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Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production

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Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production

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6 United Kingdom

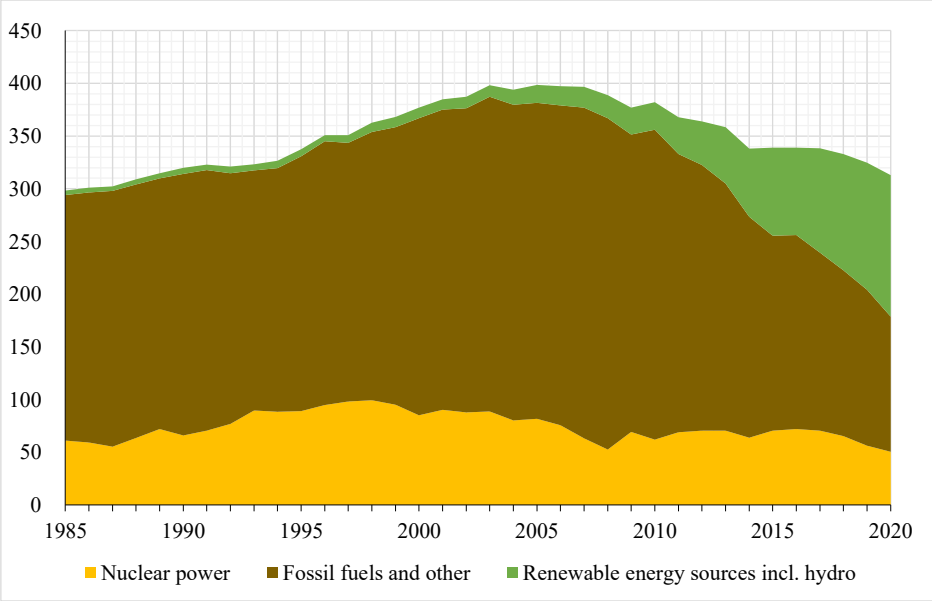
Alexander Wimmers, Björn Steigerwald, Christian von Hirschhausen

6.1 Introduction

The United Kingdom (UK) was amongst the first countries to experiment with electricity generation from nuclear power and was one of the first to implement its commercial use (Hirose and McCauley 2022). During the planning and construction of these early reactors, the necessity for safe and cheap nuclear decommissioning was neglected, resulting in an extensively complicated process experienced today (MacKerron 2012; Laraia 2018; Foster et al. 2021; NDA 2021a). During this time, nuclear waste management experienced similar neglect (MacKerron 2015). Additionally, the UK's governmental agency, the Nuclear Decommissioning Authority (NDA), has only recently regained control of the decommissioning process in the country, after an initial approach involving private consortia (so-called Parent Body Organizations, PBOs) failed to fulfill its goal (NDA 2015; Holliday, HM Government, and BEIS 2021; Schneider et al. 2021). Furthermore, as it was learnt that decommissioning experiences from one nuclear site might not be directly transferrable to others, the NDA has changed its decommissioning strategy from a high-level strategy applying the same criteria to most nuclear power plants (NPP) to one that aims at individual approaches for its Magnox fleet to achieve decommissioning as soon as possible. The envisioned release date for its last English NPP from regulation is 2125 (NDA 2021a).

Historically, the UK's electricity mix was characterized by a large share of fossil fuels such as coal and oil. The decline of the share of coal in the electricity mix has so far been mostly compensated by gas, wind and solar. Nevertheless, nuclear power has always played a major role with a share of about 20 – 25 % in electricity generation. However, in recent years one observes a steady decline, resulting from the rise of renewable energies and the subsequent shutdown of ageing NPPs, with a current share around 15 % (BP 2021). Figure 6-1 shows the development of the British electricity mix from 1985 to 2020. As of June 2022, eleven advanced gas-cooled reactors (AGR) and one pressurized water reactor (PWR), all operated by EDF Energy, a subsidiary of French majority state-owned utility Éléctricité de France (EDF), are still operational. Construction begun at two PWRs (EPR type) in 2018 and 2019, respectively (IAEA 2022c). The project is already experiencing delays and cost overruns (EDF 2022; Rothwell 2022).

Figure 6-1: Electricity generation by source in UK from 1985 to 2020



Source: Own depiction taken from BP (2021)

The UK's electricity market underwent three major reforms in the last three decades that ultimately resulted in the complete capitalization of former state-owned British utilities. The first reform, conducted in the early 1990s, created the so-called "Wholesale Pool Market", limited to England and Wales. Here, regardless of market prices and individual contracts, a single price was passed on to consumers. Initially, this led to a decrease in electricity prices, but soon resulted in very high prices and vertical integration along the electricity supply chain. This trend resulted in the creation of the Office of Gas and Electricity Markets (Ofgem) in 1999. (Thomas 2006; Liu, Wang, and Cardinal 2022)

Monopolistic tendencies and high prices that formed despite Ofgem's oversight led to the second reform that was introduced with the Energy Act of 2004. The New Electricity Trading Arrangement (NAFA) introduced bilateral contracts and an electricity market that allowed for intraday, day-ahead and future market trading. The British Electricity Transmission and Trading Arrangement (BETTA) extended this market design to Scotland in 2005. First, this reform again reduced consumer electricity prices due to fierce competition, but then again, prices began to rise and the "Big Six"[65], an oligopolistic market with over 70% market share, resulted in a steep rise in British electricity bills. (Liu, Wang, and Cardinal 2022)

The third reform, that introduced the current electricity market design, was proposed in a 2011 White Paper and later implemented (DECC 2011). This market design includes a capacity market for grid stability and contracts for difference for renewable energy promotion. The oligopolistic structure has not been touched, and consumer electricity prices have further increased, likely due to the costly

[65] Britsh Gas, EDF Energy, E.ON, Npower, Scottish Power and Scottish Southern Electricity (now Ovo Energy).

capacity market, that is also criticized for its favoring of conventional fossil fuel generation (Liu, Wang, and Cardinal 2022).

As mentioned above, the UK was one of the first countries to commercialize nuclear power production. Since the mid-1940s, the UK has built several research and commercial sites that today form the infamous legacy fleet, a fleet of mainly gas-cooled reactors (GCR) of Magnox type, built in the 1950s and 1960s, during a time when decommissioning and waste management were of low priority (MacKerron 2012; Laraia 2018; Foster et al. 2021; NDA 2021a). Later, AGRs were built, of which some are still operational today. In 1988, construction on the UK's currently only PWR Sizewell B began (Foster et al. 2021). In 1995, parallel to privatization efforts in the whole electricity sector, the decision was made to commercialize this, in comparison to the Magnox fleet, productive and more modern fleet of AGRs and the Sizewell PWR. Thus, by 1997, shares of British Energy were tradeable on the stock market, although this did not go without opposition (e.g. NAO (2004)). Ownership of the Magnox fleet was assumed by Magnox Electric, that was later incorporated to nationally owned fuel cycle company BNFL. After initially prospering, British Energy had to receive its first governmental loan in 2002 due to low wholesale electricity prices and required continuous governmental support from thereon (Thomas 2006; House of Commons 2007). After struggling for several years, British Energy was acquired by EDF in 2009, transferring ownership of all operational British NPPs to EDF Energy (EDF 2022). Figure 6-2 shows the location of British nuclear reactors, their type and current operational status.

Hand in hand with the privatization came the halt of nuclear new build under a Conservative government, as it was deemed that additional NPPs were too costly. In 2008 however, this policy was changed, when construction of further NPPs was announced by the acting Labour government (Foster et al. 2021). Plans in 2013 envisioned the construction of 16 new reactors (Hirose and McCauley 2022). However, new construction began only in 2018, when the Hinkley Point C project (two reactors) was launched (EDF 2022).

In its recently published *Energy Security Strategy 2022*, the British Government announced that it will increase funding for nuclear power in the UK and has set a target of 24 GW nuclear capacity by 2050, corresponding to approx. 25% of projected electricity demand (HM Government 2022). It remains unclear, which nuclear technology, whether existing or under development, shall be used to implement this ambitious target. The only NPP currently under construction in the UK, Hinkley Point C, had to reschedule its planned commissioning date from end-2025 to mid-2026 and financing needs already exceed original shareholder obligations, from an initial estimate of 18 billion GBP in 2016 to approx. 23 billion GBP[66] today (EDF 2022; Rothwell 2022).

In contrast to the UK government's plans, reactors at Dungeness-B and Hunterston-B were permanently shut down in 2021 and 2022, respectively, corresponding to 2.5 GW of gross electrical capacity, see Table 6-7 (EDF Energy Undated; 2021).

[66] From approx. 26.1 to 33.3 billion EUR_{2020}.

In this report, we show how nuclear decommissioning is governed in the UK. We describe the current legal framework and regulations and provide insight on liabilities and oversight. Furthermore, we provide information on the financial situation and regulations and give a short status report on the progress of decommissioning NPPs in the UK.

Figure 6-2: Location of British Nuclear Reactors

Source: Own depiction with information gathered from (IAEA 2022b).

6.2 Legal Framework

To tackle the issue of nuclear decommissioning, the UK government founded the Nuclear Decommissioning Authority (NDA) in the early 2000s. The NDA is the main authority when it comes to nuclear decommissioning and waste management in the UK. However, other actors are also involved (Laraia 2018). Therefore, in this chapter, we will describe this current regulatory framework, the structurization of oversight, liabilities and the ownership of decommissioned NPPs in detail.

6.2.1 Governmental and regulatory framework

The long history of nuclear technology utilization in the UK has resulted in a vast regulatory framework concerning mostly the safety and security of the construction, operation and decommissioning of NPPs as well as nuclear waste management. An overview is provided in Box 7-1. Figure 6-3 shows the relations of different actors in the British nuclear industry.

The Nuclear Installations Act (NIA) of 1965 lays the foundation for nuclear industry regulation in the UK. It incorporates many features of the Nuclear Installations and Insurance Act of 1959 and describes which nuclear installations require a license to operate. This was defined more precisely in the Nuclear Installation Regulations of 1971 (Statutory Instrument 1971/381): all nuclear sites – apart from few military sites under the control of the Ministry of Defense – require a nuclear license to be installed and operated. Additionally, the NIA provides oversight for the processing of uranium and plutonium and provides a special legal regime to monitor liability provisions of nuclear licensees. (ONR 2021b)

The Energy Act (TEA) of 2004 created the Nuclear Decommissioning Authority (NDA) and in its 2013 amendment established the Office for Nuclear Regulation (ONR) that, following its predecessors that had been in place since the 1960s, incorporates the role of licensing authority in England, Scotland and Wales. In Northern Ireland, this role is assumed

Box 7-1: Legal Framework of the Nuclear Industry in the UK

Nuclear Installations Act (NIA): requires licensing of nuclear installations, provides control for uranium processing and provides legal regime for liability governance of licensees

Energy Act (TEA) 2004 & 2013: establishment of the NDA in 2004 and of the ONR in 2013

Health and Safety at Work Act (HSWA): definition of regulation to reduce risks at all workplaces. Acted upon by ONR

Ionising Installations Act (IRR17): defines radiation exposure limits for workers at NPPs

Nuclear Industry Security Regulations (NISR 2003): ONR may act upon this to conduct regulatory activities and assess security arrangements

Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations (EIADR): requires a full-scale environmental impact assessment and a grant by the ONR before decommissioning of NPPs can begin

Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR19): requires licensees and local authorities to share information and provide plans in case of radiation emergencies

Nuclear Safeguards Regulations (NSR19): implemented in wake of Brexit, this regulation ensures that nuclear material is not used in military context

by the Secretary of State. Further information on the NDA is provided below. (ONR 2021b)

The Health and Safety at Work Act (HSWA) of 1974 sets regulation to reduce risks at all workplaces, including nuclear installations, and ensure safety of workers and the public. The HSWA is the basis on which the ONR acts upon. (ONR 2021b).

The Ionising Installations Act (IRR17) of 2017 guarantees further protection for workers in industries involved with ionizing radiation. A main part of this act is the definition of exposure limits. This is also enforced by the ONR at nuclear sites. (ONR 2021a; 2021b)

Furthermore, the Nuclear Industry Security Regulations of 2003 (NISR 2003) enable the ONR to conduct regulatory activities, enforce compliance in the industry and assess security arrangements. For example, they provide definitions of nuclear material and so-called other radioactive material. Applicants for nuclear licenses must provide a security plan that meet certain criteria. (ONR 2021b)

The Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations (EIADR) came into force in 1999. Following these regulations, an environmental impact assessment must be conducted before the dismantling and decommissioning of NPPs or other nuclear installations can commence. They also define various procedural requirements. This environmental assessment is conducted by the ONR and includes various stakeholders, such as environment agencies, local authorities, and members of the public. Only when the ONR grants permission, may nuclear and non-nuclear decommissioning begin. (ONR 2021b)

The Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR19) of 2019 require the licensees to prepare on- and off-site emergency plans after having conducted a hazard evaluation. Duties are also placed on the local authority to prepare for the occurrence of a radiation emergency. Both licensee and local authority must guarantee that all necessary information is provided to the affected population and amongst one another. (ONR 2021b)

On 31 January 2020, the UK left the European Union (EU). With this process, commonly referred to as Brexit, it also left the European Atomic Energy Community (Euratom). Euratom was established to create a common market for nuclear goods, services, capital, and specialized personnel. The UK has passed legislation to implement European regulations nationally (e.g., Nuclear Safeguards Regulations (NSR19) in 2019), signed nuclear cooperation agreements with Australia, Canada, the USA and the International Atomic Energy Agency (IAEA), and joined a new nuclear cooperation agreement with the EU in December 2020, which took effect from 1 January 2021. (World Nuclear Association 2022; ONR 2021b)

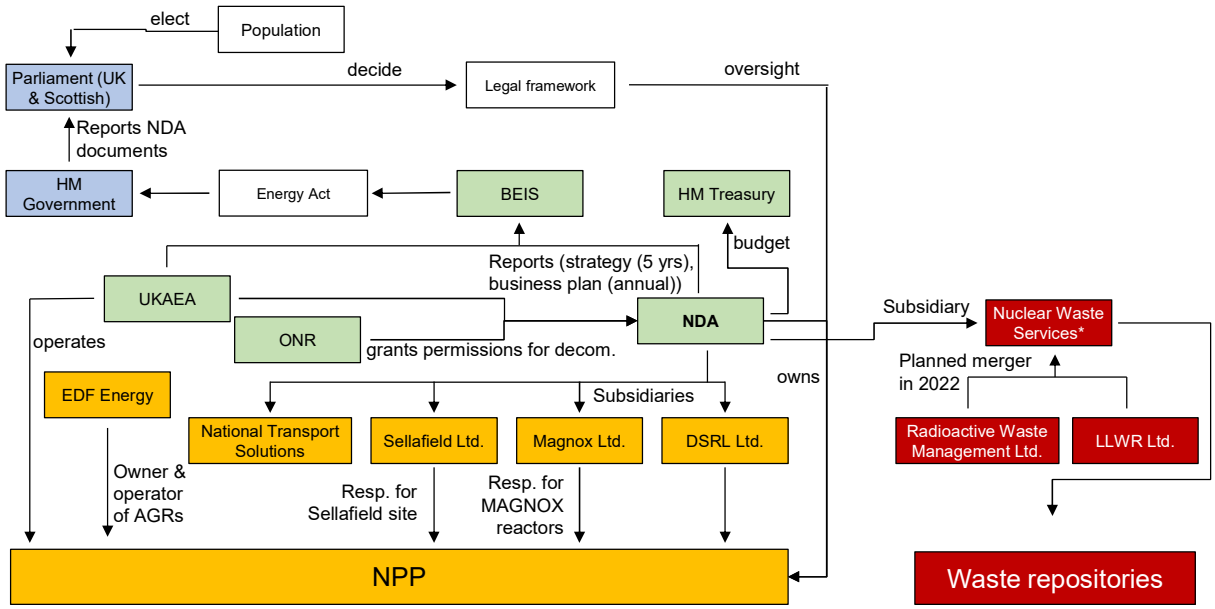
Further regulations, such as the Construction (Design and Management) Regulation of 2015, also influence NPPs. A full overview is provided at ONR (2021b).

In 2004, the Energy Act (TIA04) established the legal framework to establish the NDA in 2005. The agency was initially tasked with decommissioning the UK's legacy fleet (mostly Magnox reactors). It is funded by the Department of Business, Energy and Industrial Strategy (BEIS), but also has additional responsibilities towards Scottish ministers regarding NPPs in Scotland (NDA 2021a). The

NDA is required to publish a strategy report every five years that is presented to Parliament and a business plan every three years, while other reports, such as an annual mission progress report are published for increased transparency (NDA 2022). Initially, the UK followed a PBO (Parent Body Organisation) approach to decommissioning. In this scheme, private firms (PBO) would assume temporary control of the NDA's nuclear subsidies, so-called Site License Companies (SLC). These SLCs were – and still are – the operators of the British nuclear legacy fleet, as shown in Section 6.2.2. The PBO would perform management operations to reduce complexity and increase efficiency and earn a fee depending on performance after a certain period of time. Due to ineffectiveness and NDA oversight failure, the PBO scheme has been replaced by full NDA ownership and oversight (House of Commons 2020; Holliday, HM Government, and BEIS 2021; NDA 2021a). In Section 6.5.4 of this chapter, the PBO scheme is explained in more detail and closely examined. Following the PBO scheme's failure, the NDA now has multiple subsidiaries that are responsible for different sites and tasks concerning decommissioning. A short description of each subsidiary shall be given below, following NDA (2022).

- Sellafield Ltd is tasked with operating and decommissioning the large nuclear site at Sellafield (incl. Windscale) that also includes an interim storage facility. Nuclear waste from other sites, for example those operated by EDF Energy, will be transferred to Sellafield.
- Magnox Ltd is responsible for 12 nuclear sites across the UK, corresponding to all Magnox reactors, except for Sellafield, with a total electrical capacity of 4.7 GW, see Table 6-7 for details.
- The responsibilities of Dounreay Site Restoration Ltd (DSRL) lie in the clean-up of the Dounreay site in northern Scotland (two fast-breeder reactors (FBR)). DSRL also operates a disposal facility for low-level waste from its designated site and became a full NDA subsidiary only in April 2021.
- Nuclear Waste Services was announced in January 2022 and will be comprised of LLWR Ltd, a fully owned NDA subsidiary since July 2021, Radioactive Waste Management Ltd, that is tasked with building a geological disposal facility, and the NDA's Integrated Waste Management Programme.
- Finally, Nuclear Transport Services (NTS) was founded in 2021 as an excellence center to establish strategic capabilities for transport of radioactive waste and other hazardous materials.

Figure 6-3: Legal framework and actors in UK



Source: Own depiction.

6.2.2 Ownership

The four reactors at Dungeness and Hunterston were only recently shut down and are still owned by EDF Energy. EDF Energy is the British subsidiary of French state-owned utility-operator Éléctricité de France (EDF). It operates the British AGR fleet, formally owned by British Energy (EDF 2022; Hirose and McCauley 2022). Following an agreement between EDF Energy and the UK government, ownership of the AGRs will be transferred to the NDA once they are defueled, ideally saving up to one billion GBP[67] of taxpayer money[68]. EDF Energy also owns and operates the Sizewell B plant, Britain's only operational pressurized water reactor (PWR), and is, together with China General Nuclear Power Corporation (CGR), building two new EPRs at Hinkley Point C (EDF 2022).

The United Kingdom Atomic Energy Authority (UKAEA) owns two reactors, Windscale AGR and Winfrith SGHWR, and is the formal operator at the Dounreay FBR reactors. Decommissioning at Dounreay is conducted by DSRL, while Windscale and Winfrith are both attributed to the Sellafield site and are thus decommissioned by Sellafield Ltd (NDA 2022).

For all other shut down reactors, the NDA has assumed ownership. As described above, the operation is managed depending on the type of reactor and location. While Sellafield Ltd is the nuclear operator and thus responsible for decommissioning at the old reactors at Calder Hall (i.e., Sellafield site), all other Magnox reactors are decommissioned by Magnox Ltd. Once the reactors still in operation (currently operated by EDF Energy) reach a certain stage in the decommissioning process (once they have been defueled), ownership will be transferred to the NDA and Magnox Ltd. This is expected to

[67] Approx. 1.13 billion EUR_{2020}.
[68] BEIS (2021) Decommissioning agreement reached on advanced gas cooled reactor (AGR) nuclear power stations. https://www.gov.uk/government/news/decommissioning-agreement-reached-on-advanced-gas-cool-reactor-agr-nuclear-power-stations. Accessed on 22.04.2022.

happen in the next 10 years. An overview of all shut down reactors is provided in Table 6-7 in the appendix of this chapter (NDA 2022; IAEA 2022a).

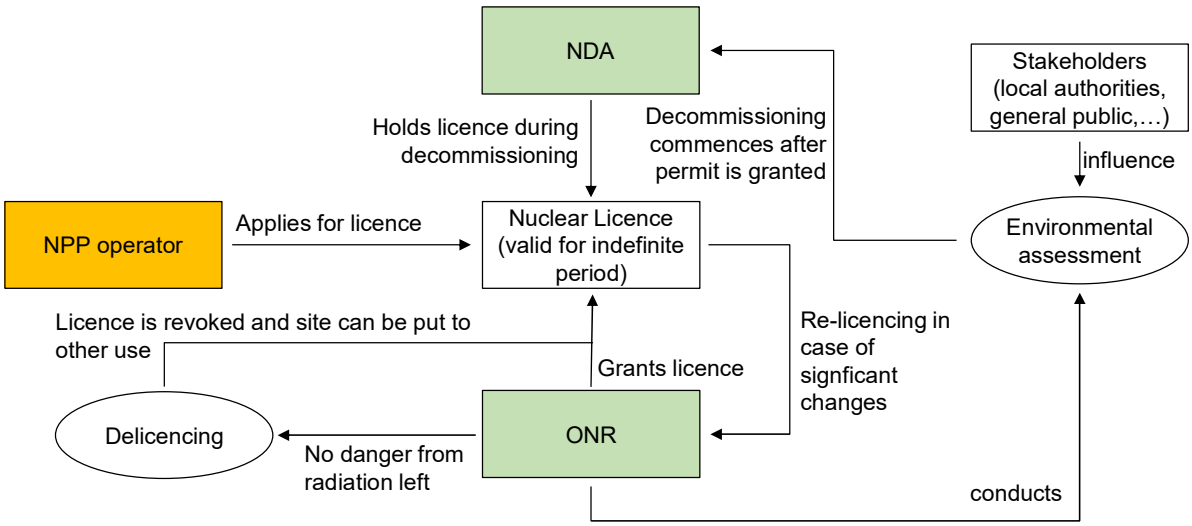
6.2.3 License provision and extension

The Nuclear Installations Act of 1965 requires the licensing of sites where nuclear reactors, and other nuclear installations, such as enrichment plants will be located and operated. Thus, in the UK, no site is to be used for this purpose unless a nuclear site license (from here on shortened to "license") has been granted by the ONR or, in the case of Northern Ireland, the Secretary of State[69]. (ONR 2021b)

A license is granted for an indefinite period to a particular legal entity as operator. License renewal may become necessary if the operator changes, new or other nuclear installations that are not included in the original license are to be built at the site, or the site is to be expanded over its initial boundaries. If none of these instances occur, the license is effective for the entire lifetime of the site, from construction to decommissioning and final site clearance. Most sites, however, will have to request replacement licenses multiple times over their lifetime. Note that before any decommissioning work can begin, the ONR must conduct an environmental assessment and grant a permit. This is not part of the license, although new NPPs must now provide plans for later decommissioning in their license application. (ONR 2021b)

Once the ONR approves that the danger from ionizing radiation from the site or material on the site to have ceased, the site can be released from regulatory control and used for other purposes. Alternatively, the site can be relicensed or put to another use that does not require a nuclear site license (brownfield). Thus, some form of licensing, be it de- or relicensing must be conducted by the ONR before the land can be put to another use (NDA 2021c; ONR 2021b).

Figure 6-4: Licensing process



Source: Own depiction.

[69] As of today, there are no operational or shutdown NPPs in Northern Ireland. The authors are unaware of any plans to change this in the future.

6.2.4 Oversight

Following the Energy Act of 2004, the NDA is required to provide an extensive status report to the British and Scottish Parliaments every five years, titled "NDA Strategy". The last report was published in March 2021. It contains reports on past activities, occurred and expected challenges and how these will be tackled in the upcoming years. Additionally, a "Mission Progress Report" is published every five years. The last issue was provided in 2019. The NDA must also publish several annual reports. These are the "NDA Business Plan" that covers three years and is an Energy Act requirement, the "NDA Mid-Year Performance Report" and the "NDA Annual Report and Accounts", the latter also being an Energy Act requirement (NDA 2021a).

In terms of safety on the to-be-decommissioned sites, the ONR's sub-division for Decommissioning, Fuel and Waste is responsible. This division also oversees the transport of radioactive materials between the NPPs and other nuclear sites. (ONR 2021c)

6.3 Decommissioning Regulation

Historically, nuclear decommissioning or waste management were not prioritized in British nuclear policies (MacKerron 2012; Laraia 2018; Hirose and McCauley 2022). The foundation of the British nuclear sector was built within a military framework: the first commercial NPP at Calder Hall was financed by the Ministry of Defense. Decommissioning was placed on the government's agenda only in 2002, with the White Paper "Managing the Nuclear Legacy" being published. Here, plans for the creation of a Liabilities Management Authority were laid out. With the ratification of the Energy Act (TEA 04) in 2005, the NDA was founded and tasked with decommissioning the UK's legacy fleet. For the AGR fleet, the operator, EDF Energy, is also partly responsible with financial obligations managed in the Nuclear Liabilities Fund created in 1996. After defueling, decommissioning responsibility will be transferred to the NDA. (MacKerron 2012; Department of Trade and Industry 2002; Nuclear Liabilities Fund 2021)

6.3.1 Decommissioning policy

In general, there are three technical strategies to decommission an NPP. These are immediate dismantling, long term enclosure and deferred dismantling, and entombment. Following the strategy of entombment has however been discouraged by the IAEA and should only be considered a solution in certain circumstances, such as when accidents occur (Laraia 2018).

For all its nuclear decommissioning practice, the UK applies a concept called ALARP ("As Low As Reasonably Practicable"). ALARP follows the legal requirement to reduce risks "so far as reasonably practicable" (SFAIRP) (ONR 2020, 2). This concept was introduced to reduce cost and increase efficiency by avoiding the application of duties that cannot be fulfilled as "absolute safety cannot be guaranteed" (Health & Safety Executive 2001, 8). As will be shown in Section 6.5, the NDA is currently applying the "lead and learn" initiative to determine the optimal decommissioning approach for its

extensive legacy fleet. This leads to the question, what "reasonable" means in the context of ALARP. This is discussed in detail by Hirose and McCauley (2022).

For its large fleet of MAGNOX reactors, the UK, i.e., the fully responsible NDA, initially adopted a strategy of deferred dismantling, planning on enclosing radioactive components for 85 years after shutdown at all NPPs. First experiences at the Bradwell site however have shown that not all sites are suitable for this strategy and after an inquiry, the NDA adopted an approach to decommission "as fast as possible" (NDA 2021a, 35) and follow site-specific strategies. Thus, at some sites, decommissioning work will commence earlier, while at other sites, long term enclosure (LTE) will continue for the next decades (NDA 2021a; MacKerron 2012).

Currently, EDF Energy is formally responsible for decommissioning a total of 14 AGRs at seven individual sites. For Hunterston B and Hinkley Point B, plans have been made for defueling to commence in 2022 and decommissioning to proceed as fast as possible. At Dungeness-B, defueling has begun. This shall be conducted by EDF Energy itself, before the plants are transferred to the NDA and its subsidiary Magnox Ltd. Defueling shall be conducted in coordination with the NDA for all other AGR sites that are planned to be shut down successively until 2030. (EDF Energy Undated; 2021)

In the early 2000s, decommissioning policy followed an approach that initially aimed at making the process as cost-effective as possible. Hereby, the NDA acted as a contractor and awarded the tasks of decommissioning NPPs to private site license companies (SLC) that were temporarily owned and controlled by separate legal entities, named parent body organizations (PBO), through share transfer. PBOs did not conduct any decommissioning activities themselves, but rather guaranteed sufficient financial resources for the process and ensured that SLCs complete their assigned tasks according to criteria defined by the NDA by essentially taking over upper management roles and tasks of the SLC. Companies had to compete in tenders in order to be awarded the rights to become a PBO. SLCs are still legally independent today and can outsource tasks to third parties for efficiency increases and cost reduction reasons. However, the PBO approach was proven to be unsuccessful in some cases. For example, information on sites was often inadequate, e.g., in terms of how much nuclear waste was actually stored at the site, complicating the exact definition of the task in the necessary contracts. Furthermore, merging actors from private and public sectors did not go as smoothly as planned with conflicts arising between SLC employees, often formerly employed at public operators such as UKAEA, and PBO management tasked with making profits. Refer to Section 6.5.4 for a more detailed description of the PBO scheme and its failure (MacKerron 2012; NDA 2021c; Holliday, HM Government, and BEIS 2021; House of Commons 2020).

Thus, in recent years, the NDA has retracted the original PBO model and has continuously reassumed control of the SLCs, with Sellafield Ltd becoming an NDA subsidiary in 2016, followed by Magnox Ltd in 2019 as well as DSRL and LLWR in 2021. After the restructuration, the NDA group with consist of the NDA itself and four key subsidiaries Sellafield Ltd, Magnox Ltd, which is to be merged with DSRL, Nuclear Waste Services Ltd, a newly formed subsidiary consisting of Radioactive

Waste Management Ltd and LLWR Ltd, and finally the excellence center Nuclear Transport Solutions, see Section 6.2.1 (NDA 2022).

6.3.2 Regulatory and legal process

Before the approval of a nuclear site license, applicants must present to ONR their detailed and suitable strategies and plans for decommissioning of the NPP and corresponding facilities as well as programs for waste treatment and disposal. Additionally, a funded decommissioning plan must be set up and be approved by BEIS. So, in order to begin decommissioning, the original nuclear site license need not necessarily be renewed, unless the operator changes. This is usually the case before decommissioning, e.g., when ownership transfers to the NDA, and thus a license renewal becomes necessary. Before decommissioning work itself can begin, the ONR conducts an extensive environmental assessment, following EIADR, see Section 6.2.1 for details. (ONR 2021b)

When decommissioning is completed, sites are considered to be in the "Site End State" and the site is suitable for other uses. The NDA encourages "the reuse of brownfield land over the development of greenfield land" (NDA 2021a, 44). To allow for land re-use (brownfield), the nuclear site license (from here on shortened to "license") must be terminated and ONR must declare the so-called "Period of Responsibility" to be over. The license and this period are independent from one another. The period of responsibility begins with the grant of the license and ends when ONR gives a written notice that there is no further hazard from ionizing radiation, a new license is granted for the site in question (e.g., when the site is transferred into NDA ownership) or when a license is no longer required. Therefore, a licensee is responsible for the entirety of the decommissioning process until their period of responsibility is officially declared to be over. Apart from this, no regulation in terms of decommissioning exists (ONR 2021b). According to many decommissioning plans of British NPPs, complete decommissioning will take several decades. Therefore, the NDA defines several "Interim States" to measure the achievement of interim goals without finally committing to an end state (NDA 2021a).

6.3.3 Oversight

Decommissioning of the legacy fleet is carried out by the NDA's SLCs, Sellafield Ltd., Magnox Ltd and DSLR Ltd. These SLCs report to the NDA who in turn provides transparent information to the public on the decommissioning progress in the form of reports, see Section 6.2.4. EDF Energy, BEIS and the NDA are working closely together to establish optimal strategies for the decommissioning of the AGR fleet. Thus, in time, the NDA's reports will contain information on these reactors, too. (NDA 2021a)

6.3.4 Liability

The Nuclear Installations Act of 1965 (see Section 6.2.1), places full liability on the nuclear license holder in case of damage to persons or property caused by nuclear materials from or on the nuclear site. This happens without proof of fault. To ensure possible damages can be compensated, the licensee must

prove that sufficient funds are available, either by insurance or other means. Thus, when the owner of an NPP changes, e.g., when the NPP is transferred to the NDA, liability is transferred, too (ONR 2021b).

As of 1 January 2022, amendments of the Nuclear Installations Act, originally proposed in September 2015, came into effect. These amendments adopted the so-called "Paris and Brussels Conventions" on third party liability in the nuclear field and raised maximum operator liability in the case of a nuclear incident from a mere 140 million EUR to 1.2 billion EUR over a period of 5 years (DECC 2012). Further, the period during which claims can be made is raised from 10 to 30 years. The NDA, as governmental agency, is insured by the government. The contingent liability was therefore increased from 700 million EUR to 1.2 billion EUR per site (Hands 2021).

6.4 Financial Regulation

6.4.1 The funding of decommissioning

Note that all monetary values are provided in the text as stated in the original sources and are referenced in footnotes in 2020 EUR to make values comparable to other country reports. For this UK report, inflation and currency conversion were taken from sources stated in the footnote below.[70]

The NDA is mostly funded through BEIS. Other income is generated from the NDA's business activities, as shown below in

Table 6-1. Planned expenditure is voted upon each year by Parliament (NDA 2022). The UK government makes provisions for its long-term energy policies that, in 2015, included 7.5 billion GBP[71] for oil and gas field decommissioning and 82.9 billion GBP[72] for nuclear decommissioning (NAO 2016). In 2021, the provisions for nuclear decommissioning had amounted to 135.8 billion GBP[73] (NDA 2021b). Given the long-term perspective of nuclear decommissioning of over 100 years, it is highly uncertain whether these provisions can cover future costs. This is shown by reflections from 2015 by the NDA that report a range of necessary provisions from 95 to 218 billion GBP[74] (NAO 2016).

For the decommissioning of the AGR fleet (currently owned by EDF Energy), the Nuclear Liabilities Fund (NLF), an external segregated fund, was created by the UK government in 1996 with an initial endowment of 223 million GBP[75]. The NLF will also cover some liabilities of spent fuel management for the Sizewell B plant. The goal was to reduce the costs for British taxpayers by planning ahead and setting aside provisions that can be invested to cover future decommissioning costs for the – at the time – modern AGR fleet, then owned by British Energy. British Energy, formally the largest British utility filed for bankruptcy, despite controversial governmental aid (supplied through the NLF)

[70] Inflation taken from inflationtool.com. Currency conversion completed with values from https://www.ofx.com/en-gb/forex-news/historical-exchange-rates/yearly-average-rates/.
[71] Approx. 10.86 billion EUR_{2020}
[72] Approx. 120 billion EUR_{2020})
[73] Approx. 153.95 billion EUR_{2020}
[74] Approx. 137.53 to 315.6 billion EUR_{2020}
[75] Approx. 398.69 million EUR_{2020}

and was acquired by EDF in 2009. Since then, the NLF has received significant capital injections from the UK government, the last accumulating to 5.1 billion GBP[76] in 2020. It is expected that more taxpayer money, additional 5.6 billion GBP[77], will be injected into the fund in the financial year 2021-2022. (Thomas 2006; Wealer, Seidel, and von Hirschhausen 2019; Nuclear Liabilities Fund 2021; House of Commons 2022; EDF 2022)

EDF, the parent company of EDF Energy, also makes provisions for decommissioning and waste management, shown in Table 6-4. These provisions will cover the cost of defueling and waste transfer for the AGR fleet before the NDA assumes ownership following the recent agreement between NDA and EDF Energy, see Section 6.2.2. Further, they are to cover costs associated with the decommissioning of Sizewell B, the only operational British PWR. These provisions are calculated with a discount rate of 1.9%, but are separate from the NLF. (EDF 2022; House of Commons 2022)

6.4.2 Current balance in funds

For 2022/2023, total planned yearly expenditure for NDA activities is expected at 3.645 billion GBP, of which 2.825 billion GBP are funded by the UK government that makes provisions on this behalf. The NDA also funds itself to some extent through income from its commercial nuclear activities, such as spent fuel and nuclear materials management or transportation services. Most of the money is spent on site-specific expenditure, divided amongst the NDA's SLCs. In total, 3.389 billion GBP will be spent at SLCs, of which 71% are dedicated for decommissioning. Sellafield Ltd is by far the most expensive SLC, requiring a total of 2.345 billion GBP. About half of the decommissioning budget (1.196 of 2.410 billion GBP) is planned for decommissioning at Sellafield alone. In the upcoming years, government funding is expected to increase, while income from commercial activities will likely decline. By 2024/2025, the NDA's budget will have accumulated to 3.864 billion GBP. An overview is provided in

Table 6-1 and Table 6-2 below. Refer to the bottom row in each table for EUR_{2020} values. (NDA 2022)

Table 6-1: Historical and planned NDA funding from 2021 to 2025 (values in million GBP)

Fiscal year	2021/2022	2022/2023	2023/2024	2024/2025
Income	964	820	802	924
Government funding	2,530	2,825	2,963	2,940
TOTAL	**3,494**	**3,645**	**3,765**	**3,864**
TOTAL in EUR_{2020}	**3,961**	**4,132**	**4,268**	**4,380**

Source: Own depiction following NDA (2022)

[76] Approx 5.74 billion EUR_{2020}
[77] Approx. 6.35 billion EUR_{2020}

At the end of the fiscal year of 2020-21, the NLF's assets were valued at 14.77 billion GBP. This increase from a starting value of 9.37 billion GBP came mostly from a capital injection of over 5 billion GBP by BEIS. Other income came from ordinary activities (428.77 million GBP) and contributions from EDF Energy (13 million GBP), see

Table 6-3. Liabilities estimated from 2021 to 2130 accumulate to 23.506 billion GBP[78] of which 18.584 billion GBP[79] are directly linked to decommissioning. The NDA acts as the administrator of the NLF and approves of payments for decommissioning and waste management. (Nuclear Liabilities Fund 2021)

Table 6-2: Planned site-specific expenditure from 2021 to 2023 (values in million GBP)

SLC / Site	Decom. Costs 2022/2023	Operations Costs 2022/2023	Planned Total Costs 2022/2023	Planned Total Costs 2021/2022
Sellafield Ltd	1,196	1,149	2,345	2,220
Magnox Ltd	515	-	515	505
DSRL	205	-	205	200
RWM	92	-	92	78
LLWR	85	-	85	77
Others	61	86	147	175
Non-Site Expenditure	256	-	256	249
TOTAL	**2,410**	**1,235**	**3,645**	**3,494**
TOTAL in EUR$_{2020}$	**2,732**	**1,400**	**4,132**	**3,961**

Note: DRSL: Dounreay Site Restauration Ltd; RWM: Radioactive Waste Management Ltd; LLWR: LLW Repository Ltd. See Section 6.2.2 for further information on NDA subsidiaries.

Source: Own depiction following NDA (2022)

Table 6-3: Overview of NLF assets in 2020 and 2021 (values rounded to million GBP)

Year	2020	2021
Asset value at start of the year	9,403	9,374.3
Contributions from EDF	22.5	13
Amounts payable to EDF	- 58.1	- 65.2
Funding from BEIS	-	5,070
Operating profit on ordinary activities before tax	16.9	428.8
Tax on profit on ordinary activities	- 10	- 49.3
Asset value at end of the year	**9,374.3**	**14,771.6**
Asset value in EUR$_{2020}$	10,542	16,746

Source: Own depiction following Nuclear Liabilities Fund (2021)

[78] Approx. 26.647 billion EUR$_{2020}$
[79] Approx. 21.067 billion EUR$_{2020}$

As mentioned above, EDF itself makes provisions for fuel management, waste removal and long-term waste management. These provisions, shown in Table 6-4, are made solely for its UK NPPs, operated by EDF's subsidiary EDF Energy. They are, to some extent dedicated for AGR defueling and waste transport, but most will be used to decommission Sizewell B, which will not be transferred into NDA ownership. Fuel from Sizewell B will be stored on-site and not be transferred to Sellafield. These costs are based on year-end economic conditions and include spent fuel and waste management over the whole operating life of the NPPs. The costs are assessed each year and are discounted with a rate of 1.9%. (EDF 2022)

Table 6-4: Provisions for the back-end of the nuclear cycle by EDF (all values in million EUR_{2020})

Year	2021		2020	
	Costs based on year-end economic conditions	Amounts in provision at present value	Costs based on year-end economic conditions	Amounts in provision at present value
Spent fuel management	2,725	1,401	2,318	1,286
Waste removal and conditioning	2,154	639	1,875	546
Long-term radioactive waste management	5,126	1,415	3,724	1,106
Back-end nuclear cycle expense	10,005	3,455	7,917	2,938

Source: Taken from EDF (2022)

6.4.3 Cost assessments

Today, provisions made by the UK government on behalf of nuclear decommissioning have amounted to 135.8 billion GBP[80]. These funds are to be used for the legacy fleet currently overseen by the NDA and are "the best estimate of how much our mission will cost over approximately 120 years". (NDA 2021b, 110–11)

Capital in the NLF is to be used for the current AGR fleet, operational and shut down, owned by EDF Energy and will also have to serve for the decommissioning of new NPPs in planning or under construction. NLF estimates liabilities directly linked to decommissioning will amount to 18.6 billion GBP[81] by 2130. For its British nuclear fleet, EDF Energy's parent company EDF also makes provisions of currently 10 billion GBP[82]. This includes provisions for the Sizewell B plant. (Nuclear Liabilities Fund 2021; EDF 2022)

[80] Approx. 153.95 billion EUR_{2020}
[81] Approx. 21.07 billion EUR_{2020}
[82] Approx. 11.34 billion EUR_{2020}

6.4.4 Cost experience and accuracy of assessments

In 1993, the National Audit Office (NAO) estimated the total undiscounted costs for the decommissioning of nuclear facilities at 17.916 billion GBP[83] after initial estimates by the Atomic Energy Authority, made in 1991, ranged between 3 and 4 billion GBP[84] were deemed too low. (NAO 1993)

As discussed above in Section 6.4.3, current cost estimates of the NDA and NLF amount to a total of over 154 billion GBP[85]. This is evidence that, historically, the costs for decommissioning have been strongly underestimated. Even after correcting the initial estimation of the Atomic Energy Authority of 1991, the NAO still underestimated the costs by a factor of 4.5. Given the timeframe of over 100 years, the uncertainty underlying any cost prediction is substantial (NAO 2016; NDA 2021b). Uncertainties include technical issues and delays but also economic developments, such as inflation and discounting assumptions. Social risks, such as the underestimation of socio-economic costs from staff retraining, redeployment or organizational changes, can also influence actual cost (Invernizzi, Locatelli, and Brookes 2017).

Further uncertainty comes from the investment of provisions in the NLF, a managed fund. The NLF was set up to reduce the cost of decommissioning NPPs for the taxpayer. This can only be achieved when the fund performs according to the defined performance goals. The NLF is structured in two sections with cash in the National Loans Fund (NatLF) and investments in the Mixed Asset Portfolio (MAP). Assets in the NatLF can be accessed on a short notice and accounted for 80% of total assets in 2021 after a 5.07 billion GBP injection by BEIS. These assets however perform with lower returns compared to the MAP portfolio. Thus, the NLF has not been able to achieve its targeted return. Target return over the last three years was set to 5.4%, but the NLF was only able to return 1.7% on investments. When regarding the MAP portfolio separately, the picture is more favorable. On the one hand, MAP portfolio return also missed its three-year target but it was able to surpass the target return set for the fiscal year of 2020-2021 by 2.5%. Target returns in 2021-2022 are 4.9% and 7.3% for the total fund and MAP, respectively. An overview of the NLF fund performance is provided in Table 6-5 (Nuclear Liabilities Fund 2021).

For investments held in the MAP, for which the NLF has more investment flexibility compared to the NatLF, the NLF is committed to ESG[86] criteria and has completed the rollout of its "Long Term Sustainable Growth Portfolio". The NLF provides information on investments in different subsidiaries and provides nondescriptive summaries of subsidiary activities. For example, Adams Steet UK Mid-Market Solutions LP, in which the NLF was invested with over 281 million GBP[87] in 2021, invests in "high growth equity investments in UK mid-market private companies" (Nuclear Liabilities Fund 2021,

[83] Approx. 34.55 billion EUR_{2020}
[84] Approx. 6.2 to 8.27 billion EUR_{2020}
[85] Approx. 174.58 billion EUR_{2020}
[86] Environment, Sustainability, Governance
[87] Approx. 381 million EUR_{2020}

45). Other investments, including such in associates or joint ventures, focus on infrastructure, such as hospitals or highway projects or the UK mortgage sector (Nuclear Liabilities Fund 2021).

A 2022 report, issued by the Committee of Public Accounts of the House of Commons, criticizes the continuous underestimation of decommissioning costs and the subsequent additional costs for the British taxpayers. The report focusses on the to-be-decommissioned AGR fleet and highlights cost uncertainties resulting from defueling processes that can strongly impact decommissioning costs. For example, the early closure of Dungeness-B will result in additional costs of up to one billion GBP[88] for defueling only (House of Commons 2022). This practice of risk transfer from private liability to public, i.e., taxpayer liability, has been common practice in the British nuclear sector. For example, in 2004, the NAO heavily criticized the lack of risk monitoring for public funds during the privatization of British Energy (Thomas 2006; NAO 2004).

Table 6-5: Actual returns of the NLF compared to target returns

Fiscal year	Total Fund Return (NatLF & MAP)		MAP Return	
	Actual Return p.a.	Target p.a.	Actual Return p.a.	Target p.a.
2018 – 2019	2.2 %	5.7 %	8.1 %	7.9 %
2019 – 2020	0.4 %	5.7 %	0.8 %	7.5 %
2020 – 2021	2.4 %	4.9 %	9.8 %	7.3 %
3 Year Period to March 2021	1.7 %	5.4 %	6.2 %	7.6 %

Source: Taken from Nuclear Liabilities Fund (2021)

It remains to be seen, whether the NLF can at some point achieve its targeted return or whether the government will have to inject further capital as was observed in 2021. As cost estimations for nuclear decommissioning, made by the NLF itself and the NDA, remain subject to high uncertainties, a risk remains that overachievement of investment targets will not generate sufficient capital and further taxpayer money will be spent.

6.5 Production

6.5.1 Overview

With its large legacy fleet of GCR MAGNOX reactors, the UK faces significant challenges in nuclear decommissioning. These challenges are of organizational nature, e.g., the reacquisition and reorganization of SLCs or incomplete documentation of nuclear inventories at legacy sites, and of technical nature, e.g., the structural nature of old NPPs, constructed during a time during which decommissioning was not taken into consideration during planning (MacKerron 2015; Laraia 2018;

[88] Approx. 1.13 billion EUR_{2020}

BEIS 2021; NDA 2021a). The decommissioning of the nuclear fleet (except Sizewell B) is managed by the NDA who is currently responsible for 17 sites across the UK, known as the legacy fleet, and has set the goal of completing the task by 2125. In time, EDF Energy's AGRs will be transferred into NDA ownership. Decommissioning work itself is carried out by NDA subsidiaries (SLCs) that will be discussed in Section 6.5.2. So far, no site has been fully decommissioned and retracted its nuclear license (NDA 2022; Schneider et al. 2021).

In accordance with the other country reports, UK reactors were classified into commercial and non-commercial following the classification scheme shown in Figure 1-7 in the appendix of Chapter 0. Following this, all UK reactors were classified to be commercial.

As of June 2022, two NPPs of the AGR type have been shut down, namely Hunterston B and Dungeness B. Initial decommissioning work will be conducted by the current owner, EDF Energy. This work includes defueling and is scheduled to commence in 2022 (EDF Energy Undated; 2021). Table 6-6 provides an overview of the status of NPP decommissioning in the UK.

Table 6-6: Summary of decommissioning progress in UK as of June 2022

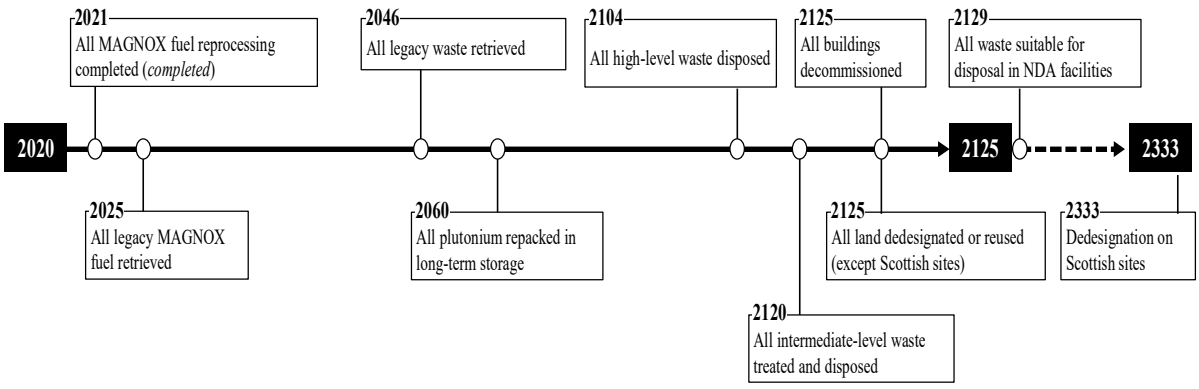
UK	June 2022
"Warm-up-stage"	13
of which defueled	*11*
"Hot-zone-stage"	9
"Ease-off-stage"	0
LTE	8
Finished	0
of which greenfield	*0*
Shut-down reactors	34

Source: Own compilation of Sellafield Ltd. (2017) and NDA (2021a; 2022)

6.5.2 Progress

After the initial blanket approach of LTE of about 85 years applied to each Magnox reactor was deemed unsuitable, SLCs are currently establishing site-specific decommissioning strategies. These strategies are scheduled to be published in the course of 2022. In the meantime, the NDA has published a roadmap that outlines the milestones of the decommissioning process of the legacy fleet, mainly Magnox reactors, as shown in Figure 6-5 (NDA 2021a). In this section, the progress for each SLC shall be presented.

Figure 6-5: Strategic roadmap of the NDA



Source: Own depiction taken from NDA (2021a)

Sellafield Ltd

Of the NDA's sites, Sellafield is the largest, oldest and most complex (Foster et al. 2021). At Sellafield, electricity generation, reprocessing and fuel fabrication were conducted. Today, operations include interim storage of fuel and waste, waste treatment as well as decommissioning. Sellafield was the first SLC to be extracted from the PBO scheme and became an NDA subsidiary in 2016 (Sellafield Ltd 2017; NDA 2021a). This subsection on Sellafield highlights the tasks that are currently being worked on. This includes fuel transfer, retrieval, and processing, as well as demolition and deconstruction of old infrastructure.

All fuel from Magnox NPPs has been successfully transferred to Sellafield. This includes fuel from the four reactors at Calder Hall, located at the Sellafield site. Most of the legacy fuel, originally stored in the "First Generation Magnox Storage Pond" and the "Pule Fuel Storage Pond", is to be retrieved, reprocessed and placed into interim storage by 2025. Some of this fuel will be transferred to the modern Fuel Handling Plant as the fuel itself has degraded too heavily to allow reprocessing at existing plants. When this fuel can then be transferred to dry interim storage has not been determined. (NDA 2021c)

Milestones that are currently being worked on include the retrieval of bulk sludge and fuel from legacy ponds and silos, expected to be completed by the early 2030s. Legacy fuel retrieval had originally been planned to be completed by 2020, but due to the Covid-19 pandemic, delays occurred. Thus, whether the envisioned dates for milestone completion can be achieved, remains to be seen. First successful fuel removal of Magnox legacy fuel was achieved in June 2022. (Sellafield Ltd 2017; NDA 2021c; WNN 2022)

The NDA plans to have received, reprocessed and stored all oxide fuel from AGR plants operated by EDF Energy by 2035. Legacy oxide fuel was fully retrieved in 2016, including that of the Windscale AGR located at Sellafield and the Steam Generating Heavy Water Reactor at Winfrith. Exotic fuel consolidation at Sellafield, including fuel coming from the Dounreay site, is expected to be completed by 2028. Plutonium stocks have been fully consolidated, with repackaging estimated to be completed by 2060. (NDA 2021a; 2021c; 2022)

In terms of decommissioning, Sellafield Ltd plans to complete the demolition of the upper diffusion section of the Windscale Pile Chimney Number 1 and begin cleaning out the Magnox reprocessing plant. Both steps are to be completed by end-2023 with first successful work on the chimney already having been completed. (NDA 2022)

Magnox Ltd

Magnox Ltd became an NDA subsidiary in 2019 and is responsible for decommissioning at Berkeley, Bradwell, Chapelcross, Dungeness A, Harwell, Hinkley Point A, Hunterson A, Oldbury, Sizewell A, Trawsfynydd, Winfrith and Wylfa. The gross electrical capacity of these old Magnox reactors accumulates to over 4.7 GW. Three of these sites, Winfrith, Trawsfynydd, and Dounreay (operated by

UKAEA and DSRL), have been nominated as “lead and learn sites” to optimize the decommissioning strategy for the legacy fleet, which includes Calder Hall at Sellafield, and determine best practices for the upcoming decommissioning of the AGR fleet operated by EDF Energy. For Winfrith and Trawsfynydd, revisions of initial strategies concluded that some contaminated underground structures will remain in place. Land will therefore be suitable for its next planned use (brownfield). Each site operated by Magnox Ltd will in time receive a revised decommissioning plan with milestone dates. These have however not yet been published for each site. An overview of the current status of strategic goal achievement and planned dates, if available, is given in Table 6-8 in the annex. (NDA 2021a; 2022)

Dounreay Site Restoration Ltd (DSRL)

At the Dounreay site in northern Scotland, two reactors are to be decommissioned. Dounreay Fast Reactor (15 MW) was permanently shut down in 1977 and is to be fully dismantled by 2025. Dismantling of Dounreay Prototype Fast Reactor (250 MW) will be completed by 2027 after it was shut down in 1994. Defueling of both reactors is to be completed by 2025. As mentioned above, this fuel will be transferred to Sellafield for processing and interim storage. (NDA 2022)

EDF Energy

EDF Energy is the owner and operator of all remaining commercial NPPs in the UK. Of these, as of June 2022, two sites, Dungeness-B (2x 615 MW) and Hunterston-B (2x 644 MW), have been permanently shut down. Since September 2018, Dungeness-B had been in a long-term outage following several safety inspections that exposed faster than expected decay of relevant, irreplaceable components. Thus, in June 2021, it was decided to defuel both reactors at Dungeness-B (EDF Energy 2021).

After initially extending the lifetime of both reactors at the Hunterston-B site to 2023 with a +/- 2 year proviso in 2012, permanent shutdown was recorded in November 2021 for the first reactor and in January 2022 for the second reactor (IAEA 2022c). Defueling is to begin in the course of 2022 (EDF Energy Undated).

Hinkley Point B, an NPP consisting of two GCR reactors with a gross electrical capacity 655 MW each, is set to be permanently shut down by July 2022. (EDF Energy Undated)

To ensure that defueling of these AGR plants is conducted efficiently, an arrangement was made with the British government. This arrangement included the possibility of EDF Energy earning up to 100 million GBP for good performance – or the loss of the same amount if performance was deemed to be insufficient. Whether this amount will be able to incentivize efficient defueling and smooth transfer of sites into NDA custody, remains to be seen. The Commission of Public Accounts remains skeptical as to the positive impact of this incentive. (House of Commons 2022)

6.5.3 Actors involved

Following the UK's return from the privatized PBO scheme to full state ownership and responsibility, bundled at the NDA, major actors have since retreated from the decommissioning market in the UK. Nevertheless, this section will briefly list former PBOs. Further detail on the PBO scheme and its failure is provided in Section 6.5.4 below.

The first SLC to be removed from the PBO scheme was Sellafield Ltd after it was realized in 2015 that the clean-up task and corresponding technical uncertainties were too great to be placed into private responsibility. The private sector was therefore to "become a supplier to Sellafield Ltd rather than a parent of it" (NDA 2015, 3). Following this, Nuclear Management Partners, a consortium of Areva[89], URS (a subsidiary of AECOM Technologies) and Amec Foster Wheeler[90], were not allowed to continue the PBO contract first established in 2008 (NAO 2013a; NDA 2015; WNN 2015).

Until the award of the *Magnox Contract* to Cavendish Flour Partnership (CFP) in 2014, from which the NDA withdrew in 2017, the PBO of Magnox Ltd was EnergySolutions EU Ltd. The 2014 Magnox Contract not only handled Magnox Ltd, but also included PBO rights to Research Restoration Limited (RSRL), that was tasked with decommissioning at research facilities Harwell and Winfrith, now both assets of Magnox Ltd. Until 2014, Cavendish Nuclear, a member of CFP and subsidiary of defense company Babcock International Group, had been PBO of RSRL. Before Cavendish Nuclear, UKAEA Ltd., also a subsidiary of Babcock, had been responsible PBO. (NAO 2013a; Holliday, HM Government, and BEIS 2021)

Former PBOs at DSRL Ltd (Dounreay) and LLWR Ltd (Low-level waste repository) were Babcock Dounreay Partnership Ltd, a consortium of Babcock, CH2M Hill and URS, and UK Nuclear Waste Management Ltd, consisting of URS, Studsvik, Areva and Serco, respectively (NAO 2013a). The NDA decided to reassume control of both SLCs in 2021 (NDA 2022).

Depending on the site and contract volume, actual decommissioning work is still tendered to the best bidder. At Sellafield, several high-volume contracts, valued at several million GBP, have been awarded to former PBOs, e.g., Cavendish Nuclear. In total, more than 680 individual tasks have been contracted to approx. 430 individual companies. A further 131 tasks are still to be assigned. A similar contract approach can be seen at Magnox Ltd, however not as detailed. Here, more than 140 individual tasks have been or are to be awarded to individual contractors. Detailed information is provided at the procurement plan information websites of Magnox Ltd (2022), updated monthly, and Sellafield Ltd (2022), updated on a quarterly basis.

[89] Areva was split into New NP (now Framatome, owned by EDF) and New Areva (now Orano) after filing for bankruptcy in 2016, see Areva (2017) for further details.
[90] Acquired by Wood Group in 2017, see Wood Group (2017) for further details.

6.5.4 Design, objectives, and results of the SLC-PBO competitive tendering scheme

In 2002, when the idea of creating a non-departmental governmental agency for nuclear waste and decommissioning management, then dubbed "Liabilities Management Authority", was first introduced, efficiency and cost-effectiveness of nuclear legacy clean-up were already major points of interest. Out of this original idea emerged the NDA and, consequentially, the PBO management scheme. (Department of Trade and Industry 2002; MacKerron 2015)

The NDA was set up as a strategic agency not directly involved in the day-to-day decommissioning operations of its nuclear sites. These operations were to be conducted by the site license companies (SLCs) who would hold the nuclear license and employ the workforce tasked with nuclear clean-up. Arrangements between the SLCs and the NDA would be made on a contractual basis to provide shared business risk and defined key performance indicators as well as to establish an incentive-driven framework to increase operational efficiency, safety and environmental standards and, most importantly, generate "the best value for money" (Department of Trade and Industry 2002, 25). A contract change, to be conducted every 5 to 10 years by competitive tender, would thus exchange upper management of SLCs, but keep the licensee itself operable. The SLC in turn may tender contracts to other subcontractors for specific tasks, as shown in Section 6.5.3. (Department of Trade and Industry 2002; MacKerron 2012)

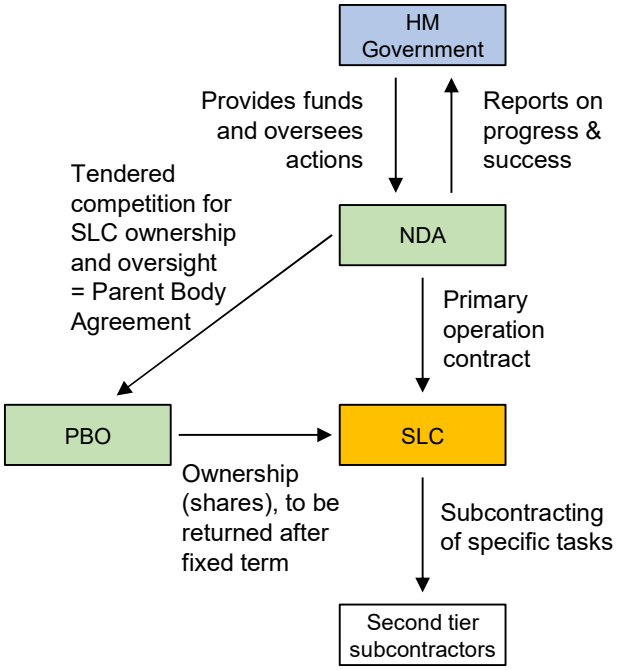
This upper management is organized in the so-called "Parent Body Organizations" (PBO) that own the shares of the SLC for which they won the competitive tender, and thus operation contract, for a pre-determined amount of time. The PBO provides strategic management and aims to improve efficiency. It can earn performance dependent fees. In this scheme, the NDA is still in full ownership of assets and liabilities, although some responsibility shift can occur. The PBO contracts were designed either as reimbursable contracts, that required the NDA to pay all costs generated by contractors, or as Target Cost (TCIF) model. In the TCIF model, a fixed target cost is agreed upon at the beginning of the contract. In this contract, the PBO is compensated with a fee that depends on achievement of the set target cost. If actual costs were higher than the target, the PBO would not be paid in full. If cost savings were achieved, the difference between actual cost and target cost could be shared between NDA and PBO, in addition to full fee payment. Figure 6-6 provides an overview of the PBO scheme. (MacKerron 2012; 2015; KPMG 2013; Holliday, HM Government, and BEIS 2021)

The PBO scheme was designed for increased efficiency and cost savings for the task of decommissioning the UK's extensive legacy fleet (esp. Magnox reactors) and the problematic Sellafield site. However, over the years it was active, the scheme failed to consequently deliver these goals and consequently, all SLCs have now been returned to full NDA ownership. (NDA 2022)

The PBO contract for Sellafield, awarded to Nuclear Management Partners (NMP) (see Section 6.5.3), was finally discontinued in 2015 after it was determined that the clean-up and resulting technical uncertainties at Sellafield were too complex to be placed into private responsibility (WNN 2015). Sellafield Ltd thus became the first SLC to be fully retransferred into NDA custody, effective from 2016

(Schneider et al. 2021; NDA 2021a). Before this decision, the NDA had initially decided to allow the PBO contract to continue, even after concerns about the adequacy of NMP to perform had been reported (KPMG 2013; MacKerron 2015).

Figure 6-6: PBO scheme



Source: Own depiction following MacKerron (2012) and KPMG (2013)

In 2013, the NDA conducted a tender competition for the *Magnox Contract*, a highly controversial 6.2 billion GBP[91] 14-year PBO contract for SLCs Magnox Ltd and RSRL. After having been awarded to the bidder Cavendish Fluor Partnership (CFP) by end March 2013, with work to commence in June 2014, the termination of the contract was initiated by the NDA in 2017, and it finally ended in 2019. The main reason for termination was the initial false estimation of the so-called baseline. This is the initial on-site situation in terms of remaining fuel, contamination, components, buildings and so on. It is used to determine the target that is to be achieved by the end of the contract, including the target cost. This initial false evaluation resulted in an increased cost assumption of over 1.8 billion GBP[92], giving the NDA a valid reason to terminate and resulting in negotiated termination costs of additional 20 million GBP[93] paid to CFP. (House of Commons 2020, 9–10; Holliday, HM Government, and BEIS 2021, 45–73, 102–16)

[91] Approx. 7.3 billion EUR_{2020}
[92] Approx. 2.12 billion EUR_{2020}
[93] Approx. 23.56 million EUR_{2020}

Furthermore, the tender itself had been overly complicated and falsely conducted, when the Magnox contract was awarded to CFP (Holliday, HM Government, and BEIS 2021, 18–19). EnergySolutions, the Magnox PBO before 2014 had competed in the tender in a consortium named Reactor Site Solutions (RSS) with Bechtel Management Company Ltd. EnergySolutions initially filed a claim against the tender at the High Court of England and Wales. Bechtel followed later on, once it had become clear that the claim was valid. Inquiries showed that the NDA had made mistakes in the calculations to determine the best bidder and had thus falsely awarded the contract to CFP instead of RSS, who had actually presented the better offer. This led to a settlement between RSS and the NDA, resulting in additional costs of 122 million GBP[94] in compensation and legal fees for the NDA. (House of Commons 2020; Holliday, HM Government, and BEIS 2021)

After the two largest PBO contracts for Sellafield and Magnox had been retracted, the NDA decided to also terminate remaining PBO contracts at DSRL and LLWR and to reinstate both SLCs as full NDA subsidiaries by 2021. This decision ended the NDA's PBO scheme and now the NDA aims to achieve efficiency, value for money and better performance, ironically the initial goals of the PBO scheme, from its new organizational design. (NDA 2021a)

The reasons for the failure of the PBO scheme can be summarized into four key points that are described below.

Operation

As was mentioned above, the Sellafield contract was terminated due to the overly complex nature of decommissioning a nuclear site whose legacy fuel had been neglected over several decades, especially with poor reporting and record keeping. For a PBO scheme to function and to fulfil its goals, the baseline status of the site must be determined. Due to lack of knowledge of waste amounts and contamination as well as poor oversight of what previous PBOs had achieved, an accurate determination of a baseline status and subsequent definition of necessary tasks to achieve the desired status by the end of contract, was not possible. (MacKerron 2012; Holliday, HM Government, and BEIS 2021; BEIS 2021)

Furthermore, operational challenges occurred when new PBOs implemented process and management changes. This lead to wasted time that could have been more effectively used for actual decommissioning work. (Holliday, HM Government, and BEIS 2021)

Organization

BEIS, the department charged with overseeing the NDA, concluded in their most recent report on the NDA, that two main organizational issues impacted PBO performance. First, SLC employees, often former employees of restructured public companies UKAEA and BNFL[95], still considered themselves as to belonging to the public sector and were discontent with PBO management style that aimed at

[94] Approx. 143.72 million EUR_{2020}
[95] British Nuclear Fuels Limited, see MacKerron (2012) for further details.

increasing private value. This discontent was further increased by the second issue: it was virtually impossible for SLC employees to advance through the management structure imposed by the PBOs and thus resulted in low morale and loss of qualified personnel. (BEIS 2021)

NDA Management

When the NDA was created, little experience, especially commercial, existed in the agency. This lack of skilled staff and knowledge resulted in the inability to provide adequate oversight over the PBOs. For example, after having awarded the Magnox Contract to CFL, NDA oversight staff consisted of only 20 members, as opposed to 3,500 staff at CFL. Only since deeper inquiries into the NDA's shortcomings have been made, has the NDA increased its recruiting efforts. (House of Commons 2020; BEIS 2021; Holliday, HM Government, and BEIS 2021)

Trust

In-depth inquiries into the NDA's shortcomings have led to an increase in governmental oversight of the NDA and several critical reviews (NAO 2013b; House of Commons 2020; BEIS 2021). Failure to produce accurate cost estimates, mistakes made during the Magnox competition and resulting litigation, as well as costs resulting from the retraction of all PBO contracts, have led Parliament to place the NDA under increased scrutiny over the years to come. However, BEIS is also heavily criticized for its lack of oversight in the past. Thus, due to the perceived incompetence of the NDA, the agency will have to restore governmental and public trust in its capabilities by delivering on its set decommissioning targets. With all SLCs in governmental ownership, oversight can be guaranteed in a more efficient and effective manner (House of Commons 2020; BEIS 2021; NDA 2021a).

6.6 Country specific nuclear and decommissioning developments

Decommissioning in the UK highlights three important issues: Firstly, as one of the leading countries of the post WWII nuclear expansion, the UK did not consider the long-term issues of decommissioning and waste management. Secondly, the time horizons now envisaged by the NDA, after some decades without significant progress in decommissioning must be further stressed: The NDA is now planning a process stretching over the next century and more, well into the 22nd century. And finally, an interesting feature of the UK approach is to include competitive elements, mainly competitive tendering and some incentive contracts. Although the PBO approach has since failed in achieving its goals, incentives are still included in contracts with EDF Energy, see Section 6.5.2 – a development that must be closely monitored.

6.6.1 Neglection of long-term nuclear responsibilities in the early days

As one of the first countries to adopt nuclear power, and as a global nuclear superpower after 1945, the UK's authorities gave only little consideration to longer-term issues such as decommissioning of nuclear

installations, and nuclear waste management. Starting with the first reactors, the Calder Hall series, problems of decommissioning started to accumulate, both having to do with the complex technical structure (graphite moderation), but also the absence of technical considerations of the post-operational period. A similar trend is observed vis-à-vis waste management, which was not considered an issue at all in the early nuclear period: Until today, all sorts of waste are stored at seemingly random locations, and in various technical states (liquid, solid), which is both dangerous and costly. Sellafield, where most of these fuel ponds and storage sites are located today, has since become one of the most complex and dangerous nuclear sites to face decommissioning, as was described in Section 6.5.2.

6.6.2 Extensive time horizons

The Sellafield site also represents the long time horizons and high technical and economic uncertainties related to nuclear decommissioning in the UK. According to current planning, the retrieval of the legacy wastes from the reactors will last until the late 2040s, whereas the dedesignation of the lands used for the nuclear sites is planned to have occurred by 2125, while Scottish sites will be reusable only in the year 2333. Waste treatment for disposal in final storage facilities is currently planned for 2129. Not all technological steps are known at this point, in particular the treatment of the graphite. The vast timeframe also implies major economic and financial risks, as highlighted by the low returns of the NLF and the variation in stated provisions made on behalf of the NDA, shown in Section 6.4.2. Given the divestment of the legacy companies of decommissioning and waste risks observed in other countries, full nationalization of economic and financial risks might be likely within the next decades in the UK, too.

6.6.3 Competitive tendering gone wrong

Perhaps the most interesting lesson from the UK is the failure of the real-world experiment of competitive tendering in the presence of high asset specificity and, thus, incomplete and asymmetric information about the technical and economic challenges of decommissioning. Awarding the control of site licence companies (SLCs) to parent body organizations (PBOs) and thus create temporary monopoly rights in the decommissioning sector was a bold idea, which was hoped to accelerate the process and make it more cost-effective. However, difficulties of establishing appropriate incentives for the agents, in terms of timing and remunerate and other issues, discussed in Section 6.5.4, have led to longer decommissioning times, and lower cost-efficiency. This was particularly salient in the case of the Magnox legacy reactors. The fact that the NDA had to regain control of all sites, and withdraw from the experiment, highlights the challenges and most likely pushed the UK’s decommissioning efforts back by several years.

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Appendix

Table 6-7: Ownership of shut down UK NPPs

Nuclear reactor	Type	Model	Owner	Operator	Gross El. Capa. [MW]	Constr. Start Date	Com. Op. Date	Perm. Shut-down Date
Berkeley-1	GCR	MAGNOX	NDA	Magnox Ltd.	166	01.01. 1957	12.06. 1962	31.03. 1989
Berkeley-2	GCR	MAGNOX	NDA	Magnox Ltd.	166	01.01. 1957	20.10. 1962	26.10. 1988
Bradwell-1	GCR	MAGNOX	NDA	Magnox Ltd.	150	01.01. 1957	01.07. 1962	31.03. 2002
Bradwell-2	GCR	MAGNOX	NDA	Magnox Ltd.	150	01.01. 1957	12.11. 1962	30.03. 2002
Calder Hall-1	GCR	MAGNOX	NDA	Sellafield Ltd.	60	01.08. 1953	01.10. 1956	31.03. 2003
Calder Hall-2	GCR	MAGNOX	NDA	Sellafield Ltd.	60	01.08. 1953	01.02. 1957	31.03. 2003
Calder Hall-3	GCR	MAGNOX	NDA	Sellafield Ltd.	60	01.08. 1955	01.05. 1958	31.03. 2003
Calder Hall-4	GCR	MAGNOX	NDA	Sellafield Ltd.	60	01.08. 1955	01.04. 1959	31.03. 2003
Chapelcross-1	GCR	MAGNOX	NDA	Magnox Ltd.	60	01.10. 1995	01.03. 1959	29.06. 2004
Chapelcross-2	GCR	MAGNOX	NDA	Magnox Ltd.	60	01.10. 1995	01.08. 1959	29.06. 2004
Chapelcross-3	GCR	MAGNOX	NDA	Magnox Ltd.	60	01.10. 1995	01.12. 1959	29.06. 2004
Chapelcross-4	GCR	MAGNOX	NDA	Magnox Ltd.	60	01.10. 1995	01.03. 1960	29.06. 2004
Dounreay DFR	FBR		NDA	UKAEA	15	01.03. 1955	01.10. 1962	01.03. 1977
Dounreay PFR	FBR		NDA	UKAEA	250	01.10. 1966	01.07. 1976	31.03. 1994
Dungeness A-1	GCR	MAGNOX	NDA	Magnox Ltd.	230	01.07. 1960	28.10. 1965	31.12. 2006
Dungeness A-2	GCR	MAGNOX	NDA	Magnox Ltd.	230	01.07. 1960	30.12. 1965	31.12. 2006
Dungeness B-1	GCR	AGR	EDF Energy	EDF Energy	615	01.10. 1965	01.04. 1985	07.06. 2021
Dungeness B-2	GCR	AGR	EDF Energy	EDF Energy	615	01.10. 1965	01.04. 1989	07.06. 2021
Hinkley Point A-1	GCR	MAGNOX	NDA	Magnox Ltd.	267	16.02. 1965	30.03. 1965	23.05. 2000
Hinkley Point A-2	GCR	MAGNOX	NDA	Magnox Ltd.	267	01.11. 1957	05.05. 1965	23.05. 2000
Hunterston A-1	GCR	MAGNOX	NDA	Magnox Ltd.	173	01.10. 1957	05.02. 1964	30.03. 1990

| Nuclear reactor | Type | Model | Owner | Operator | Gross El. Capa. [MW] | Constr. Start Date | Com. Op. Date | Perm. Shut-down Date |

Hunterston A-2	GCR	MAGNOX	NDA	Magnox Ltd.	173	01.10. 1957	01.07. 1964	31.12. 1989
Hunterston B-1	GCR	AGR	EDF Energy	EDF Energy	644	01.11. 1967	07.02. 1976	26.11. 2021
Hunterston B-2	GCR	AGR	EDF Energy	EDF Energy	644	01.11. 1967	01.04. 1977	07.01. 2022
Oldbury A-1	GCR	MAGNOX	NDA	Magnox Ltd.	230	01.05. 1962	31.12. 1967	29.02. 2012
Oldbury A-2	GCR	MAGNOX	NDA	Magnox Ltd.	230	01.05. 1962	30.09. 1968	30.06. 2011
Sizewell A-1	GCR	MAGNOX	NDA	Magnox Ltd.	245	01.04. 1961	25.05. 1966	31.12. 2006
Sizewell A-2	GCR	MAGNOX	NDA	Magnox Ltd.	245	01.04. 1961	15.09. 1966	31.12. 2006
Trawsfynydd-1	GCR	MAGNOX	NDA	Magnox Ltd.	235	01.07. 1959	24.03. 1965	06.02. 1991
Trawsfynydd-2	GCR	MAGNOX	NDA	Magnox Ltd.	235	01.07. 1959	24.03. 1965	04.02. 1991
Windscale AGR	GCR	AGR	UKAEA	UKAEA	36	01.11. 1958	01.03. 1963	03.04. 1981
Winfrith SGHWR	SGHWR		UKAEA	UKAEA	100	01.05. 1963	01.01. 1968	11.09. 1990
WYLFA-1	GCR	MAGNOX	NDA	Magnox Ltd.	530	01.09. 1963	01.11. 1971	30.12. 2015
WYLFA-2	GCR	MAGNOX	NDA	Magnox Ltd.	540	01.09. 1963	03.01. 1972	25.04. 2012

Source: Own compilation based on IAEAs Operating Experience with Nuclear Power Plants (IAEA 2022b)

Table 6-8: Overview of strategic goals and achievements at UK MAGNOX NPPs. Dedesignated land (in hectares, ha) has been released from nuclear licensing. The entry TBD is used when no date has been set.

Site	Area dedesignated	Free from Spent Fuel	Free from Nuclear Materials	All Radioactive Waste Disposed	All Buildings Decommissioned or Relicenced	All Land Suitable for Reuse	All Land Dedesignated or Reused
Berkeley	11 of 27 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Bradwell	0 of 20 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Sellafield	0 of 276 ha	-	-	-	TBD	2125	2125
Chapelcross	0 of 96 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Dungeness A	0 of 20 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Dounreay	0 of 60 ha	2025	TBD	TBD	TBD	TBD	TBD
Harwell	23 of 107 ha	Achieved	Achieved	2025	TBD	TBD	TBD
Hinkley Point A	0 of 19 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Hunterston A	0 of 15 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Oldbury	32 of 47 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Sizewell A	0 of 14 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Trawsfynydd	0 of 15 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Winfrith	10 of 81 ha	Achieved	Achieved	TBD	TBD	TBD	TBD
Wylfa	0 of 21 ha	Achieved	Achieved	TBD	TBD	TBD	TBD

Source: Compiled from NDA (2022, 36–52).