Financing Nuclear Decommissioning

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Abstract

While more and more nuclear installations facing the end of their lifetime, decommissioning financing issues gain importance in political discussions. The financing needs are huge along the Uranium value chain. Following the polluter pays principle the operator of a nuclear installation is expected to accumulate all the necessary decommissioning funds during the operating life of its facility. However, since decommissioning experience is still limited, since the decommissioning process can take several decades and since the time period between the shutdown of a nuclear installation and the final disposal of radioactive waste can be very long, there are substantial risks that costs will be underestimated and that the liable party and the funds accumulated might not be available anymore when decommissioning activities have to be paid. Nevertheless, these financing risks can be reduced by the implementation of transparent, restricted, well-governed decommissioning financing schemes, with a system of checks and balances that aims at avoiding negative effects stemming from conflicts of interests.

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1 Introduction

By the end of 2017, 166 nuclear power reactors had been permanently shut down, of which 144 were in the process of dismantling or had already been fully demolished (IAEA 2018). Moreover, 64% of the operational nuclear power reactors in the world at this time were 30 years old or older, and are thus candidates for being shut down in the near future (cf. Fig. 1).

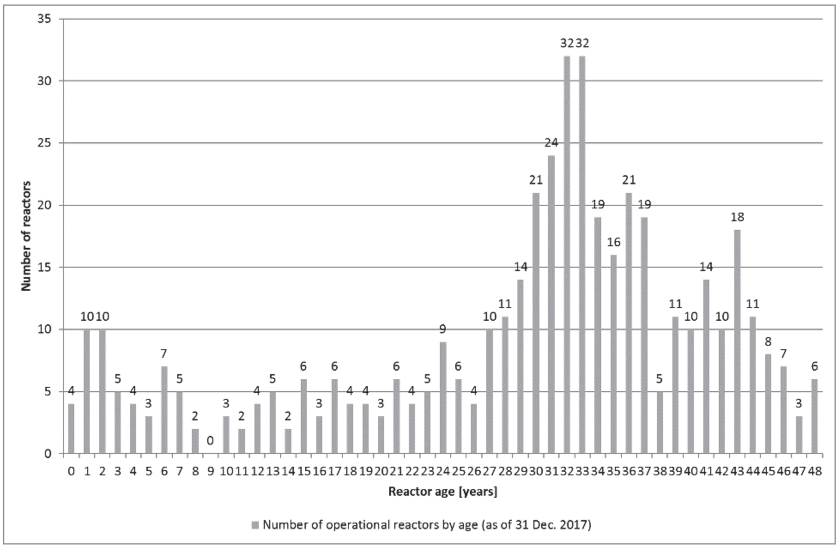

Fig. 1 Number of operational nuclear power reactors by age (as of 31 Dec. 2017) (Based on IAEA, 2018, 78)

This will result into the need to dismantle, decontaminate and demolish these nuclear facilities as well as to undertake processing, conditioning and disposal of nuclear waste and spent fuel ('decommissioning')(Irrek et al., 2007). It is of paramount importance that the funding of these decommissioning activities will be adequate and available when needed in order to avoid negatively affecting the safety of citizens and natural environment. Although this has been principally known since early days of NPP operation (cf., e. g., Lukes et al., 1978), the political pressure to identify and implement respective solutions has only increased within recent years due to changes in the electricity markets in the course of liberalisation and transformation towards a sustainable energy system and the respective impacts on the economic situation of NPP operators and their mother companies, and due to more and more NPPs facing their end of operation.

In general, decommissioning financing needs are huge along the Uranium value chain. Underground uranium mines and mills, open pits, uranium and thorium processing, conversion, enrichment and fuel fabrication facilities, nuclear reactors, nuclear fuel reprocessing plants, interim storages and further nuclear installations have to be decommissioned in a way that human beings, flora and fauna, air, soil, open and ground water sources will be protected against radiation exposure and radioactive contamination. Decommissioning and rehabilitation of the nuclear sites represents a challenge in ecological and economic terms for the former operators. The amount of radioactive waste from all steps of the Uranium value chain adds to the complexity of task (Hagen et al., 2005).

Operators of nuclear installations are expected to accumulate all the necessary decommissioning funds during the operating life of facilities. However:

- The decommissioning process can take several decades;
- In particular, the time period between the shutdown of a nuclear installation and the final disposal of radioactive waste can be very long;
- Therefore, the liable party and the funds accumulated might not be available anymore when decommissioning activities have to be paid;
- Moreover, expected decommissioning costs are only partly assessable since nuclear decommissioning experience is still limited, and technical concepts for important decommissioning steps, particularly for final disposal of higher activity waste (HAW), often do not yet exist;
- Finally, unexpected radiation and contamination problems might lead to additional financing needs even after decades, hundreds or thousands of years after final disposal of radioactive waste.

Therefore, this chapter will analyse

- to which extent the Polluter Pays Principle can be implemented in order to ensure the complete financing of a safe decommissioning by the operators of nuclear installations;
- the different decommissioning financing steps needed;
- who will benefit from the amounts of finance accumulated;
- and compare selected decommissioning financing concepts realised in different countries.

Based on this analysis, conclusions will be drawn and recommendations given for the design of safe decommissioning financing concepts. The chapter will thereby focus on decommissioning financing of commercial nuclear power plants (NPP). However, the general findings can also be transferred to other private or publicly-owned nuclear installations.

2 Basic liability principles

Nuclear liabilities of a NPP operator include liabilities for the dismantling, decontamination, demolition and site clearance of the nuclear facilities at the end of their lifetime as well as for the storage, processing, conditioning and disposal of nuclear waste and spent fuel. They arise with the start of operation of a nuclear facility, i. e. as the first activation or contamination takes place, and usually increase with operation.

A main principle with regard to the distribution of liabilities is the 'Polluter Pays Principle'. In general, the Polluter Pays Principle is broadly accepted in environmental and economic policy. In theory, in a world of perfect information, perfect competition and full rationality of market actors, allocative efficiency will be gained if all external costs are internalised into the market. In order to maximise the net benefit to the society, in principle, the NPP operators should be fully responsible for covering the full costs of decommissioning a NPP. This requires a clearly defined obligation to plan, implement and finance all decommissioning activities including nuclear waste management and final disposal operations. Since the NPP operator does not earn money with the NPP after its shutdown, all necessary financial means have to be collected during operation of the plant via the electricity prices to cover associated decommissioning costs. If decommissioning is not paid by those who have benefited from its operation inter- and intra-generational justice will not be ensured.

However, in contrast to theory, the Polluter Pays Principle is not fully implemented in every country. In some countries like Finland and Sweden, the 'Polluter Pays Principle' is a legal requirement, and there has been made substantial progress during the last ten years in several European countries with respect to better ensuring its implementation (Irrek et al., 2007; European Commission 2013; European Commission 2013a). But still in several countries, the liability of NPP operators ends with transfer of radioactive waste to a state-governed organisation. According to international law, the state has the responsibility for final disposal of radioactive waste. Therefore, financial liabilities for final disposal (and partly waste management, too) are not always fully with the ‘polluters’ but in some cases at least partly transferred to the state. For example (Irrek et al., 2007; European Commission 2013; European Commission 2013a):

- In Slovenia, the fees the operator pays for dealing with radioactive waste include the cost of final disposal. They discharge the operator from any waste management and disposal liability. However, the levy is periodically reassessed based on available technical data and other inputs.
- In the case of Bulgaria, Lithuania and Slovak Republic, there are agreements between the state governments, the European Union and some Member States about European contributions to finance decommissioning of the nuclear power plants in the context of the countries’ accession to the European Union in order to ease an early shutdown of these NPPs for safety reasons (cf. Schmidt et al. ,2013, and Ustohalova/Schmidt, 2014, for recent discussion on this support and its effectiveness).
- In Germany, in mid 2017, NPP operators transferred all liabilities for interim storage and final disposal of radioactive materials to the state against a lump sum of Euro 24.1 bn, with financing regarding these activities managed by a state-governed fund. Any costs exceeding this amount will not have to be borne by the NPP operators. This severely violates the Polluter Pays Principle. The argument behind this was fed by a substantial decrease in electricity wholesale prices which has caused severe losses of the large energy companies. It was argued that it would be better to secure a lump sum paid by the NPP operators now instead of not knowing if the companies will be able to finance radioactive waste management activities in the future. It should be noted that the cost estimate behind this amount is just a rough one, partly based on an extremely rough estimate of 1997 by a German authority (Bundesamt für Strahlenschutz – BfS) for a final disposal site which is not a technically feasible one (Gorleben). Moreover, it does not take into account various problems with interim storages which have already been foreseen by nuclear experts (cf., e. g., Neumann, 2016). In parallel to the transfer of liabilities and money in 2017, the state took over two central interim storages. From 2019 onwards, the state will also be responsible for the decentral interim storages at the NPP sites, which have been in operation by the NPP operators. From 2020 onwards, the German state will be responsible for all interim storage sites as well as for any final disposal activities.

Even in those countries, in which the Polluter Pays Principle is a legal requirement, a NPP operator will not be made financially liable for

- any radiation exposure and radioactive contamination in the Uranium value chain before the fuel arrives at the NPP. While it theory, for this part of the nuclear fuel chain, the respective owners of the Uranium mill or the Uranium processing, conversion, enrichment and fuel fabrication plants should be made financially liable, ethical considerations could lead to the argument, that the NPP operator has to bear some social responsibility also for these parts of the value chain.
- any problems arising after the final closure of the final disposal facility. The responsibility usually ends as soon as all waste has been finally disposed of and the safety authorities have accepted that the final closure of the final disposal facility has been concluded fulfilling the pertinent safety requirements for final closure.

However, the example of the German Asse II mine shows that unforeseen problems can arise after closure of such a final disposal. From 1967 to 1978, 125,787 drums and waste packages containing low-level and intermediate-level radioactive waste were emplaced in this test repository. The legal basis for this was mining law, not nuclear law, and there was no proof of long-term safety before the waste was disposed. Today, the large total volume of open drifts and chambers and the closeness of the chambers to the adjoining rock cause severe problems in the Asse mine. The salt rock and adjoining rock loosen, and clefts have formed through which groundwater flows into the mine. The severeness of this disposal problem has been increased by the fact that the inventory of radioactive waste in this mine is not exactly known, particularly with regard to the amount of plutonium disposed. It is now planned to retrieve the radioactive waste and to dispose it elsewhere (www.asse.bund.de; status: 08 May 2016). The fees collected for the final disposal of radioactive waste during operation of the mine summed up to about Euro 8.25m, while current estimates for retrieval costs are between Euro 4–6bn (Kirbach 2009; N.N. 2013; www.atommuellreport.de; status: 08 May 2016). There has been some discussion in Germany on who should be made financially liable for these extra costs. In 2010, some German politicians (e.g., Kelber et al., 2010) argued that the introduction of the nuclear fuel tax could be justified, among others, by the fact that the NPP operators have benefited from disposal sites like Asse II and thus should contribute to the additional costs that will occur.

Anyway, if such problems arise decades or hundreds of years after the closure of the final disposal facility, the NPP operators might not exist anymore. This could also happen if problems arise during the final disposal activities decades after the NPP shutdown. Therefore, full implementation of the Polluter Pays Principle cannot be 100% secured in any decommissioning financing scheme. Nevertheless, it should become a legal requirement and should be implemented as far as possible in every country with nuclear facilities in order to increase allocative efficiency. Nevertheless, the implementation of the Polluter Pays Principle will only function well if there is a sufficient amount of transparency to the public in the interest of current and future generations of electricity customers and taxpayers. Therefore a requirement to ensure transparency should be added, which should include transparency of the following steps of decommissioning financing (Irrek et al., 2007):

- Determination of decommissioning strategies and time schedules;
- Identification and estimation of decommissioning costs including cost breakdowns by cost items and details of cost estimation methodology,
- Collection of decommissioning funds;
- Management and investment of funds until the money is used for payment of decommissioning activities;
- Use of funds for the original purpose, i. e. for payment of decommissioning activities.

These steps are analysed in more detail in the following chapters.

3 Technical decommissioning strategies and time schedules

In principle, there are three technical decommissioning (decontamination and dismantling) strategies for NPPs (Irrek et al., 2007; OECD/NEA, 2012; OECD/NEA, 2016):

- *Immediate dismantling:*
  Decontamination and dismantling immediately after operation period. All contaminated material is removed or decontaminated to a level at which no more regulatory control is required. In this case, dismantling starts shortly after the permanent shutdown of the NPP and might take between 15–20 years, with no unforeseen incidents happening. In case of unavailability of routes for the spent nuclear fuel, this is kept in an interim storage on-site, which might be decommissioned decades after the demolition of the NPP has been completed.
- *Deferred dismantling (safe enclosure / safe storage):*
  First, spent fuel is removed from the facility. The plant is then kept intact and in a safe and stable state to enable the radionuclides activity to decay until it reaches levels that reduce difficulties of handling. Decontamination and dismantling

then starts several decades after the permanent shutdown of the NPP. Deferral periods range between 20 and around 100 years, e. g. 25 years in Spain, 60 years in the United States, and a century or more in the United Kingdom.

- *Entombment*
  This option involves encasing radioactive structures, systems and components in a long-lived substance, such as concrete. The encased plant would be appropriately maintained, and surveillance would continue until the radioactivity decays to a level that permits termination of the plant's license and end any regulatory control. Most nuclear plants will have radionuclide concentrations exceeding the limits for unrestricted use even after 100 years. Therefore, special provisions would be needed for the extended monitoring period this option requires. To date, no facility owners have proposed the entombment option for any nuclear power plants undergoing decommissioning. In fact, this is more an emergency option than a strategy option, so far used only in the case of Chernobyl.

The choice of strategy depends on several parameters and framework conditions, the decontamination, dismantling and demolition stage aimed at, and the planning for the future use of the site. Operators of nuclear facilities usually take into account the following criteria when deciding on a dismantling strategy (Irrek et al., 2007; OECD/NEA 2016, 46):

- *Radiation protection*
  There is one major argument for deferred dismantling which is radioactivity decay, as it will ensure the reduction of radiation hazard during dismantling and a reduction of volume of radioactive waste. Moreover, new techniques (e. g., robotics) might be invented that could further reduce radiation harzards. Finally, deferred dismantling might ease disposal routes for radioactive waste if a final disposal site is available by this time. On the other hand, with immediate dismantling, radiological characterisation is much easier and less costly. Moreover, there will be reduced effects of deterioration and ageing like corrosion.
- *Know-how of employees*
  Immediate dismantling ensures the availability of qualified and experienced workforce with internal knowledge on the design and history of the facility from its operation. On the one hand, immediate dismantling might ease a socially acceptable reduction in employed and contracted staff at the site of the nuclear facility after the installation has been shut down (cf. Irrek, 2005). On the other hand, workers might not be motivated to demolish a plant where they had been working. Moreover, deferred decontamination and dismantling might make it easier to outsource dismantling activities at cheap labour costs

because of existing wage differentials between employees in the nuclear sector and employees of contractors.

- *Reuse of site*
  Immediate dismantling allows an earlier reuse of the site, with respective economic effects for the region.
- *Costs*
  A thorough evaluation and comparison of different strategies is needed in order to assess which strategy will be the least-cost while fulfilling all the nuclear safety obligations. For example, for the deferred decontamination and dismantling strategy, it has to be taken into account in how far existing ancillary equipment can be used for decommissioning activities decades after the end of operation as well as the costs for maintenance and surveillance. Moreover, economies of scale could be achieved if several similar plants are dismantled in co-ordinated manner. A general question is how much cheaper is it to outsource decontamination and dismantling activities or to carry them out in-house with existing know-how. Furthermore, total costs also depend on the availability of waste management, storage and disposal options, and on the decision about the use of the site for other purposes after its release from radiological restrictions. However, such cost estimation is not an easy task. Different assumptions on the underlying decontamination and dismantling processes, on the technical feasibility of possible technical solutions and technical developments, on person-years needed, on labour, material/equipment and capital costs, on time horizons, and on developments of the labour market and the general economic environment can lead to different strategic choices.
- *Financial risks*
  Risks and uncertainties of changes in benefits and costs have to be adequately taken into account because of all these possible influences, time horizons of several decades are considered. For example, a long period of deferment not only gives the chance to yield interest over a longer period of time, but includes also a higher risk that the funds will be lost or will significantly lose value.

The preferred decommissioning strategy can differ from case to case, even within the same country. In most cases, economic arguments with respect to expected financial benefits and costs as well as perceived financial risks are the decisive arguments for the operators to choose a specific decommissioning strategy, particularly for privately owned facilities. However, there are also strategic or tactical arguments for particular decommissioning strategies of the NPP operators in the course of political discussions on the distribution of liabilities (cf., e. g., discussion in Germany on the possible final repository site). Nuclear safety authorities are mostly in favour of immediate dismantling, particularly in recent years in the European Union. The reasons given for this include the consideration that the risk of the loss of memory on the conception and operation of a facility will be significant.

4 Identification and estimation of decommissioning costs

Based on the decommissioning strategy and time schedule determined, cost planning starts with an identification and estimation of costs. The direct comparison of decommissioning cost estimates generated for different plants by different cost estimate providers is limited due to different cost structures, different combinations of individual cost items, different methodologies applied and different ways of dealing with uncertainties. This holds true, even if the results are presented in a similar manner, e. g., by using the International Structure for Decommissioning Costing (ISDC). Following the ISDC, costs can be split up for principal activities as follows (OECD/NEA, 2012):

01 – Pre-decommissioning actions.
02 – Facility shutdown activities.
03 – Additional activities for safe enclosure and entombment.
04 – Dismantling activities within the controlled area.
05 – Waste processing, storage and disposal.
06 – Site infrastructure and operation.
07 – Conventional dismantling, demolition and site restoration.
08 – Project management, engineering and support.
09 – Research and development.
10 – Fuel and nuclear material.
11 – Miscellaneous expenditures.

For each of these principal activities, on a second level, several activity groups can be distinguished. For example, according to ISDC (OECD/NEA 2012), pre-decommissioning actions consist of decommissioning planning, facility characterisation, waste management planning and further activity groups, each differentiated on a third level into single activities (e. g., strategic planning, preliminary planning and final decommissioning planning). For each activity, labour costs, investment costs (capital, equipment, material costs), expenses (consumables, taxes, etc.) and contingencies (a specific provision for unforeseeable elements of costs within the defined projects scope) should be identified.

In many cases, cost estimates are bottom-up ones taken into account the specific decommissioning activities required. However, there are also cost estimates by specific analogy to similar past projects, by parametric estimating based on historical databases on similar systems and subsystems, by cost reviews that just look at those cost items to be updated or by rough expert opinion when other techniques or data are not available (OECD/NEA, 2015). As with other complex construction or deconstruction or other engineering projects, cost estimates are based on a number of technical and economic assumptions, and on assumptions influenced by the political-administrative framework conditions. Therefore, there are financial risks to be taken into account in any ex ante-evaluation of decommissioning project costs. In practice, there are different methodologies how to take into account uncertainties and risks, for example (Irrek et al., 2007; Däuper et al., 2014; OECD/NEA, 2016):

- *Risks and uncertainties ignored*
  In Switzerland, in 2014, the Swiss Federal Audit Office claimed that cost estimates were based on an ideal scenario leading to too low contributions to the decommissioning funds and a high degree of risk borne by the Federal Government. However, in the future, following a new ordinance implemented in 2014, a 30% contingency for unexpected costs should be included according to a new ordinance.
- *Conservative estimates*
  In France, national regulation demands dismantling cost estimates to be 'conservative' ones;
- *Cost estimates with flat or specific contingency factors*
  In the Slovak Republic, based on risk analysis and risk assessment, contingency factors between 0.2 and 16.5% are considered;
- *Scenario calculation with sensitivity analysis of major cost drivers*
  In Lithuania, scenario calculations take into account different wage levels;
- *Probabilistic and deterministic cost estimates*
  In Sweden, probabilistic cost estimates performed in Sweden in addition to deterministic ones;
- *Complex modeling*
  Monte Carlo analysis and other quantitative modeling approaches can be used to simulate possible deviations from assumptions taken, if there are many independent variables with significant uncertainties. In the United Kingdom a combination of computational modeling with Monte Carlo simulation and

management judgement based on experience of previous projects leads to contingencies in the range between 1–24%.

In general, optimism bias can cause a NPP operator to believe that the respective NPP is less at risk of experiencing a future cost increase compared to others. Therefore, regulation has to ensure that adequate cost estimation methodologies are applied that properly take into account possible risks of cost increases. Moreover, international organisations and national authorities should ensure that information on costs of past decommissioning activities are widely spread and could be used for calculation of future costs. Information on past decommissioning activities and improved methodologies have led to substantial increases in cost estimates in various countries during the past 15 years (cf. OECD/NEA, 2016).

5 Collection of decommissioning funds

After the costs have been properly estimated, it has to be determined, if, when and how funds should be set aside at the beginning of and/or during plant operation. In general, any financing scheme should ensure and be managed and periodically reviewed in a way that sufficient funds will be collected during the lifetime of a nuclear facility and will be available at the time decommissioning and waste management expenses occur. Basically, the funding schemes can be differentiated into (cf. also Irrek et al., 2007; OECD/NEA, 2016):

- Payment of decommissioning activities from the current budget of public authorities (e. g., for decommissioning of Uranium mines in Germany): Provisions might be collected during lifetime of a plant via a levy or taxes, but very often there is no collection of funds during lifetime of the plant.
- Internal unrestricted fund of a private company (e. g., for dismantling and demolition and waste processing of NPPs in Germany): On the liabilities side of the balance sheet, the liable company discloses the amount of provisions accumulated by the respective year. However, it is not required that any assets are separated and reserved or earmarked for decommissioning purposes. Therefore, if decommissioning activities have to be paid it might happen that there will not be any financial means available. In case of insolvency of the company, the state has to step into the breach.

- Internal restricted fund of a private liable company with public regulation (e. g., for NPPs in France): In contrast to the internal unrestricted fund, there is an enhanced insolvency protection because assets are separated and earmarked for decommissioning purposes and restrictions on investment of funds are imposed.
- External restricted fund (in most of the European countries, e. g., in Switzerland, Finland and Sweden): The funds are managed externally, i. e. not within the liable company, but by a dedicated body that may be a private or state-owned entity, and with respective transparency. This dedicated body has to follow specific restrictions with regard to the investment of financial means in order to enhance insolvency protection. In most cases, although there is an external fund installed the liabilities remain with the NPP operators. Thus the Polluter Pays Principle will be followed. For example, if there is an increase in costs, NPP operators will have to make additional payments to the funds. However, this is not the case with the new external fund for radioactive waste management and final disposal installed in Germany recently, where NPP operators have just paid a lump sum to the fund.
- External unrestricted fund (e. g., the 'Cassia conjugation per ill set tore electric – CCSE' in Italy, which allows surcharges on the electricity price for several purposes, among others, for nuclear decommissioning).

Accruals to an internal fund or contributions to an external fund are usually set up in regular installments or according to the electrical energy produced. For this, costs are usually inflated up to the year they will incur, and then discounted to its current value to determine the size of the accrual. Since discounting rates are usually higher than inflation rates, this leads to the sum of accruals or contributions being lower than the cost estimates. This, in turn, demands to yearly provide funds not only for the regular installment, but also for the difference between the present values of the actual year and the past year. The determination of the inflation and discounting rates is of central importance in any of these funding regimes. Only in few countries, provisions are based on undiscounted costs.

However, there are also funding regimes, where the full amount of costs has to be provided for from start of operation (Irrek et al., 2007; Däuper et al., 2014; OECD/NEA, 2016): For example, in France, since 2006, with a transition period until 2010, provisions for dismantling and decontamination of a NPP have to be fully collected already with start of operation. In Finland, a special requirement exists which, in principle, demands to cover the full nuclear liability already at the start of operation by special financial securities. In Sweden and in the Netherlands, with start of operation, NPP operators have to provide a guarantee for early shutdown.

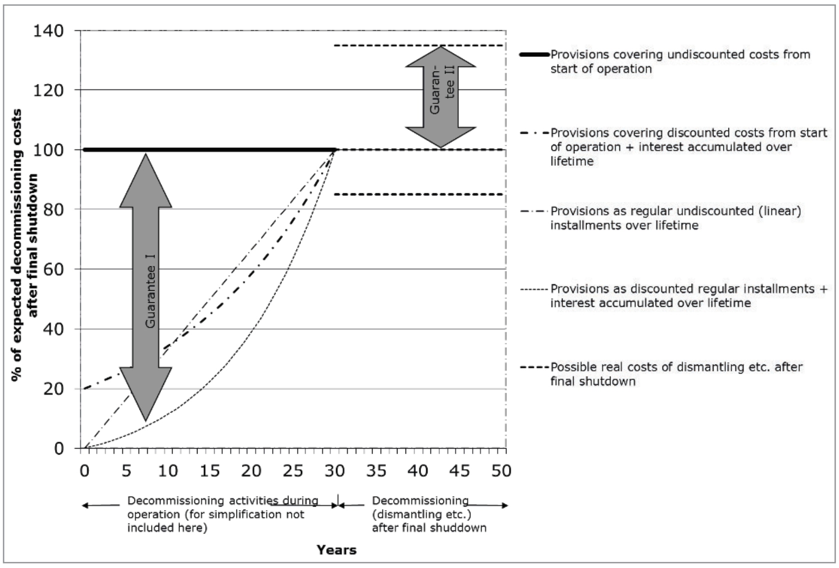

Fig. 2 Guarantees covering financial risks related to decommissioning costs occurring in case of early shutdown (Guarantee I) or after final shutdown of the plant (Guarantee II) (Irrek et al., 2007, 152)

Such schemes substantially reduce the risk that the state will have to pay for early shutdown of plants and contribute to implementing the Polluter Pays Principle. In addition to such guarantees for early shut down (Guarantee I in Fig. 2), in some financing schemes, NPP operators have to provide additional guarantees for additional costs exceeding the cost estimates that might occur after final shutdown (Guarantee II in Fig. 2). For example, in Finland, the state has the possibility to demand such guarantees up to 10% of the sum of liabilities. In Sweden, such guarantees amount to 16–17% of estimated costs. And in Switzerland, there partly is a joint liability of all operators in case one of the NPP operators cannot pay its contributions.

6 Management and investment of funds

A well-designed governance regime of the fund and a high level of quality of fund management is crucial for maintaining or even increasing the value of the funds so that sufficient funds will be available at the time decommissioning activities have to be paid. Funds can be managed by public or private fund managers. Specific restrictions beyond general accounting principles and general accounting law can be imposed on managers of internal or external funds, e. g., with regard to (Irrek et al., 2007):

- the way funds have to be accumulated;
- the investment of the financial means collected until they are used to pay for decommissioning activities;
- the payment for decommissioning costs;
- the regular reporting on funds and fund management;
- the control by the public (e.g., government, parliament, special boards, information rights of the public).

Typical examples of investment restrictions and guarantees required for internal or external funds in practice are (Irrek et al., 2007; Däuper et al., 2014; OECD/NEA, 2016):

- Restrictions regarding the degree of risk allowed to be taken, e. g. by limiting the share of asset classes with higher risks. For example, in France, assets of the internal restricted funds have to present a sufficient degree of security and liquidity. However, since 2010, diversification into real assets has been increased. In Slovenia, it has to be invested not less than 30% in state bonds, not more than 5% in stock, not more than 15% in other bonds, not more than 5% in stocks of one issuer, and approximately 10% in securities on foreign financial markets. In the US, there are just simple guidelines such as using a "prudent investor" standard, with restrictions on self-investing and on foreign investment.
- Restrictions that do not allow investment in companies associated with the legally obliged parties or that have invested the majority of their assets in nuclear facilities.
- In Finland, there is the special situation that the lincensee can borrow back up to 75% of the capital of the fund against securities and at current interest rates.

Actual performance of the funds differs depending on the investment restrictions imposed, i. e. on the degree of risk taken, and on the general economic situation.

Tab. 1 Yield on investment of the Swiss decommissioning and waste management funds (quarterly reports)

		Nuclear Decommissioning Funds		Radioactive Waste Management Funds		
Quarter	Year	Nominal Yield on Investment per Quarter	Real Yield on Investment per Year	Nominal Yield on Investment per Quarter	Real Yield on Investment per Year	Inflation
2	2017*	0,11%/0,17%		0,20%		
1		2,81%/2,84%		2,82%		
4	2016	1,24%	6,85%	1,25%	6,78%	-0,43%
3		2,38%		2,33%		
2		2,60%		2,59%		
1		0,07%		0,06%		
4	2015	3,28%	0,61%	3,23%	0,66%	-1,14%
3		-2,44%		-2,42%		
2		-2,75%		-2,78%		
1		1,52%		1,62%		
4	2014	1,38%	11,54%	1,47%	11,52%	-0,02%
3		3,57%		3,69%		
2		2,78%		2,58%		
1		3,54%		3,87%		
4	2013	4,87%	7,39%	4,93%	7,58%	-0,20%
3		-1,61%		-1,60%		
2		1,30%		1,33%		
1		2,55%		2,62%		
4	2012	4,38%	10,19%	4,45%	10,33%	-0,70%
3		0,51%		0,52%		
2		3,44%		3,41%		
1		0,85%		0,87%		
4	2011	1,27%	-0,32%	1,31%	-0,34%	0,22%
3		-2,41%		-2,43%		
2		-3,45%		-3,57%		
1		4,69%		4,78%		
4	2010	3,47%	3,29%	3,57%	3,35%	0,69%
3		-3,39%		-3,42%		
2		2,91%		2,86%		
1		1,08%		1,12%		

Investment Strategy 2010-2017**

Category	Strategy	Lower Bound	Upper Bound
Liquidity (Cash)	0%	0%	5%
Bonds (CHF)	25%	15%	35%
Bonds (Other Currencies; hedged)	15%	10%	20%
Shares	40%	30%	50%
Real Estate	10%	7%	13%
Other Investment	10%	7%	13%

* Since 1 April 2017, there is a separated investment strategy for the NPP Mühleberg (KKM) compared to the investment strategy for the NPPs Beznau (KKB), Gösgen (KKG), Leibstadt (KKL) and for the interim storage Würenlingen AG (Zwilag); therefore the first number is relevant for KKM, the second fo KKB, KKG, KKL, Zwilag.

** not including KKM

While the European Commission (2013a) recommends that a secure risk profile should be sought in the investment of the assets, ensuring that a positive return is achieved, a 100% security of a positive return over any given period of time cannot be guaranteed over the many decades of lifetime of such a fund. Moreover, there is a general tradeoff between security and the yield on investment.

The Swiss example in Table 1 shows that an investment strategy with up to 50% of funds invested into shares at the stock market can lead to comparatively high returns in some quarters of a year, but also to a decrease in funds value in others. If the liable company feeds the fund with discounted contributions, the fund will have to yield positive returns to make up for the difference between the cost estimate and the discounted value, or additional contributions by the liable company will be needed. This will be also required with a secure investment strategy, if there are negative real interest rates on safe investment into bonds of solvent states as it could be observed in some states recently.

The internal unrestricted fund differs from the restricted solutions in one important aspect: The provisions accumulated on the liabilities side of the balance sheet do not guarantee that there will be financial means available when decommissioning activities have to be paid. The cash flow from the financial equivalent of the set-aside provisions can be freely used by the companies as a portion of corporate revenue.

In Europe, Germany is the only country where such an internal, completely unrestricted fund still exists for the dismantling and demolition of reactors and for the conditioning of radioactive waste. Here, no information is available on how nuclear power plant operators or their parent groups have invested the unrestricted funds from the nuclear provisions. A direct link cannot be drawn between individual liability items and individual asset items on a group's balance sheet. Just because provisions are set up does not necessarily mean that the funds are being invested to finance dismantling and disposal. Groups can employ any type of financing whatsoever to provide future funding for dismantling and disposal activities (cf., e. g., Perridon et al., 2012, for the general financing options). Using the German groups E.ON and RWE as examples, the financing options can be investigated as follows:

- With regard to financing from current cash flow, one needs to consider that operating margins have fallen sharply in recent years and have been negative at times, while revenue and EBITDA have also fallen year-over-year in most of E.ON's and RWE's business divisions. There is no guarantee that the cash flow generated during the next years will be adequate to finance higher provisions or pay for activities related to nuclear dismantling and the long-term storage of radioactive material.

- The options that E.ON and RWE have for using debt to finance activities related to nuclear dismantling and disposal are becoming more limited in light of their declining credit ratings and relatively high debt-to-equity ratios.
- For financing through asset restructuring, one needs to take a closer look at the groups' assets, especially tangible assets, shareholdings, financial assets and – to the extent that they are not required to cover current liabilities – liquid assets. Assets available in the short-term are not sufficient to cover net nuclear provisions. The sum of the values of E.ON's and RWE's plant and machinery assets and shareholdings declined significantly from 2013 to 2016. There is a risk that this trend will continue.

While observing the availability of the groups' current financial resources to cover their obligations in the nuclear sector, one must also bear in mind that the groups must use their assets and cash flow not only for their nuclear provisions, but also to cover other obligations. Therefore, it is necessary to compare the groups' total financial resources with all of their assumed obligations. For example, for RWE, based on annual reports it can be calculated that the long-term financial resources at RWE's disposal at the end of 2016 were hardly sufficient to cover all of RWE's long-term obligations (own calculation based on annual company reports and Irrek / Vorfeld 2015).

7 Use of nuclear decommissioning funds

In general, decommissioning funds should be used only for the purpose for which they have been established and managed, i. e. to pay for decommissioning and radioactive waste management activities. Therefore, the degree of independence between the operator of a nuclear installation as the liable polluter and contributor to the funds, the company carrying out decommissioning activities and thus using decommissioning funds, the funds management and the position disposing of the power of authorising payments is a key issue in any decommissioning financing system.

In general, market actors in nuclear decommissioning business making use of nuclear decommissioning funds are the following:

- Operators of nuclear facilities, who benefit already during operation as well as after shut-down, depending on the degree they are involved in the decommissioning activities. During dismantling it is important to make use of existing know-how of the personnel of the NPP operator;

- National or international firms specialised in nuclear decommissioning;
- Local firms without any specialisation in nuclear decommissioning, e. g. craftsmen, scaffolders, unqualified staff that can be trained for decontamination activities, etc.

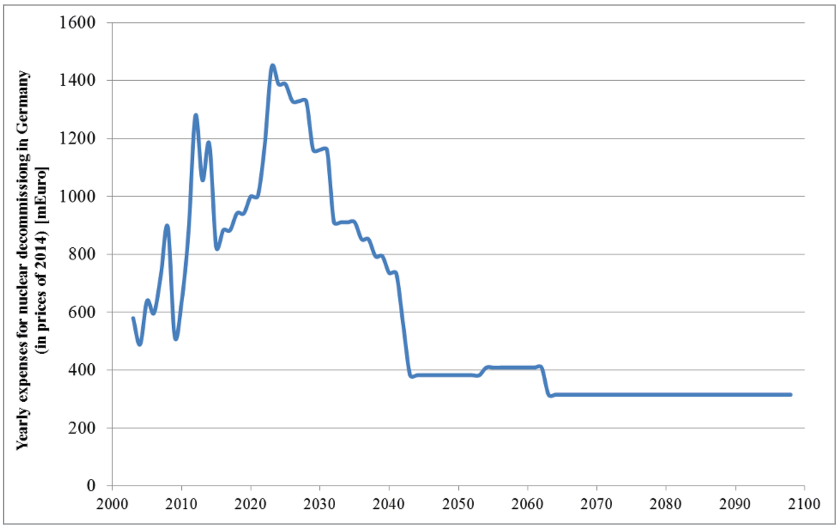

Fig. 3 Past and expected future yearly payment for decommissioning activities in Germany, following groups' balanced sheets and cost estimates by the NPP operators of 31 December 2014 including cost estimates for final disposal of HAW although there is no technical concept or site available yet (balanced sheets of E.on, RWE, EnBW and Vattenfall, 2003–2015; own calculation based on Warth & Klein Grant Thornton, 2015)

Tab. 2 Profits and losses of selected companies active in the German decommissioning market (companies' income statements of 2014, 2015 and 2016 as far as available)

Company	Year	Profit / Loss [1,000 Euro]	Year	Profit / Loss [1,000 Euro]
Nukem Technologies GmbH [Russian Rosatom group]	2014	-26,960	2015	
Siempelkamp Ingenieur und Service GmbH [Siempelkamp Nukleartechnik GmbH]	2014	-2,683	2015	2,176
Celten Service GmbH	2015	105	2016	141
Eckert & Ziegler UmweltdiensteGmbH	2014	-1,367	2015	-4,266
SAT Kerntechnik GmbH	2014	32	2015	
EWN Entsorgungswerk für Nuklearanlagen GmbH [Energiewerke Nord GmbH; German state-owned company]	2015	0 (per definition)	2016	0 (per definition)
Safetec Entsorgungs- und Sicherheitstechnik GmbH	2014	791	2015	793
EnBW Kernkraft GmbH [NPP operator]	2015	0 (per definition)	2016	0 (per definition)
Vattenfall Europe Nuclear Energy GmbH [NPP operator]	2014	-173,100	2015	-459,4000
GNS Gesellschaft für Nuklear-Service mbH	2015	27,400	2016	30,000
AREVA GmbH [incl. losses from NPP construction and modernisation]	2014	-764,164	2015	-632,392

In Germany, following the shutdown of NPPs after the Fukushima accident, decommissioning activities have increased during recent years (Fig. 3). It can be expected that the level of expenses will continue in the coming years when further NPPs will be shut down. With regard to the age of NPPs in the world (Fig. 1), a growth in international decommissioning expenses can be expected, too. In 2013, Nukem Technologies GmbH estimated, that the international market volume until 2030 could sum up to more than Euro 250bn. However, in general, as stated in AREVA's financial report of 2014, the international decommissioning market is only slowly developing yet. The available income statements of selected companies active in the German decommissioning market show that several of them are still facing losses (Table 2).

Nevertheless, there are several attempts to reduce costs and thus losses. For example, Nukem Technologies expects that a 15–20% decrease in costs of decontamination and dismantling might be possible (Kutscher 2015). Possible optimisation includes the following:

- Portfolio planning: co-ordination of and synergy effects from parallel activities at different sites including specialisation and centralisation of specific dismantling activities;
- Standardisation and modularisation of decontamination and dismantling activities;
- Mobilisation: Mobile equipment for conditioning of nuclear waste;
- Increase in decontamination and in the share of radioactive waste that does not have to be stored in a final disposal site but can be used with or without any restriction for other purposes if remaining radiation does not exceed specific levels, which can be a problem from the nuclear safety perspective if concerns and new medical knowledge with regard to risks from low-dose level radiation are ignored;
- Lean management and professional logistics, project management, process management, risk management and cost management: reduction in overhead costs by concentration of administrative activities, mergers and acquisitions; optimised planning and control.

It can be expected that international companies specialising in back-end activities like companies of the Russian Rosatom group like Nukem Technologies GmbH will be the first benefiting from such developments. This might lead to market concentration processes, which will be a challenge for governments aiming at getting insight and control of activities with respect to nuclear safety.

8 Comparison of selected decommissioning financing concepts

Existing European and international analyses of decommissioning financing schemes (Irrek et al., 2007; European Commission 2013; European Commission 2013a; OECD/NEA, 2016) show that financing schemes in practice substantially differ with regard to

- Cost estimates and accounting procedures;
- Collection and investment of funds;
- How risks and uncertainties have been addressed;

- Implementation of Polluter Pays Principle;
- Use of funds: Incentives for reducing costs;
- Different degree and ways of public control – differing public information rights.

Table 3 compares the financing schemes in Switzerland, Sweden and Finland from which can be particularly learned for future design of decommissioning financing concepts. In order to implement the polluter pays principle as far as possible and to ensure that governments will be able to control decommissioning activities with regard to nuclear safety, the following central questions have to be addressed when designing the governance scheme for nuclear decommissioning financing (Irrek et al., 2007):

- Who defines or regulates decommissioning (financing)?
  In most cases, this task is assigned to public licensing authorities (government level). A key issue thereby is the independence of the authority, which has to align different objectives from different stakeholders. Employees of the authority should dispose of sufficient personal independence from the operators and, if the operators are public entities, from the government.
- Who is liable or who has to pay the decommissioning activities?
  Due to the polluter pays principle assumption, the operators of nuclear installations should have to carry all decommissioning costs. They should pay through a decommissioning funding system, which urges them to financially contribute to a designated decommissioning fund. Guarantee schemes like the ones in Sweden and Finland aim at ensuring the implementation of the polluter pays principle even in case of an early shutdown of the nuclear installation or in case of increasing decommissioning costs after the end of operation.

Tab. 3 Comparison of decommissioning financing schemes in Switzerland, Sweden and Finland (Däuper at al., 2014; Kaberger/Swahn, 2015; Irrek/Vorfeld, 2015; OECD/NEA, 2016; quarterly reports of Swiss funds)

Country	Switzerland	Finland	Sweden
Legal form	Two separate public law foundations for decommissioning and radioactive waste management.	One single public law foundation.	One single public law foundation.
Nuclear installations included	All 5 NPPs and an interim storage.	All NPPs with their on-site interim storages.	All NPPs.

Country	Switzerland	Finland	Sweden
Obliged party	Operator of nuclear installations remains responsible for decommissioning activities.		
Governing bodies	Operational fund management by an agency at an industrial organization. Board with a cost committee and an investment committee: 4 of 9 members of the board and 4 of 7 (2 of 7) members of the investment (cost) committee are representatives from NPP operators. Revision by certified auditor.	Fund governed by the Ministry for Labour and Economy.	Operational fund management by a state-owned agency. Board of Governors and Administration, with 2 of 7 members being representatives from E.on and Vattenfall.
Cost estimate	Every 5 years.	Every 3 years.	Every 3 years.
Fund allocation	Regular installments over 50 years of operation.	Regular installments over 25 years of operation or depending on the amount of waste produced via a ca. 10% surcharge on the electricity price	Regular installments over 40 years of operation via a surcharge on the electricity price.
Fund investment	Cash, currencies 0–9%, Bonds 38–55%, Shares 30–50%, Real Estate 7–13%, Others 7–13%.	75% of the fund can be borrowed back by the NPP operator who has to invest it in a productive way. 25% state bonds.	Assets with low risks only. In 2013: Covered bonds 62%, Index-based securities 24%, Cash, currencies 14%.
Payment of decommissioning activities	Operators of nuclear installations hand in bills for decommissioning activities. They receive respective payment after bills have been checked by fund management.		
Common advantages	External restricted funds (public law foundation) with a specific degree of public transparency and control in order to ensure a safe decommissioning. Economic risk remains with NPP operator, who has additional payment liabilities in case of short-fall of funds aiming at fully implementing the polluter pays principle.		
Common problems	Cost estimates probably too low and thus the funds. More realistic cost estimates are partly planned but controversially discussed.		

Country	Switzerland	Finland	Sweden
Special disadvantages	Strong influence of NPP operators on funds.	No specific asset constitution strategy determined by legislation.	Weak economic situation of NPP operators might lead to less restrictive governance.
Special advantages	Reform of 2014 foresees a 30% surcharge on estimated costs to cover possible uncertainties. Joint liability of NPP operators in case one of them cannot pay.	100% funding guaranteed from start of operation. NPP operators are allowed to borrow back up to 75% of funds against guarantees. Up to 10% additional guarantee covering cost uncertainties can be required by the state.	Public cost estimates. Prudent investment strategy so far. Guarantees covering short-fall of funds: Guarantee I covering the case of early shut down and plant-specific Guarantee II covering cost uncertainties (16-17% on average).

- Who is the entity, which holds the fund in its general accounts?
  In practice, various solutions are implemented from internal unrestricted to external restricted. However, only a restricted fund has the objective to ensure that assets will be available when needed to pay for decommissioning activities.
- Who outlines the investment policy and the investment guidelines?
  In general, the prudence principle should be followed in order to ensure that sufficient financial means will be available for a safe decommissioning. For this, the independence and competence of all involved stakeholders is important. The example of Switzerland shows that the strong influence of the NPP operators on the fund management can lead to a more risky investment strategy, which, in turn, can lead to substantial returns in some years, but also to a substantial decrease in asset value in others. The incentive to finance part of future decommissioning costs through a high investment performance is evident. A high performance on its part can conflict with the prudence principle. However, the professional application of asset and liability management allows managing a slightly higher risk. Special attention has to be paid to lending practices to related parties like in the example of Finland. In particular, lending can be beneficial for the NPP operator, but should be backed up by respective guarantees. Furthermore, means of finance should be invested in such a way that correlations between the investment and the development of the nuclear industry are avoided. It is recommended to develop guidelines, which describe the required qualifications of investment managers and which give a basic investment policy frame also

defining the acceptable risk levels. A kind of oversight board or decommissioning financing committee could provide such guidance.

- Who manages the fund?
  A sufficient degree of independence between the operators of nuclear installations (as polluters and thus contributors to the funds) and the investment managers is a key issue.
- Who disposes of the power of authorising payments for decommissioning?
  As mentioned already before, the degree of independence between the operator of a nuclear installation as the liable polluter and contributor to the funds, the company carrying out decommissioning activities and thus using decommissioning funds, the funds management and the position disposing of the power of authorising payments is a key issue in any decommissioning financing system. The conflict potential always remains with the entity that has access to the decommissioning funds (power of authority). If the NPP operator solely disposes of the power of authority (e. g., in internal unrestricted funds), he could be tempted to defer payments in periods, where he wishes to use the financial resources for other purposes, or where he has general liquidity problems. If the government solely disposes of the power of authority and the liable NPP operator has to contribute to the fund for any additional costs occurring, the government could be tempted to use the financial resources in an inefficient way or for additional activities not really needed.
- Who monitors or controls decommissioning (financing) and who has the authority for sanctions in the case of non-compliance?
  Like the definition and regulation of decommissioning financing, this task usually is assigned to public licensing authorities on the government level. The independence of the authority from the interests of the various stakeholders is of vital importance here, too.

9 Conclusions and recommendations

In conclusion, with regard to the financial consequences and risks involved in the different nuclear decommissioning financing schemes, existing schemes could be improved by (Irrek et al., 2007; OECD/NEA, 2016):

- Measures that establish a system of checks and balances in the governance chain in order to avoid negative effects stemming from conflicts of interests;

- Measures that increase transparency including regularly reviewed, realistic, well-founded, published cost estimates. Within this context, a much better understanding of the uncertainties affecting decommissioning activities and how to best take them into account in cost estimations should be aimed at;
- Measures that set incentives to cost reduction while at the same time maintaining the level of radiation protection needed;
- A system of rules for regular contributions to the fund and to cover cases of short-falls like the guarantees in the Swedish system in order to ensure the full implementation of the polluter pays principle from the first until the last day of operation of a nuclear installation and beyond;
- Measures that ensure that fund assets will be separated from other assets and liabilities and invested according to the prudence principle so that they are available at the appropriate time and used only for their original purpose.

References

Balance sheets and income statements, annual financial statements and further annual reports, information and documents from websites and further publicly available information from operators of nuclear facilities and decommissioning funding organisations.

Däuper, O.; Fouquet, D.; Irrek, W.; et al., 2014. Finanzielle Vorsorge im Kernenergiebereich – Etwaige Risiken des Status quo und mögliche Reformoptionen, expert opinion of the law firm BBH [Becker Büttner Held] in co-operation with Prof. Irrek prepared on behalf of the German Ministry for Economy and Energy (BMWi), Berlin.

European Commission, 2013. Communication from the Commission to the European Parliament and the Conuncil on the use of financial resources earmarked for the decommissioning of nuclear installations, spent fuel and radioactive waste, COM (2013) 121 final, Brussels.

European Commission, 2013a. Commission Staff Working Document "EU Decommissioning Funding Data" accompanying the document Communication from the Commission to the European Parliament and the Conuncil on the use of financial resources earmarked for the decommissioning of nuclear installations, spent fuel and radioactive waste, SWD (2013) 59 final, Brussels.

Hagen, M.; Kunze, C.; Schmidt, P., 2005. Decommissioning and Rehabilitation of Uranium and Thorium Production Facilities, Kerntechnik (Nuclear Technology) 70, 1–2, pp. 91-99.

IAEA [International Atomic Energy Agency], 2018. Nuclear Power Reactors in the World, Reference Data Series No. 2, Vienna.

Irrek, W., 1996. Volkswirtschaftliche Vorteile und höhere Finanzierungssicherheit durch einen Stillegungs- und Entsorgungsfonds: Eine Untersuchung der Bildung und Verwendung von Rückstellungen für Stillegung, Rückbau und Entsorgung im Kernenergiebereich, Wuppertal Paper No. 53, Wuppertal: Wuppertal Institute for Climate, Environment and Energy.

Irrek, W., 2005. Development of jobs and supporting measures at nuclear power plant sites in the context of decommissioning, in: Tagungsbericht: Jahrestagung Kerntechnik 2005; 10.-12. Mai 2005, Meistersingerhalle Nürnberg. – Berlin:INFORUM-Verl. u. Verwaltungsges., 594–599.

Irrek, W., 2009. Improving financing schemes for nuclear decommissioning and radioactive waste management in European member states and at EU level, in: Davies, Christophe (ed.): Euradwaste '08: Seventh European Commission Conference on the Management and Disposal of RadioactiveWaste – Community policy and research & training activities, Luxembourg: Publications Office of the European Union, pp. 527–531.

Irrek, W.; et al., 2007. Comparison among different decommissioning funds methodologies for nuclear installations", study by the Wuppertal Institute for Climate, Environment and Energy et al., conducted on behalf of the European Commission, service contract TREN/05/NUCL/S07.55346, Wuppertal.

Irrek, W.; Vorfeld, M., 2015. Liquidity and valuation of assets in unrestricted funds from provisions set up for nuclear decommissioning, dismantling and disposal, Brief study on behalf of the Alliance 90/The Greens parliamentary group in the German Bundestag, Wuppertal.

Kaberger, T.; Swahn, J., 2015: Model or Muddle? Governance and Management of Radioactive Waste in Sweden, in: Brunnengräber, A.; et al.: Nuclear Waste Governance, An International Comparison, Wiesbaden.

Kelber, U.; et al., 2010. Brennelementesteuer – Windfall Profits der Atomwirtschaft abschöpfen. Antrag der Abgeordneten Ulrich Kelber et al., Deutscher Bundestag, Drucksache 17/2400 (06 July 2010), Berlin.

Kirbach, R., 2009. Das Lügengrab, Die Zeit, 38 (10.09.2009) [http://www.zeit.de/2009/38/DOS-Asse/komplettansicht; Status: 08 May 2016]

Kutscher, U., 2015. Challenges, Strategies and Approaches of NUKEM to meet the Changing Boundary Conditions and Needs of Nuclear Decommissioning Tasks, Presentation at the International Conference on Decommissioning of Nuclear Installations, 9–11 November 2015, Moscow.

Lukes, R.; Salje, P.; Feldmann, F.-J., 1978. Finanzielle Vorsorge für die Stillegung und die Beseitigung kerntechnischer Anlagen, Energiewirtschaftliche Tagesfragen, 28, 11, pp. 680–689.

N.N., 2013. Marodes Endlager Asse: Bundestag beschließt Gesetz zu Atommüll-Bergung. Spiegel online, (28.03.2013) [http://www.spiegel.de/politik/deutschland/marodes-endlager-asse-bundestag-beschliesst-gesetz-zu-atommuell-bergung-a-886236.html; Status: 08 May 2016].

Neumann, W., 2016. Mängel beim Sicherheitsstandard von atomaren Zwischenlagern in Bayern, Präsentation beim Atomkongress der bayerischen Landtagsfraktion von Bündnis 90/Die Grünen, 16 April 2016, Augsburg.

OECD [Organisation for Economic Co-operation and Development] / NEA [Nuclear Energy Agency], 2012. International Structure for Decommissioning Costing (ISDC) of Nuclear Installations, Issy-les-Moulineaux.

OECD [Organisation for Economic Co-operation and Development] / NEA [Nuclear Energy Agency], 2015. The Practice of Cost Estimation for Decommissioning of Nuclear Facilities, Issy-les-Moulineaux.

OECD [Organisation for Economic Co-operation and Development] / NEA [Nuclear Energy Agency], 2016. Costs of Decommissioning Nuclear Power Plants, Boulogne-Billancourt.
Perridon, L.; Steiner, M.; Rathgeber, A., 2012. Finanzwirtschaft der Unternehmung, 16., überarbeitete und erweiterte Auflage, München: Vahlen.
Schmidt, G.; Ustohalova, V.; Minhans, A., 2013. Nuclear Decommissioning: Management of Costs and Risks, Study by Öko-Institut Darmstadt on behalf of the European Parliament's Committee on Budgetary Control, IP/D/CONT/IC/2013_054, Brussels.
Swiss Federal Audit Office, 2014. Stillegungs- und Enstorgungsfonds, Prüfung der Governance, EFK-14172, Bern
Ustohalova, V.; Schmidt, G., 2014. Klare Zuständigkeiten und Strukturen für Rückbau von Kernkraftwerken: Herausforderungen des EU-mitfinanzierten Rückbaus von Kernreaktoren in Osteuropa, Präsentation bei der Tagung „Sicherheitsmanagement in der Kerntechnik", 16.-17. Oktober 2014, München.
Warth & Klein Grant Thornton, 2015. Gutachterliche Stellungnahme zur Bewertung der Rückstellungen im Kernenergiebereich im Auftrag des BMWi, Düsseldorf.