plus the spread of UK Corporate bonds rated A to AA, again over the longest-term duration. The implicit inflation rate used in determining the discount rate was based on a long-term forecast of adjusted retail prices. EDF Energy discounted the receivables corresponding to the amounts payable by the NLF and by the British government at the same real rate as the obligations they are intended to finance (EDF, 2018; EDF, 2019). Cost estimating processes for the currently operating reactor fleet were, although EDF Energy formally does not have to adopt the NDA's requirements, similar to those applied by the NDA, which are described below (NEA, 2015).

b) Older reactors ("1st generation"): Regarding the costs estimates established by the NDA in the context of nuclear legacy sites in the UK, they are based on expected costs of decommissioning, dismantling and demolishing the buildings, managing and disposing of all waste, and remediation of land. In other words, it covers the entirety of NDA's costs of dealing with its radioactive waste, nuclear fuels and decommissioning of legacy facilities (NAO, 2016).

The NDA requires all estimates of anticipated final cost and schedule to be prepared as deterministic base estimates directly including a provision made for optimum bias adjustment informed by relevant reference class data supported by robust quantitative risk analysis. The NDA uses a proportional approach to assessing risk and uncertainty over time and, since 2014, emphasises uncertainty in official publications by overtly including ranges around the central cost and schedule estimate and by emphasising the existence of significant uncertainties in NDA's major project expenditure for the period that exceeds 20 years in the future (Oldham, 2016). The NDA also considers credible threats and opportunities which may increase or decrease the cost and schedule estimate, but which are deemed less probable than the best estimate.

The key sensitivities are as follows:

i) the construction of a DGR is currently planned to allow receipt of waste from around 2040. The key sensitivity is around the cost of constructing and operating the repository in the long-term. That ranges from a level USD 5.99 billion below the current estimate, to one that is USD 35.92 billion above it; and

ii) the Sellafield site's activities associated with site operation, reprocessing and its eventual decommissioning.

Decommissioning the 17 legacy nuclear sites under the NDA's responsibility is estimated to cost USD 185 billion over 120 years (2019 NDA forecast) (Figure 16.2). In addition to these estimates, the NDA publishes a range of estimates that "could potentially be realistic" laying between USD 157 billion and USD 313 billion for the NDA's future liabilities in 2017. Principal sensitivities are around the cost of delivering the plan, particularly the costs of new construction, decommissioning and post-operational clean out work in the long term. The potential costs range from a USD 28.77 billion reduction against the current estimate, to a USD 127.28 billion increase (NDA, 2019). The large range of these estimates shows the intrinsic difficulty of calculating the precise long-term liabilities arising across the NDA estate.

c) New build nuclear reactor post 2008: Costs estimates regarding the future liabilities for decommissioning and RWM arising from new build reactors are part of the DWMP that have to be submitted by the operators as part of their FDPs.

Those DWMPs shall cover both "Designated Technical Matters" (which are to be funded through the FDP) and "Technical matters" (which are to be funded by the operator), encompassing the totality of back-end activities to demonstrate that its operators have realistic, clearly defined and achievable plans (BEIS, 2011a). Therefore, a submitted FDP must separately include the estimates of the costs in connection with the disposal of ILW and SNF, all other designated technical matters and non-designated technical matters. The DWMP submitted by the operators should be based on a DWMP base case, in accordance with guidance for development and establishment of an FDP. However, deviation from this is acceptable subject to approval of a justification to depart from this standard by the Secretary of State.

The governmental DWMP base case covers all phases from pre-generation to post-generation and its main assumptions include: i) a 40-year operational lifetime, though operators may propose alternative lifetimes; ii) prompt decommissioning with no care and maintenance period, in addition to being restored to a state similar to greenfield or its state prior to construction; iii) decommissioning will be undertaken using equipment and techniques available at the time the FDP is submitted; iv) encapsulation of SNF is carried out on site; v) ILW and SNF will be stored on site until disposal facilities are available; and vi) ILW and SNF will be disposed of in a DGR, but the government expects to take title to and liability for the operator's ILW and SNF before the assumed disposal date of the radioactive waste. The latter would require two payments from the operator: a lump sum to cover RWM costs for the period between this early transfer and the disposal date of the waste, and another payment determined with the WTP methodology for the disposal per se (BEIS, 2011a; Middleton, 2016).

With regards to the cost estimation methodology for the WTP, the following parameters form part of the considerations: i) it is based on the NDA estimates of geological disposal costs; ii) the costs per unit of SNF/ILW are calculated based on estimated variable costs of disposal plus a contribution to the DGR fixed costs; iii) the fixed cost contribution is proportional to the estimated share of total variable costs; iv) costs estimates are uplifted for risk and uncertainty (Middleton, 2016; BEIS, 2011b).

The expected price the operators will be supplied with during the deferral period by the government in order to allow for the establishment of prudent provisions is calculated as detailed in (BEIS, 2011b). For HPC's FDP, the cost estimate included in the DWMP took a hybrid approach to determine the overall contingency, comprising of uncertainty and risk estimates, for each decommissioning and RWM task.

The target values of the FDP fund for HPC decommissioning costs and costs of SNF management were determined on a "P80 plus 25% contingency basis" for each activity included in the FDP. P80 means that there is 80% chance of the actual costs proving to be lower than the estimates. The operator is required to fund to the P80 figure together with a further 25% contingency buffer (NLFAB, 2016a).

Two uncertainty and risk analysis methodologies have been employed as part of HPC's FDP cost estimate development, an interim project-specific hybrid process and a conventional risk analysis process using a Monte Carlo analysis (EDF Energy NNB, 2014).

The Secretary of State for BEIS is legally obliged to call upon independent advisors to verify that the FDP is prudent; for Hinkley Point C this activity was undertaken by the Nuclear Liabilities Financing Assurance Board (NLFAB).

For Hinkley Point C, the fund build-up will be considered in two sub-periods, 0-37 years and 37-60 years. The aim is to ensure that the full undiscounted cost of decommissioning and ILW disposal is in place at the end of the first period, thus minimising the risks of fund insufficiency and early decommissioning. The decommissioning costs would be discounted from the date at which they are expected to be incurred to the end of the secondary funding period (year 60). The NLFAB advised the Secretary of State that this approach made prudent provision for the financing of HPC's decommissioning costs (see NLFAB, 2016b for an indicative graphic of this accrual for HPC can be found at reference).

The scheme installed for reactors created after 2008 Energy Act appears to provide a comprehensive framework to ensure that future costs for decommissioning and RWM of these reactors will be effectively allocated to the nuclear operators.

Assets, investment rules and performance

a) Newer reactors ("2nd generation"): The assets supposed to cover the funding liabilities in relation to the currently operating reactor fleet are held in the Nuclear Liabilities Fund. The fund places considerable emphasis on diversification in its investment approach, both by asset class and geography. In 2017–2018, the NLF's total assets less current liabilities amounted to USD 13.24 billion, with 96% of assets in pounds, 1.9% in US dollars and 1% in euros (NLF, 2018).

The assets of the NLF are split into two parts, the national loans fund and a mixed assets portfolio aimed primarily at a regular and sustainable yield, with a certain degree of inflation protection. A substantial part of the assets of the fund, USD 10.42 billion, i.e. about 80% of the fund in 2018, is held in the national loans fund where cash can be accessed at short notice and its security is backed by the government. It is used to meet the current and shorter-term liabilities of the fund and to make early repayments.

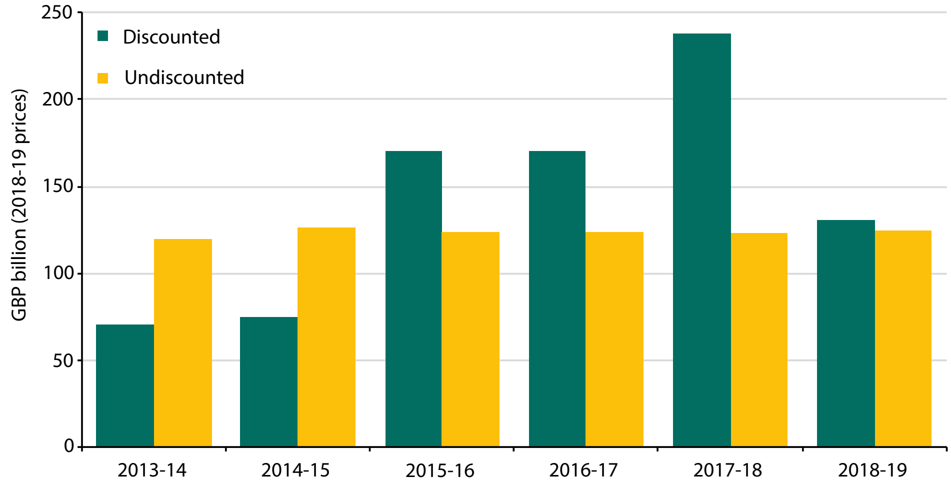
The NLF's Trustees, working with the Fund's advisors, estimate how much return will be needed to meet the liabilities and design an investment approach which targets the rate of return, while taking into account the risk of significant falls in the value of the assets. The target returns on the NLF's investments over 2015-18 to meet the full expected future liability obligations as estimated by EDF Energy in its baseline decommissioning plans was 5.6% for the national loans fund and the mixed assets portfolio together, and 7.7% for the mixed assets portfolio alone. In 2018, the total portfolio return was 1.6%, while the return for the mixed assets portfolio alone was 7.3% (NLF, 2018). Total portfolio return has been significantly hit by the low interest rate environment. The current difference between the actual and target returns is being addressed by developing plans for transferring assets from lower return liquid assets to higher return mixed/illiquid assets.

Regarding decommissioning, EDF Energy produces lifetime decommissioning plans for each of its nuclear power plant sites covering the period from station closure to final site clearance. These are submitted to the NDA every five years, or three years prior to station closure, or if legislation or policy significantly changes, whichever is earlier, and are reviewed by the NDA (NEA, 2013). The government can initiate a fund review if it believes the assets of the NLF will outstrip the liabilities by 125% at specific intervals, the first of which was 2015. If the said review confirms that position, the government has a right to extract the excess funds from the NLF (EC, 2013).

The NLF is a legally separate entity from the operator and the fund may not owe any obligations directly to any creditors of the operator (BEIS, 2011a). The future liabilities to be covered by the NLF are estimated by EDF Energy to be around USD 28.57 billion (NLF, 2018).

b) Older reactors ("1st generation"): The NDA, which is responsible for the decommissioning and radioactive waste management of the legacy sites in the UK, is financed by a combination of government funding and commercial activities. As such, it is not exposed to the degree of financial risk faced by other business entities. Consequently, financial instruments play a more limited role in creating and managing risk than would apply to a non-public sector body. It does, however, experience some degree of risk due to the variability of commercial income (NDA, 2019).

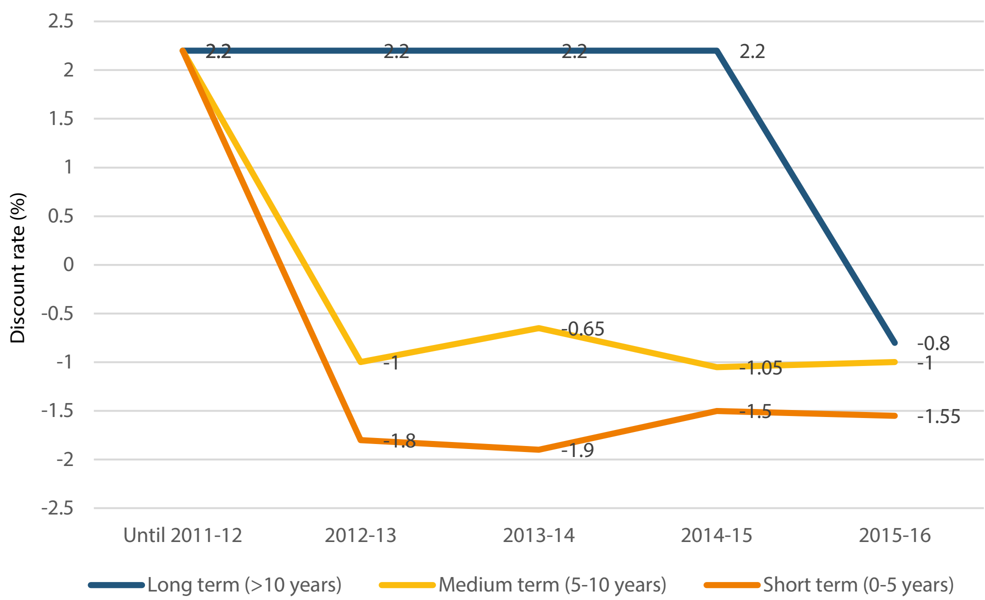
Figure 16.2:
Discounted and undiscounted cost estimates for future NDA nuclear liabilities in GBP billion



Source: UK OBR, 2019: p. 160.

The NDA provides an updated nuclear provision figure for every full year in its annual accounts, representing the discounted estimated cost of the NDA's decommissioning mission. Since 2013, different discount rates have been applied to value short-term (0-5 years), medium-term (5-10 years) and long-term cash flows (over 10 years) by the British Treasury, which sets the short- and medium-term discount rates each year in line with the accounting standard for provisions and based on the yields on UK index-linked gilts. The long-term rate is similarly based on gilts but reviewed before each spending review period. Recently, the British Treasury introduced negative discount rates to reflect that the cost of government borrowing was lower than inflation (Figure 16.3).

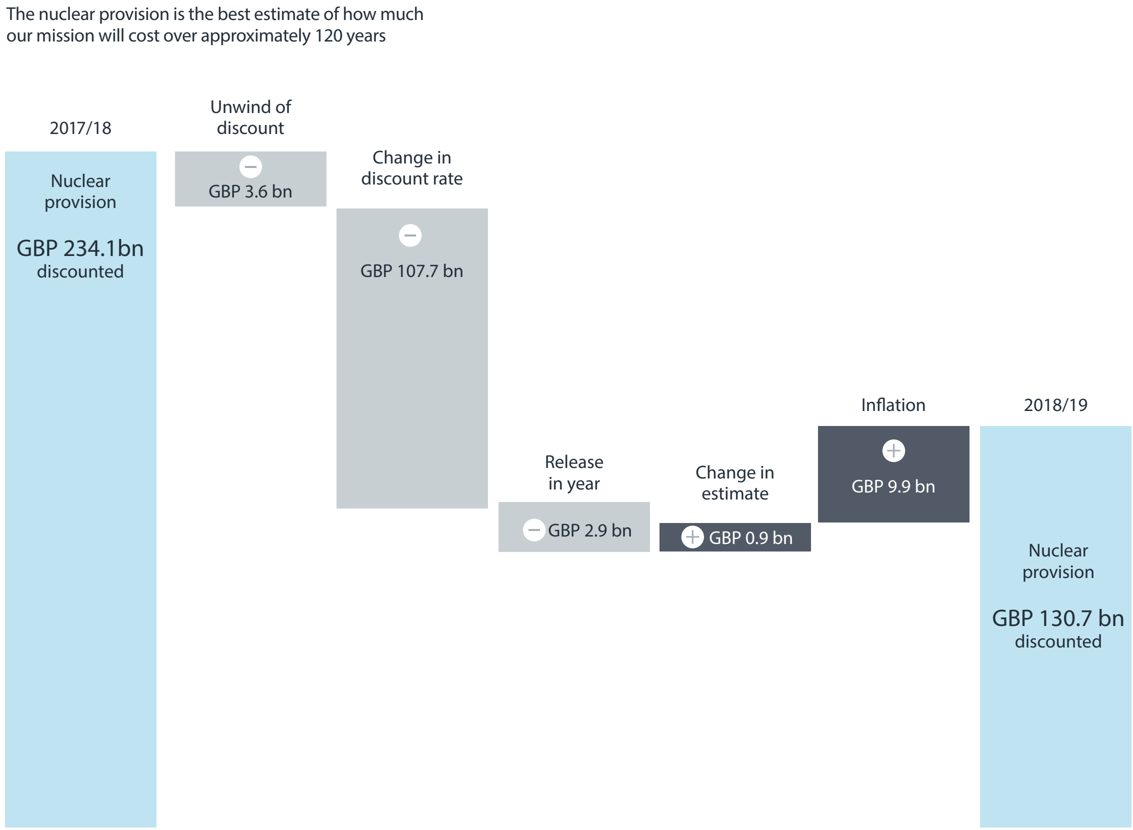
Figure 16.3:
Changes in the UK discount rates (FY 2011-2012 to 2015-2016)



Source: NAO, 2016: p. 22.

Naturally, the application of a negative rate implies that the reported value of a provision in current prices will be higher than estimates of future cash flows (NAO 2016, HM Treasury 2017). The latest discount rates determined by HM Treasury (2018-19) were: i) -1.34% for short-term rates; ii) -0.96% for medium-term rates; and iii) -0.11% for long-term rates (NDA, 2019). The NDA's nuclear provision is discounted using the rates determined by HM Treasury, which has recently led to a major reduction of the current discounted cost estimates (Figure 16.4) (NDA, 2019). The application of negative discount rates in the provisions assessment of the NDA consistently reflects the current market environment. The application of volatile and up-to-date discount rates by the NDA and the resulting differences in cost estimates underline the uncertainty of future real prices for costs of nuclear liabilities. The difference between the discount rates applied by the industry compared to those applied by the public authorities appear remarkable in this context. Fortunately, the considerations based on market rates have little impact on the actual ratio between available funds and costs as activities by the NDA are financed out of the current government expenditure. Dealing with negative discount rates would be quite a different challenge in fully funded systems.

Figure 16.4:
Correlation between discounted and undiscounted NDA provisions dependent on discount and inflation rates applied



Source: NDA, 2019: p. 84.

c) New Build Nuclear reactor post 2008: The operator of the first and for the time being only new plant under construction, at HPC, expects a total decommissioning cost of USD 10.42 billion (in 2016 price-level) (UK OBR, 2017).

To cover these costs, assets will be collected into a secure and independent external fund during plant operation through a levy on electricity production. For the HPC reactor, the waste and decommissioning costs have been accounted for in a "strike price" of USD 132 (2012 price-level) per

MWh of electricity produced during the first 35 years of operation, increasing with inflation. The operator will pay a higher proportion of the strike price into their FDP fund if costs go up, but will benefit if they manage costs effectively (UK OBR, 2014).

In general, a FDP set out the fund's investment strategy including: i) investment objectives; ii) risk exposure limits and principles for the definition, measurement, mitigation and monitoring of risk; iii) permitted and prohibited asset or class of asset types; iv) performance measurement criteria and benchmarks; and v) policy on realising investments. The FDP will also detail responsibilities and processes for reviews of the investment strategy. Changes to the fund's investment strategy will be a modification to the FDP and as such will require approval by the Secretary of State (BEIS, 2011a).

In the case of HPC's FDP, it was decided that all FDP investments will be made under investment orders issued by the operator or its authorised representatives to the FDP fund company (EDF Energy NNB, 2015). Furthermore, the operator agreed to take the investment risk, i.e. to remedy any deficits in the fund from a failure to achieve the annual growth milestones for so long as the plant is operating. Accordingly, the investment rules which apply up until the de-risking period (see panel below) set broad boundaries only. They contain limitations, such as restrictions on asset classes, the maximum size of individual investments and maximum exposures to particular institutions, but give the operator wide flexibility to determine and vary investments. A prohibited practice includes investment in the shares of the operator or its affiliates, shorting of securities and making loans or investing in derivatives other than loans or derivatives permitted by the investment rules. The FDP fund company has the ability to challenge investment orders if they believe them to be prohibited.

Gradual de-risking of the asset portfolio for HPC

Following the 2008 Energy Act, the investment strategy and asset portfolio set aside to fund nuclear decommissioning liabilities has to be gradually adapted when approaching the end of the estimated lifetime. Investment rules tighten at four key dates during HPC's lifecycle progressively de-risking the portfolio. By the defined dates the fund is required to have implemented specific actions to de-risk its investment portfolio:

- by year 25 and until year 32: no more than 35% of the Fund assets value may be invested directly or indirectly in equities;
- by year 32 and until year 37: no more than 30% of the Fund assets value may be invested directly or indirectly in equities;
- from year 32 until year 37: the operator may only issue investment orders for specified government securities, corporate bonds or permitted derivatives and from the last day of year 37, the total value of corporate bonds may not exceed 50% of the Fund assets value;
- by the last day of year 37: at least 50% of the Fund assets must comprise specified government securities and the fund assets must contain no assets other than specified government securities or corporate bonds;
- from year 55 until site end state is achieved: the operator must only issue investment orders that provide for investment in specified government securities and permitted derivatives;
- from the last day of year 60 until site end state is achieved: 100% of the Fund assets must comprise specified government securities, cash and cash equivalents or permitted derivatives (NLFAB, 2016b).

The concept of an investment portfolio that is gradually decreasing its risk profile while approaching the expected end of the reactor's lifetime, and accordingly the time where majority of disbursements will be effected, appears to be an interesting investment solution regarding the long-term nature of the investments. Such a solution allows for a certain degree of flexibility without jeopardising the crucial on-time availability of the assets. Given the current low-risk investment environment, shaped by very low rates of return, a more flexible approach in the early stage of investment appears favourable to ensure adequate return.

Conclusion

The United Kingdom has a sophisticated and solid funding scheme in place to cover decommissioning and RWM costs. This is completed by a fairly advanced waste storage system, including multiple interim storage facilities and plans for the construction of a DGR by 2045. The threefold funding system is the result of the historical transfer of funding assets and liabilities from the public nuclear energy sector to the private sector between 1990 and 2009. While the decommissioning and RWM for the current reactors fleet, as well as for reactors built after 2008, is ensured through dedicated funds, a large amount of legacy waste is to be funded through the governmental budget. The majority of this legacy waste arises from the Sellafield site, the decommissioning and RWM costs of which have significant uncertainty in cost and schedule.

The application of market-based interest rates, recently translating into negative interest rates, for the estimation of NDA's liabilities highlights the challenges in the context of the choice of an appropriate discount rate. While the NDA's liabilities are financed through current governmental expenditure, the application of negative interest rates in a fully funded system appears to be a difficult undertaking.

The funding system established for reactors constructed after 2008 appears comprehensive in nature. Especially the prescription of a gradually decreasing risk investment strategy in the approach to the end of a reactor's lifetime appears advantageous given the current difficult market environment. In this context, a more flexible investment approach in the early stage of investment appears appropriate to ensure adequate return. Further, the transfer of ownership of radioactive waste from the nuclear operators to the government in exchange for a waste transfer fee might underline the willingness of the UK government to manage the future long-term treatment of nuclear waste under its own supervision.

Exchange rates: Monetary values in USD are calculated using the 2018 OECD annual exchanges rates as indicated by the OECD: OECD (2021), Exchange rates (indicator), doi: 10.1787/037ed317-en (accessed on 28.04.21)

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Chapter 17

United States: Country case study

KEY FACTS	
Funding model	External public fund for RWM and internal provisions for decommissioning
Assets	• RWM: USD 53.4 billion (30 September 2018) • Decommissioning: USD 65 billion (31 December 2018)
Liabilities	• RWM: Multitude of forecasts resulting in different outcomes • Decommissioning: Individual estimates at level of operators
Avg. effective real return	• RWM: ~ USD 1 billion/year • Decommissioning:?
Discount rate	• RWM: Multitude of economic forecasts resulting in different outcomes. • Decommissioning:?
Assumed operational lifetime of nuclear power plants	40 years with 20 years periodical renewals, no maximum lifetime.
Investment rules	• Nuclear Waste Fund (NWF): Investment in equity securities, fixed-income securities. • Decommissioning: No investment in parent companies. Trusts have to be held outside of administrative control of licensees. No more than 10% invested in securities or obligations of the licensee or any other owner/operator of a nuclear power plant. No investments in a mutual fund in which at least 50% is invested in a licensee or a parent company whose subsidiary is an owner/operator of a nuclear power plant.
Evaluation of fund adequacy	• RWM: Annual review of nuclear waste fee adequacy relative to future liabilities. • Decommissioning: Several mandatory reports issued bi-annually and at specific dates throughout the lifetime.
Issues at stake	• Since 1998, the Department of Energy (DOE) has been legally obliged to begin taking SNF/HLW for final disposal. However, the lack of a DGR has delayed the DOE's ability to start accepting SNF. As a result, commercial utilities have stored SNF on site longer than expected. This situation exists for both operating reactors as well as sites that have already been decommissioned. Furthermore, nuclear utilities sued DOE and have been able to receive payments from the US Judgment Fund to offset financial damages from DOE's delay in accepting SNF. • The status of the NWF is included in the US national budget. • Despite positive contributions that the use of nuclear energy provides, nuclear generators are facing a challenging economic situation as recent use of shale gas is mitigating the profitability of nuclear power plants compared to other energy sources.

Decommissioning and RWM in the United States

The United States has separate funding systems for costs arising from decommissioning and radioative waste management (RWM) with a well-functioning funding mechanism for decommissioning expenses and a decentralised system for the interim storage of radioactive waste. Currently, most spent nuclear fuel (SNF) arising from commercial nuclear energy generation in the United States is stored on site at nuclear power plants in so-called "Independent Spent Fuel Storage Installations". Historically, SNF has been stored in pools until capacity issues have led to further storage in dry casks as well. By the end of 2016, 78 591 tonnes of SNF had been discharged from US reactors, about 40% of which was in dry storage at reactor sites.

In the United States, the liabilities for decommissioning and RWM are separated. While nuclear operators have to hold external provisions and assurances in order to finance their future decommissioning liabilities, the federal government is responsible for the costs and tasks arising in the context of the disposal of HLW and SNF. To this end, the public NWF was created in 1983, financed through fees paid on the electricity produced by commercial nuclear power generators.

Commercial nuclear operators must issue mandatory reports to the US Nuclear Regulatory Commission (NRC) in order to show adequate funding for their decommissioning liabilities. These include the provision of an initial certification amount at the operating license stage, the annual adjustments of the certification amount over the operational life of the facility, the provision of a preliminary cost estimate five years before the end of operations, as well as the periodical provision of Decommissioning Funding Status Reports (DFS) before and after the end of operation. Finally, the provision of updated cost estimates for the post-shutdown and the license termination stage is required (US NRC, 2011). Regarding RWM funding adequacy, the Secretary of Energy is required to annually review the adequacy of the established nuclear waste fee, in order to determine whether the collected fees offset the commercial utilities' share of life cycle costs related to the federal disposal obligations and activities, as set out in the 1982 Nuclear Waste Policy Act (NWPA) (Section 302(a)(4)). As noted later in this case study, the courts suspended the collection of the nuclear waste fee and the DOE stopped publishing their annual fee adequacy report.

Nuclear operators are responsible for their decommissioning obligations. Parent companies or shareholders of nuclear operators are not entitled to nuclear operating licenses and therefore not responsible for any shortfall in funding of a nuclear operator under normal circumstances (US-NRC, 2015b). Even if the licensee of a nuclear power plant or its parent company declares bankruptcy, it must still fulfil its decommissioning obligations. Accordingly, nuclear licensees are responsible for maintaining a minimum amount of funds in their decommissioning trusts and any funding shortfall is an inalienable liability that has to be settled by the licensee (NEA, 2016). The NRC regulations require that the operating license of a closed reactor is to be terminated and decommissioning activities to be completed within 60 years after the final shutdown (IEA, 2014; WNA, 2019).

Nuclear power as a percentage of total US electricity generation increased quickly from nearly 5% in 1973 to 9% in 1975. In 2018, around 20% of the country's electricity output came from nuclear energy, making it to the world's largest nuclear power producer with a share of more than 30% of the global production of nuclear energy. Currently, there are 98 active nuclear reactors in the United States, operated by 30 different companies. After a hiatus of the commissioning of new nuclear reactors following the 1979 Three Mile Island accident, 16 license applications to build 24 new nuclear reactors were filed since 2007. Despite a rather difficult economic situation for nuclear power plants, given the availability of cheap domestic shale gas in the United States and an accordingly competitive electricity price level, two new reactors are under construction since 2013 and foreseen to be commissioned by 2021. Another three reactor units are planned and a further 18 new reactors have been proposed (WNA, 2019). The lifetime of nuclear power plants in the United States is not generally limited in time. The NRC licenses nuclear power plants for an initial term of 40 years, with the possibility for these licenses to be renewed periodically, usually in intervals of 20 years. Most reactors in the US have licenses for lifetimes of at least 60 years, some potentially even up to 80 years (WNA, 2019). Between 1987 and 2019, 12 plants in the United States have been shut down, mostly for economic reasons.

The financing system for RWM in the United States is based on mandatory contracts between the government and the nuclear operators. Since 1982, these contracts foresee the government disposing of spent nuclear fuel in exchange for a fee levied on nuclear power sales, including the commitment of the government to begin removing SNF from reactor sites as of 1998 (IEA, 2014). Delays in establishing a functioning DGR at Yucca Mountain meant that the government was unable to meet its deadline and utilities have had to continue storage operations at these sites. The complex process leading up to the suspension of the licensing process for the Yucca Mountain final repository plays an important role in this context. A number of utilities have thus sued the federal government for not meeting its obligation under the NWPA and have been awarded damages by the courts. In other cases, utilities have settled with the government and are receiving reimbursements for spent fuel management costs under those settlement agreements. The industry is reported to estimate that damages for all utilities with which the DOE has contracts will ultimately amount to at least USD 50 billion. The DOE estimates the government liabilities at USD 36.5 billion as of 30 September 2019, assuming a full year 2021 restart of licensing activities, and using timeframes contained in the NWP A and the Yucca Mountain License Application. The DOE reported that a total of approximately USD 8 billion had been paid from the taxpayer-funded US Judgment Fund through 2019. The outstanding government liabilities are thus estimated at USD 28.5 billion as of 30 September 2019.

In view of the ongoing legal disputes and the suspension of the Yucca Mountain final repository, a Court of Appeals decision from November 2013 ordered that the fee be set to zero, meaning that no new contributions from the utilities to the NWF will occur, until there is either compliance with the NWPA or until the Congress enacts an alternative waste management plan. This order went into effect in May 2014 (IEA, 2014). Because of a Federal Court ruling which found that the government could not use the NWF to pay for storage costs resulting from DOE's delay in performance, damage payments to utilities are paid by the US Treasury Judgment Fund (see Alabama Power Co. v. United States Department of Energy). Therefore, the costs for the on-site storage of SNF are currently directly attributed to the government and hence the taxpayers. The settlement of the disputes between the government and the nuclear operators, including the development of a solution for a final storage facility, is likely to be a highly policy-relevant issue. Finding a long-term solution would also impact nuclear new build. Under new standard contracts with the DOE, proponents of new reactor construction must undertake to store used fuel on site indefinitely, so that the DOE does not become liable for delays (WNA, 2018).

The funding system

The establishment of decommissioning provisions by the nuclear operator is regulated under rules set up by the US NRC. The NRC rules set out that nuclear licensees are to provide reasonable assurance that provisions will be available for decommissioning after a reactor has permanently ceased operations (Turtil, 2016). In this context, a decommissioning report must be submitted, containing a certification that financial assurance for decommissioning will be provided in an amount that may be more, but not less, than a specific amount varying between USD 85 million and USD 135 million (1986 price level). The specific amount to be provided depends on the reactor type and its power level. It is to be adjusted annually, using a rate at least equal to the equation shown in Figure 17.1 (NRC Regulation 10 CFR 50.75). Financial assurances regarding the costs for decommissioning may be provided in form of a prepayment account, an external sinking fund, contractual obligations, guarantees from a parent or third party, or a combination of the previous.

Assurances in form of a prepayment account have to be deposited before the submission of the decommissioning report into an account segregated from the licensee's assets and outside of its administrative control. Most commercial operators constitute trust funds during operations from contributions from electricity ratepayers. Deposits have to be made in cash or liquid assets such that the amount of funds would be sufficient to pay the decommissioning costs at the time permanent termination of operations is expected. The prepayment method can be coupled with a surety method, insurance, or other guarantee method, the value of which may decrease by the amount accumulated in the sinking fund.

Assurances in form of an external sinking fund have to be held in a separate account outside of the licensee's control in which deposits are made periodically, but at least annually, if the licensee recovers the costs of decommissioning through ratemaking regulation or non-bypassable charges. Such an external sinking fund may, for instance, come in the form of a trust, an escrow account or the deposit of government or other securities. The external sinking fund may also be coupled with added insurance or other guarantee methods.

A licensee might also assure the decommissioning costs through contractual obligation(s) on the part of its costumer(s), the total amount of which over the duration of the contract(s) will provide the licensee's total share of uncollected funds estimated to be needed for decommissioning. All proceeds from the contractor(s) for the funding of decommissioning are to be deposited in an external sinking fund.

If a licensee assures the decommissioning costs through guarantees from a third party, this might happen in form of a surety, an insurance, or a parent company guarantee. Such guarantee is supposed to assure the acquisition of financial responsibilities for decommissioning through a third party in the case of default by the licensee.

Approximately 50-60% of licensees are authorised to accumulate decommissioning funds over the operating life of their plants. These owners – generally traditional, rate-regulated electric utilities or indirectly regulated generation companies – are not required to have the full amount of funds needed for decommissioning available prior to the start of their decommissioning activities. For annual deposits in external sinking funds, the deposits should attempt to approximate the total amount remaining to be accumulated, divided by the remaining years of the license, as determined by the initial and updated certification amount set by the NRC.

As far as RWM is concerned, under the 1982 NWPA, the commercial nuclear utilities in the US have to pay fees, set at USD 1/MWh of nuclear energy produced, which are deposited in the publicly managed NWF. The NWF is intended to cover costs arising in the context of radioactive waste disposal, including a) the processes involved in and activities related to any repository, monitored retrievable storage facility, or test and evaluation facility constructed under the NWPA; b) the conducting of non-generic research, development, and demonstration activities under the NWPA; c) the administrative costs of the radioactive waste disposal programme; d) any costs that may be incurred by the Secretary of Energy in connection with the transportation, treating, or packaging of SNF to be disposed of in a repository, to be stored in a monitored retrievable storage site, or to be used in a test and evaluation facility; e) the costs associated with acquisition, design, modification, replacement, operation, and construction of facilities at a repository site, a monitored retrievable storage site, or a test site necessary or incident to such repository, monitored retrievable storage facility, or test and evaluation facility; and f) the provision of assistance to States, units of general local government, and Indian tribes under specific sections. Fee payments and investment income are deposited into the NWF account and are made available to the DoE through an annual appropriation from the NWF authorised by the US Congress. Fees collected in excess of expenses incurred are invested in Treasury securities. If, at any time, monies available in the NWF are insufficient to discharge responsibilities under the NWPA, borrowings may be made from the US Treasury (US DOE, 2016a). Part of and managed by the Department of Energy, the NWF is not subject to federal, state, or local income taxes and its budget is to be included in the national budget of the United States (US DOE, 2016a; 1982 NWPA). This organisation reinforces the liability of the United States as inalienable guarantor for all costs arising in the context of RWM. However, it is important to continue to ensure that the assets of the NWF are also in the future only used to cover costs arising in the context of radioactive waste disposal and to ensure long-term availability of the assets.

The cost side

Regarding decommissioning costs, an initial cost estimate must be provided by the nuclear licensees in the licensing process. At its discretion, a power reactor licensee may submit an initial certification amount of funds for decommissioning based either on the NRC formula or on a site-specific cost estimate that is equal or greater than that calculated in the NRC formulas (US-NRC, 2011; Crozat, 2017).

The NRC formula is a non-site-specific cost estimate that only covers radiological decommissioning and which is used to define a minimum funding amount, adjusted for changes in labour, energy, and LLW burial costs over the life of a reactor. The NRC formula is composed of a regulatory formula amount and of an adjustment factor as laid out in Figure 17.1. The escalation factors for labour and energy are to be taken from the US regional statistics and the LLW burial escalation factor are to be taken from the NRC Report on Waste Burial Charges (NRC Regulation 10 CFR 50.75). The NRC formula is intended to ensure that the utility has the "bulk" of the required funds available for decommissioning.

Figure 17.1:
NRC calculation formula for the non-site-specific minimum decommissioning funding amount

Example calculations (approximate estimates):
PWR and BWR of 3 400 MWt capacity or greater
(data as of 31 December 2014)

- **PWR** **(USD 105 million) x (labour, energy and LLW burial adjustment factor of ~5.00)**

  = ~USD$_{2014}$ 525 million

- **BWR** **(USD 135 million) x (labour, energy and LLW burial adjustment factor of ~5.00)**

  = ~USD$_{2014}$ 675 million

PWR = Pressurised water reactor, BWR = Boiling water reactor.
Source: Turtil, 2016: p. 5.

Five years prior to the projected end of operations, each nuclear operator is required to submit a preliminary decommissioning cost estimate to the NRC with an updated assessment of major cost factors that could affect anticipated radiological decommissioning costs (US NRC, 2015a). This estimate must be site-specific and is typically, but not required to be, performed by third parties (Crozat, 2017). The site-specific cost estimate must be greater than or equal to the NRC Minimum Formula Amount (Turtil, 2016). An updated site-specific cost estimate of remaining decommissioning costs must be submitted prior to or within two years after permanent cessation of operations. Cost estimates are based on current assumptions, and are updated periodically to ensure adequacy of funding. Most estimates are prepared using a bottom-up costing analysis employing unit cost factors against a detailed inventory of equipment and structures. The cost estimate must account for the entire decommissioning work scope. The NRC cost formula only covers decommissioning costs needed to remove a facility or site safely from service and reduce radioactivity to safe levels to allow for termination of the license, which means that the costs of removal of non-radiological systems and structures and of on-site SNF storage are not included. As a general rule, the NRC's non-binding Regulatory Guide sets out that estimates should provide costs for each of the following major activities and phases: a) major radioactive component removal; b) radiological decontamination and decommissioning; c) management and support, e.g. expenses such as labour costs of utility support staff and decommissioning contractor staff, energy costs, regulatory costs, small tools, insurance, etc.; d) waste packaging/shipping: placing waste in packages and shipping to waste vendors or burial site; e) waste burial or waste vendor: waste burial charges, including waste vendors' processing fees; f) contingency allowance for unexpected costs; g) assumptions, references, and bases for unit costs used in developing the estimates, as well as description of how the cost estimate accounts for inflation (US NRC, 2011). The cost estimate should be provided in current-year dollars. Escalation of the waste disposition costs is considered separately from the general inflation rate applicable to labour, material, and energy costs.

Regarding RWM of HLW and SNF, the DOE issued yearly reports in which it assessed the adequacy of the nuclear waste fee in view of the probable costs arising in the future. Due to the fee being set to zero in 2014, the last yearly report dates to 2013. In early 2020 the Administration announced plans to move away from Yucca Mountain and pursue other storage and disposal options. At this time, no total lifecycle costs projections have been prepared as part of this new policy. The last annual fee adequacy report in 2013 is no longer relevant because of the fee having been set to zero in 2014 and because the Administration has moved away from Yucca Mountain to pursue other storage and disposal options that have yet to be established. The report however constitutes a very well made example of a cost estimation. For this reason, we have included a description of it in Appendix A.

Assets, investment rules and performance

The NRC rules set out specific investment prescriptions for decommissioning trust funds: a) it is prohibited to invest the funds in securities or other obligations of the licensee or any other owner or operator of any nuclear power reactor or their affiliates, subsidiaries, or successors; b) it is forbidden to invest in a mutual fund in which at least 50% of the fund is invested in the securities of a licensee or a parent company whose subsidiary is an owner or operator of a foreign or domestic nuclear power plant; c) trusts should not be held under the administrative control of the licensees; and d) it is permitted to invest in securities tied to market indices or other non-nuclear sector collective, commingled, or mutual funds, provided that no more than 10% of trust assets may be indirectly invested in securities of any entity owning or operating one or more nuclear power plants, i.e. the decommissioning Funds cannot invest more than 10% in parent companies (Crozat, 2017; NRC Regulation 10 CFR 50.75(i)). Further, the NRC regulations allow assumption of 2% real rate of return in projections. Higher rates must be certified by state regulators, while actual returns above 2% reduce the need for future payments (Crozat, 2017). The NRC non-binding guidelines state that licensees do not need to submit a complete listing of all investments within the biennial Decommissioning Funding Status Reports (DFS) to the NRC (NRC, 2011). The NRC staff performs regularly analysis of the decommissioning funding.

In case of funding shortfall, the licensee must replenish its funds and report such actions to the NRC. In cases where the total cost of decommissioning is provided through cost-of-service ratemaking it may make a good-faith effort to obtain rate relief to cover its shortfall.

Further, the NRC may require the licensee to take one or more actions, including but not limited to: a) produce a funding guarantee from a parent company; b) develop a specific catch-up funding plan; c) provide more frequent or additional funding reports; d) make additional payments; or e) obtain a surety bond (US NRC, 2015b). The financial flexibility is a pre-requirement for the evolution of decommissioning into an essentially industrial challenge all the while ensuring adequate funding.

As far as radioactive waste management is concerned, the NWF received over USD 750 million in utility fees each year before the fee was set to zero in May 2014. By the end of 2019, utilities had contributed nearly USD 21.6 billion into the NWF since the Fund's inception in 1983. There have been some USD 7.5 billion as funding disbursements for first repository costs (Yucca Mountain and other first repository activities). The government's financial report for FY 2019 listed the fund's assets at USD 40.9 billion (UST, 2019). By 2011, the NWF's average annual interest rate was reported to be 5% by the DOE (NEA, 2013). Investment income is over USD 1 billion per year (Crozat, 2017). The rate of return varies according to the type and maturity of the NWF's investments in US Treasury securities. In 2013, the NWF's investment portfolio contained US Treasury securities with maturities through 2040. The issuance of 30-Year Treasury Bonds allowed the NWF to invest in longer-term bonds, thus increasing the average maturity of the investments. The investments consisted of 76% investments in Zero Coupon Bonds (ZCB), which do not pay interest but are purchased at a deep discount, with profit accumulating at maturity when the bond is redeemed for its full face value. Further, 16% of the investments were in conventional Treasury securities ("Notes"), whose interest payments and maturity dates were specified when each security was purchased. Finally, 8% of the investments were in Treasury Inflation-Protected Securities (TIPS), whose return does not include an expected inflation component – instead, interest is calculated at the "real" rate and the principal values of

TIPS securities are adjusted semi-annually by the Treasury to pay investors for actual inflation. The interest rate is normally lower than for fixed rate bonds with a comparable maturity. However, as the principal amount grows, the payments increase with inflation. By July 2013, the NWF's investments yield rates were reported to range between 0.7% and 6.8% for Notes (maturity dates spanning from 2013 to 2022), 1.6% and 2.9% for TIPS (maturity dates spanning from 2025 to 2032) and 4.1% and 6.4% for Zero Coupon Bonds (maturity dates spanning from 2012 to 2040) (US DOE, 2013). As of 30 September 2019, cumulative billings from fees and the defense nuclear waste appropriation totaled about USD 25.4 billion, while cumulative interest earnings and other revenue totaled approximately USD 27.0 billion. Cumulative expenditures by the DOE from appropriations and amounts authorised by Congress totaled approximately USD 11.4 billion. Investment income and net gains from the maturity of securities totaled USD 1.6 billion for the FY 2019 (US DOE, 2019a).

The NWF is invested in US bonds and investments of the NWF are made in US Treasury securities from funds in excess of current needs (Crozat, 2017). They are stated at cost net of amortised premiums and discounts as it is the DOE's intent to hold the investments to maturity. Premiums and discounts are amortised using the effective interest yield method.

Conclusion

The United States possesses sophisticated funding systems for both the management of SNF and decommissioning of nuclear power plants. The current decentralised storage scheme for radioactive waste is a consequence of the lack of a central interim or final repository for SNF. The liability for decommissioning costs, including the disposal of LLW and ILW, is effectively allocated to the industry, including systematic reporting, reassessment and assurance obligations. The liability for the management of SNF from commercial nuclear reactors was transferred to the federal government, in exchange for a nuclear waste fee that is to be borne by the industry and payed into a public nuclear waste fund. The nuclear waste fee was annually assessed for its adequacy before it was set to zero in 2014. The nuclear waste fund is integrated into the US national budget, underlining and reinforcing the substantial liability of the state for the long-term management of SNF.

Such inclusion of the resources for RWM into the national budget appears coherent under the condition that its assets are exclusively to be used under the dedicated purpose and that the on-time disbursement of resources is ensured. While the legal framework in the US establishes a funding scheme that appears coherent, the omission of the government to come up with a final or interim repository to fulfil its legal obligation of SNF storage currently weakens the functionality of the system. This resulted in a number of expensive lawsuits and compensation payments to the industry, borne not by the dedicated nuclear waste fund, but tax-funded resources. The first best option in order to solve the current gridlock would of course be the selection and construction of a final repository for SNF. In the absence of such a first best solution, it is necessary to continue the establishment of a comprehensive scheme for interim storage. The history of funding the liabilities for SNF management in the United States shows how even well-funded and sophisticated systems can be unsettled by political decisions that question the underlying assumptions of the funding system in fundamental ways. For the time being, taxpayer-financed government contributions are the source of funding of last resort and allow the system to continue with day-to-day operations. Advancing towards a robust long-term solution for SNF management from commercial reactors, however, will most likely include a careful and systematic effort at the institutional level to bring together all major stakeholders to achieve political sustainability, which can then be translated it into the full financial sustainability of the funding system.

Appendix A: Methodology of the fee cost estimation (valid until 2013)

The fee assessment method follows the approach employed by the DOE from 1983 to 2009 of conducting a detailed evaluation of the projected costs of the plan for safe management and disposal of SNF and comparing those costs to the projected fee revenues. The assessment is based on: (a) the disposal system configuration and the implementation schedule; (b) the projected costs of disposal activities, based on a rough cost comparison of nuclear waste repositories across various types of geologic formations performed by DoE laboratories (Table 17.1); (c) the projected revenues from the Nuclear Waste Fund, assuming constant nuclear waste fee levels; and (d) the projected economic conditions over the total life cycle of disposal activities. Activities were assumed to last 75 years following the end of nuclear operation and accordingly fee collection, while no new nuclear reactors were expected to be built after 2035. The estimated costs for site characterisation and licensing are in the same order of magnitude as the estimated costs for the repository engineering, procurement and construction (Table 17.1). This might be an indication for the scale of the challenges arising in both areas. In the context of future economic conditions, considerations of seven interest and inflation rate forecasts to 2157, the date when disposal activities are projected to end, issued by five separate sources were taken into account (Table 17.2). Despite the range of assumptions tested, the length of the relevant period of estimation (more than 140 years) shows the heroic nature of these assumptions. Over such long timeframes any assumptions are inevitably speculative as they are based on some implicit idea of stable framework conditions allowing for compounding over 140 years. The Yucca Mountain debate shows to which extent long-term RWM can be subject to radical policy-related uncertainty and thus requires sufficiently flexible frameworks for analysis and policy making. The US system is perhaps the system that is accompanied by the most thorough and sophisticated economic analysis. And yet, such sophistication does not ensure that the assumptions on which it is predicated are always relevant to events and policy decisions on the ground.

Table 17.1:
Cost items used for the 2013 cost estimate

Cost item	Assumed costs (USD)
Storage costs	
Siting costs	19 million
Design, engineering, licensing and startup costs	52 million
Total storage infrastructure costs	53 million
Fuel storage facility	111 million/60 000 tonnes
General administrative costs	12 million/year
Storage overpack costs	0.03 million/tonne
Loading operations costs	7 million/year
Decommissioning costs	358 million
Repository costs	
Pre-selection site evaluation	3 260 million
Site characterisation and licensing	8 514 million
Repository engineering, procurement, and construction	7 819 million for a 3 000 tonnes of uranium/year facility
Waste packages	0.11 million/tonne of heavy metal
Subsurface facilities	0.06 million/tonne of heavy metal
Emplacement costs	0.11 million/tonne of heavy metal
Monitoring costs	56 million/year
Closure costs	145 million/year
Transportation costs	
Transportation investment total cost	1 544 million
Canister cost	0.81 million/canister
Transportation cask cost	5.44 million/cask system
Annual transportation and operations support costs	101 million/year
Shipment costs	0.012 million/ tonne
Remaining programme costs	
Construction phase	244 million
Operations phase	114 million
Monitoring phase	27 million

Source: US DOE, 2013: Appendix G.

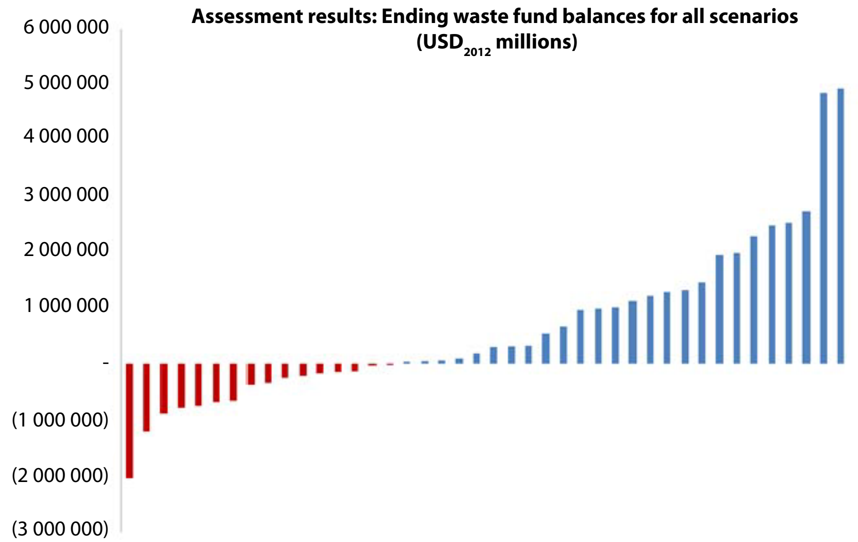
Table 17.2:
Different economic forecasts used in the 2013 cost estimate

Economic forecast	Average inflation	Average real interest	Maximum ending fund balance USD_{2012} trillion	Minimum ending fund balance USD_{2012} trillion	Number of scenarios with positive NWF ending balance
Global insight pessimistic	3.52%	3.73%	4.95	(2.05)	4 of 6
Global insight trend	1.98%	3.11%	2.54	(0.88)	4 of 6
Global insight optimistic	1.61%	2.90%	1.99	(0.65)	4 of 6
Ibbotson historical	4.37%	2.73%	1.03	(1.2)	4 of 6
DOE Energy Information Administration	2.12%	2.66%	1.34	(0.74)	4 of 6
Office of Management and Budget	2.10%	1.67%	0.32	(0.38)	4 of 6
Taylor Advisors market yield rates	2.87%	0.51%	0.05	(0.18)	2 of 6

Source: US DOE, 2013: p. 32.

All scenarios were then grouped into those scenarios in which funding levels would fall short in financing future liabilities and those in which the future assets would be adequate. In 2013, the number of scenarios deeming the fee level of USD 1 /MWh adequate outweighed those in which funding would be insufficient (Figure 17.2). Therefore, there is a good probability that a positive scenario will emerge.

Figure 17.2:
Assessment results of the different economic scenarios used in the 2013 cost estimate



Source: US DOE, 2013: p. ES-2.

Accordingly, the last Adequacy of the Nuclear Waste Fund Fee report proposed to keep the nuclear waste fee constant. Until 2013, the Department of Energy had never proposed an adjustment to the fee. The use of discounting rates in the cost estimate includes the estimation of the future value of cash flows by adding undiscounted cash flow streams in year of expenditure values, before discounting that total value by using the assumed inflation rates in order to estimate the balance on a 2012 price-level (US DOE, 2013: Appendix G, p.4). The model uses a multitude of different economic forecasts for its cost estimates. In view of the recent changes in the decommissioning and RWM environment in the US, including inter alia the licensing of new reactor units and the abolishment of the nuclear waste fee since 2014, it appears that a renewal of an adequacy assessment for RWM funding might be revealing for all sides in order to throw light on potential ways forward. Especially the assessment of funding adequacy solely based on an assessment of the nuclear waste fee might have to be revised in view of the abolishment of the fee.

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PART III

Elements of good policy practice

Preamble

The preceding conceptual framework and the twelve country case studies have set out the theory and, in many cases, the practice of modern, future-oriented policies to ensure the adequacy of financing for decommissioning and radioactive waste management (RWM). Such policies move away from comparing estimations of highly uncertain future liabilities discounted by social discount rates with little grounding in the long-term economic environment to currently constituted assets. They are mindful that liabilities of such orders of magnitude will ultimately need to be borne by the parties that are best placed to manage the specific risks associated with funding decommissioning and RWM.

The conceptual framework has argued that the great uncertainties in this area, many of which are of a non-quantifiable, discontinuous nature, require a change in approach. Instead of linearly discounting hypothetical costs with hypothetical discount rates, funding frameworks should explicitly be conceived in a manner that enables them to react flexibly to new information as it comes in. Changes in RWM solutions, their timing, location and costs, the financial return on assets, the lifetime of operators, the emergence of new stakeholders and institutions and so forth would thus each time require adjustments in all the other parameters of the system. Of course, this does not imply continuous tinkering but rather regular and transparent reviews at well spaced-out intervals with broad public involvement, where all pertinent elements are discussed, adapted where necessary and considered to be the relevant reference until the next revision.

Elements of such a circular approach are the recognition of the interdependence of all elements through bi-directional causalities. Future costs are not an exogenous, objective data point but the result of endogenous policy decisions taken and adapted in function of new incoming information concerning available technologies and their costs, public preferences and social choices. The possibility of discontinuous changes in any of these parameters, including the allocation of liability for residual risk, for which neither expected values nor probabilities can be assigned, is fully acknowledged.

Ultimately, such a circular approach will also include a broader interpretation of the Polluter Pays Principle (PPP). In the context of decommissioning and RWM, the latter is commonly understood to imply that costs should be borne by electric utilities and their customers. As has been pointed out throughout the study, the prospective lifetimes of such utilities, their uncertain outlook in fast-moving electricity markets and their inability to influence decisive cost parameters such as timing or choice of RWM technology does not allow for a straightforward application of the original reading and intent of the PPP. At the same time, there is continuing agreement that electric utilities and their customers need to honour their original financing commitments. While situations differ from country to country, in many instances, the transfer of both constituted assets and liabilities to public or quasi-public institutions with the ability to carry the multiple dimensions of residual risks provides a promising perspective for improving the adequacy of financing in the area of RWM.

Such a change in perspective does not imply a radical change from established practice. For obvious reasons, governments and legislators have closely regulated and overseen funding arrangements since their very beginning. Implicit forms of public-private sharing of funding and its risks can also be identified in many countries. However explicitly adopting a circular approach would allow such risk-sharing and, where appropriate, transfers of liabilities and assets to proceed in a more systematic and transparent fashion.

The situation in the area of decommissioning is slightly different as the timeframes are shorter, the technologies better established, objectives are well-defined and hence incalculable residual risks can overall be expected to be of lesser importance. This makes a literal interpretation of the PPP far more pertinent. Nuclear operators are indeed much better placed to assume the responsibility for both the funding and the operational implementation of decommissioning than for RWM solutions. The emergence of a secondary market for the transfer of decommissioning liabilities on a commercial basis in some countries shows the high degree of industrial maturity and codification that has been achieved in this area. While there remains, of course, a need to manage the interface of decommissioning and RWM carefully, overall the results of this report suggest somewhat different approaches to ensuring the adequacy of funding for decommissioning and RWM.

Finally, over the years ongoing work on the adequacy of funding by independent research institutions and inter-governmental organisations such as the NEA has also generated a wealth of information on specific forms of funding, investment strategies and cost estimations. Experiences with many of these can be found in the twelve country case studies. While the preceding remarks and the "Elements of good policy practice" listed below do indeed suggest the adoption of a broad new approach to ensure the adequacy of funding, particularly in the area of RWM, it is also quite evident that no single well-defined framework would work for all NEA countries. The structure of the electricity and the nuclear industries, the timing of RWM solutions, the institutional context as well as political commitments and social preferences vary widely from country to country and require bespoke solutions.

The following "Elements of good policy practice" thus do not intend to provide prescriptive solutions based on theoretical considerations with little bearing on the practical realities of an issue as complex as this one. They rather aim at enlarging the framework in which current discussions are held thus assisting NEA countries in finding their own solutions. In other cases, they will allow to address in an explicit manner changes that are already taking place in member countries implicitly. In all cases, they are meant to provide reference points in an ongoing effort to continuously improve the adequacy of funding systems for decommissioning and RWM.

Elements of good policy practice in ensuring the adequacy of funding for decommissioning and RWM

1. **Sustainable funding arrangements for decommissioning and RWM need to respond to the specific situation of each NEA country**. One size does not fit all. National circumstances with respect to the structure of the electricity and nuclear industries, the timing of RWM solutions, the institutional context as well as political commitments and social preferences can differ widely and will require differentiated solutions.

2. **Funding arrangements need to be considered in a broad perspective**. The financial sustainability of funding arrangements ultimately depends on the political sustainability of the chosen decommissioning and RWM solutions.

3. **Ensuring the adequacy of funding of decommissioning and RWM is a long-term issue, which, over time, is subject to significant technological, economic and socio-political changes**. Such largely inevitable changes in one or more parameters of the system can create considerable risks when funding frameworks are not sufficiently adaptable.

4. Aligning the costs of sustainable solutions for decommissioning and RWM with concrete technical solutions thus requires moving away from a funding system conceived in a linear framework, in which the hypothetical future costs of a prospective technical solution are discounted at a constant institutionally set discount rate to define funding requirements. **Ensuring the adequacy of funding for decommissioning and radioactive waste requires instead a *circular approach*, in which all key elements of the funding system are adapted at regular intervals in function of major changes in any one element**. Such key elements will include the technological solution considered, the timing of its implementation, the expected return on constituted assets and the corresponding risk profile, the amount of assets and, of course, the liability arrangements.

5. Discontinuous change may arise both on the cost and the funding side. On the cost side, new technologies, changed timeframes or new societal and political requirements may either enable or require radically new solutions. **On the funding side, the situation of the liable party, frequently a nuclear operator, is likely to change significantly over the timeframes expected, in particular, for the management of radioactive waste**. Even external segregated funds can be subject to long-term changes in expected returns. Given their size, very few operators will be able to compensate for such risks.

6. **In terms of appropriate allocation of liabilities, the latter should, as a general principle, always be assumed by the party that is best equipped to handle them**. In a first instance, this refers to the ability to handle the risks related to funding liabilities, including the diversification, hedging or sharing of such large risks. Often, however, it also relates to its ability to influence and reduce the underlying risks and their costs.

7. In this logic, private operators should be responsible for the technical and economic risks that arise from their commercial activities. However, radical uncertainty and discontinuous change, for instance, in political or legal framework conditions, cannot be appropriately diversified or hedged by private actors. **Such residual, non-diversifiable risks require some form of public participation**. If not adequately taken into account, there is a possibility that such risks will be "socialised" implicitly (e.g. through bankruptcy, shortfalls, exploitation of informational asymmetries etc.), which is likely to be more costly for society as a whole.

8. At the current state of knowledge and technology, the relative shares of privately manageable risk and residual, non-diversifiable risk differ between decommissioning and RWM. Decommissioning is becoming rapidly a mature industrial activity. **Excepting special national circumstances, funding decommissioning would thus be expected to remain a responsibility of nuclear operators**. Despite the fact that the first DGR will become operational in the coming years, RWM is likely to rely on bespoke solutions defined according to specific national needs and evolving preferences.

9. Financial liability arrangements will need to be robust over the long term and capable of providing adequate financing also in the event of unforeseen circumstances. This would require, in many cases, also a broader interpretation of the Polluter Pays Principle (PPP). The PPP holds, in particular, that "polluters" can choose among well-known cost-minimising technologies in order to minimise the costs of attaining clearly defined social objectives. **These conditions are only very partly fulfilled in RWM. Those that cause nuclear waste, i.e. nuclear utilities and their customers, are usually not the party best placed to implement the often not yet fully codified societal internalisation strategies**.

10. In particular, RWM takes place in an evolving societal context. **Governments as the stewards of societal preferences thus determine the technologies, timing and location of RWM solutions**. Explicitly or implicitly, they are also already now the ultimate bearers of residual risks. In order to align societal preferences, technical solutions, costs, timing and available assets, there might be a case in some countries for governments taking on direct liabilities for RWM somewhat earlier and somewhat more explicitly than is currently the case.

11. **Any transfer of liabilities from current holders to national governments obviously needs to be accompanied by a transfer of the totality of constituted funds**. In no way should such a transfer constitute an opportunity for freeriding for nuclear operators, utilities or their present and future customers. Risk premiums or indemnities over and above constituted funds may also be included in such transfers.

12. **Ensuring the adequacy of funding of decommissioning and, in particular, of RWM requires the adaptability of all key elements of the funding system, including the technologies for the interim storage and disposal of radioactive wastes**. There is broad consensus that national deep geological repositories (DGRs) constitute a safe and effective approach to disposal. However, additional solutions such as multilateral repositories, extended interim storage, reprocessing, deep borehole repositories, loaning or exporting of radioactive wastes may exist either as substitutes or as complements to DGRs

13. Assumptions about the rates at which to discount future liabilities and at which to assume returns on invested funds loom large in assessing the adequacy of funding. **Consistent with taking a circular approach to establishing the adequacy of funding, the alignment between rates of returns, defined contributions, timelines, technological choices and funding commitments needs to be ensured at regular intervals**.

14. Current long-term outlooks anticipate very low, zero or even negative returns on risk-free or low-risk assets. According to societal and political preferences, NEA countries have different options to respond to this new environment. They include (a) increasing assessed contributions,

(b) postponing implementation of decommissioning or RWM solutions, (c) resorting to less costly solutions or (d) resorting to a broader set of often riskier investment strategies with higher returns. Several countries have chosen option (d) in recent years to ensure the adequacy of funding. **Pursuing investment strategies with potentially higher returns requires that associated risks are well identified and communicated to stakeholders, that the party liable for any potential future shortfall is identified in advance and that, other things equal, funding risk decreases as the date of disbursement approaches**.

15. Ultimately, the difference between a regular updated linear approach as practised in the past and a full circular approach as advocated in the preceding publication is one of degree. Much sensible discussion and work on ensuring the adequacy of funding has been ongoing in NEA countries in recent years. However, only a circular framework foresees the regular adjustment of all parameters embedded in broad decision-making processes involving all stakeholders. **Transitioning from a linear to a circular approach would recognise explicitly that ensuring the adequacy of funding for decommissioning and RWM is not akin to traditional project finance, but a dynamic societal process requiring multiple adjustments along the way**.

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Ensuring the Adequacy of Funding Arrangements for Decommissioning and Radioactive Waste Management

The world's nuclear power reactors are ageing, with the majority approaching the end of their planned operational lifetimes in the coming years. The adequacy of funding for decommissioning and radioactive waste management (RMW) thus increasingly commands the attention of decision-makers.

This report by the OECD Nuclear Energy Agency (NEA) combines a solid conceptual framework with the insights from twelve case studies of NEA member countries to propose a new approach to the adequacy of funding that is both robust and flexible.

Current funding systems in NEA countries are overall adequate. The challenges ahead however are formidable: decommissioning and RWM are moving from design to implementation, returns on assets are low and societal preferences can evolve. The very long-term nature of the solutions, in particular for radioactive waste disposal, is also not easily compatible with the economic lifetimes of the original liability holders.

This requires that all elements of the system – accrued funds, expected future returns, the lifetimes of nuclear power plants, the expected costs of politically sustainable technical solutions and the liabilities for residual risks – are reviewed and realigned at regular intervals. Complementing existing approaches with such a circular approach will strengthen funding arrangements and ensure their adequacy for decades to come.

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