Introduction

1 Introduction: The Governance Challenge of Radioactive Waste Management

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1.1 An Extreme Long-Term Governance Challenge[1]

In 1989, the US federal government initiated research into how future generations could be warned and protected against the hazards of an isolated high-level nuclear waste disposal site. One project focused on the risks posed to the site. Scientists from various prestigious American universities designed imaginary future worlds surrounding the site and assessed the probability and impact of a list of possible future risks. A second project investigated how to mark the site in such a way that people in the future would understand the kind and hazards of the materials stored in the location. Experts, among them artists, made suggestions for the design of markers. The first study concluded that in the long-term human intrusion of the waste disposal site was unavoidable (Hora et al., 1991), while the second study looked at how markers could be used to prevent such human intrusion (Trauth et al., 1993).

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The fascinating thing about the studies was their timeframe: 10,000 years from now. It was concluded that governmental control of the site is highly unlikely over the entire time period of 10,000 years. The survival of information on the content and hazards of the site was considered best preserved when it becomes part of a legend or a myth. The experts stated that the conservation of incomplete information is the most dangerous: “Knowing that something is there, but not knowing what it is or what its value may be, may serve to attract investigations such as archaeological digs or salvage operations” (Hora et al., 1991, ES-8).

This US research shows that the challenges and uncertainties incorporated in the long-term disposal of radioactive waste are multifold. This book focuses specifically on how ten European countries are dealing with the long-term disposal of radioactive waste (also see Box 1.2). Long-lived radioactive waste needs to be disposed of safely for extremely long periods, mainly due to various unique characteristics of radioactive waste. It emits ionized radiation (energy) that can destroy (and disturb) the mitosis of all living organisms, and can remain dangerous for time periods up to hundreds of thousands of years, depending on the composition of a radioactive atom (UNSCEAR, 2000). Therefore, radioactive waste needs to be managed to protect humans and the environment until it is no longer harmful.

Although radioactive waste is mainly associated with the production of electricity in nuclear power plants (NPPs), it is also generated during other applications of nuclear technology, such as in health care, non-destructive research and military activities. At present, there is no standard universal categorization of radioactive waste; however, it is usually categorized as low-level waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW). Which waste should be stored in a long-term repository depends not only on the degree of radioactivity, but also on how long the waste will remain radioactive. This can differ between countries since they can decide for themselves on how they categorize and deal with different types of radioactive waste. This book therefore focuses on all radioactive waste that is part of a nation’s long-term management policy, regardless of how it is produced (i.e. in a research facility, NPP etc.) and how long and intensely it will be radioactive. We note, however, that in all ten countries studied, nuclear-based power generation contributes the largest share of HLW. Moreover, historically, the public debate about radioactive waste management (RWM) has become strongly intertwined with the often polarised discussions about nuclear energy. Recently, the debate on nuclear energy has become topical again in various European countries (cf. Schneider & Frogatt, 2020) due to the climate crisis (Rogner, 2010), and in 2022 the gas supply crisis due to the Russian invasion of Ukraine.

Currently, deep geological disposal (DGD) is the dominant preferred option in ongoing research on final disposal options being considered internationally (IAEA, 2003). The assumption is that disposal of radioactive waste for a time period of hundreds of thousands of years should be possible from a geophysical perspective. However, there are various uncertainties and disputes: to this day, no geological disposal site is in operation, and there are concerns about the adequacy of various—natural or geological, technical, and social—barriers that a geological repository must maintain (cf. Di Nucci & Brunnnengräber, 2019).

From a societal and political perspective, it is hard to imagine how the world will look some 10,000 years from now—e.g. in the year 12,023—let alone in 100,000 years or longer. This is however, the timeframe we are facing when it comes to political decision-making about the long-term disposal of radioactive waste. These decision-making processes are ongoing in most European countries. The history of RWM shows that when specific sites are designated for the establishment of a (deep geological) repository, most European countries face domestic resistance from significant segments of the population (cf. Thurner et al., 2017). Such resistance illustrates that RWM is not just a technical, but rather a "wicked" sociotechnical issue (Brunnengräber, 2019). Section 1.2 presents ten characteristics of the challenges of RWM.

Faced with considerable social resistance, and a consequent standstill in the implementation of the chosen RWM policy, many European countries have started looking for new approaches. This change in governance style is sometimes typified as the 'participatory turn' in RWM governance strategy (Bergmans et al., 2014). More attention is being paid to the input of local authorities, social organisations and citizens in decision-making processes, but also in the production and use of scientific and technological knowledge. But in addition to this participatory turn, the new governance style in the field of RWM also involves recalibrating institutions and jointly establishing policy principles, including in legislation and regulations. The premise of this book is that the ten countries described have been renewing their decision-making processes and the institutions that support them over the past two to three decades. Thus, the central question of this book is: What lessons do the country studies teach us about the governance of long-term RWM?

To address this question, we use a comprehensive framework, which will be introduced in Section 1.3. The assumption behind this multi-level governance ecosystem framework is that decision-making takes place within a complex field of political, social, scientific, technological, economic and legal actors and institutions from different levels of government (from international and European to national, regional and local). The function of the framework is twofold: analysing current problems in different national contexts in a comparative way, and identifying approaches and strategies for advancing the democratic decision-making process around RWM.

The authors of the ten country chapters have been asked to analyse the state-of-the-art of the governance of radioactive waste in each setting by means of the governance ecosystem framework. Such an approach identifies the strengths and weaknesses of the current institutional setting for democratic decision-making on final disposal in several European countries. Chapter 12 addresses the question: What lessons do the country studies teach us about the governance of long-term RWM? Based on the ten country descriptions and analyses it aims to distill productive ways to improve democratic decision-making on RWM.

This introductory chapter ends with a reader's guide to the contents of the book.

1.2 Ten Challenges of Radioactive Waste Management

The three previous books on nuclear waste governance published in this Springer VS series on energy policy and climate protection provide a good picture of the nature of the problem of radioactive waste: *Nuclear waste governance: An international comparison* (Brunnengräber et al., 2015), *Challenges of nuclear waste governance* (Brunnengräber et al., 2018), and *Conflicts, participation and acceptability in nuclear waste governance an international comparison* (Brunnengräber & Di Nucci, 2019). In particular, the third book in the series (Brunnengräber & Di Nucci, 2019) provides an elaborate understanding of the specificities of nuclear waste siting as a highly complex, a so-called "wicked planning problem" (Rittel & Webber, 1973) or "intractable controversy" (Hisschemöller & Hoppe, 1995) along ten dimensions. Five of those dimensions refer to the nature of the issues at stake, while another group refers to questions of how to deal with those issues.

With regard to the nature of the issues, Brunnengräber (2019, pp. 336–352) identifies the following five dimensions. First, nuclear waste siting concerns problems that are not only characterized by facts, but are socially constructed, and in which *changing narratives* (with a central role for visions, values and expectations) play an important role. Second, it is not just a technical challenge, but a *sociotechnical challenge*. And given the complex interplay between social and technical issues, a blueprint for solving the problem does not exist. Third, Brunnengräber talks of a *double jeopardy situation* because radioactive waste disposal raises both safety and security issues, and responses to safety concerns may strengthen security concerns. Fourth, in dealing with radioactive waste *systemic risks* are involved, that arise from the interaction between technology, politics, society and economics. Fifth, the radioactive waste problem is characterized by *vast time scales*.

With regard to organising the governance of long-term RWM, Brunnengräber presents five dimensions. First of all, the governance task is specific to each country, because it depends on the national context, and the political, social and cultural background. Second, it presents a *multi-level governance* challenge, which implies that radioactive waste disposal is part of a system of international, supranational, and country-specific institutions and policies. Third, a multiplicity of actors is involved in the decisions regarding the management of radioactive waste at different levels of governance. Various actors bring in different ideologies and interests, which leads to a *landscape of conflicting actors*. Fourth, dealing with the radioactive waste issue requires inter- and transdisciplinary research and thus crosses the *boundaries of different scientific fields*. Last but not least, radioactive waste governance forms a *democratic challenge,* which is ultimately about "reshaping state authority, a shift in responsibility and the integration of civilian knowledge and experience" (Brunnengräber, 2019, p. 350).

This book draws on these entry points by exploring how countries in Europe are currently organising or planning decision-making regarding long-term RWM, explicitly acknowledging that this is a deeply challenging issue. In addition to continuing the analysis and explanation of problems, we intend to suggest approaches and strategies for advancing the democratic decision-making process around RWM.

1.3 Multi-Level Governance-Ecosystem Framework

Knowing that societal resistance in combination with (scientific and technological) uncertainties on radioactive waste disposal options are central issues in national debates, our analysis focuses on trust-building policy measures and socially robust institutions that are capable of shaping a continuous process of interaction between politics, law, science and technology, and society over a long period of time, far beyond electoral periods. To thoroughly analyse and compare these decision-making processes we use a governance ecosystem approach. Below we introduce its conceptual background and the design of the multi-level governance ecosystem framework, which is based on an historical review of how the Netherlands has dealt with ethical and social issues surrounding various new technologies, like biotechnology, ICT, clinical trials and animal experiments (Kool et al., 2017).

1.3.1 Conceptual Background

The governance ecosystem framework combines two concepts. While the concept of governance has a social science background, the concept of ecosystem originates from biology and ecology.

Multi-level governance

The concept of governance implies that the government is not seen as the only guardian of public interests, but that public services can be delivered by a diverse set of actors in the public and private sectors, ranging from organisations at different levels of government (from international and European to national, regional and local) to companies, scientific institutions, non-governmental organizations (NGOs), and citizens (Kersbergen & Waarden, 2001). There will therefore often be so-called *multi-level governance*, within which we can make an analytical distinction between vertical, horizontal and diagonal interactions. Vertical interactions take place between the public authorities of different administrative layers. Horizontal and diagonal interactions are interactions between public and private actors, respectively, within a particular tier of government and across different tiers of government. Moreover, governance does not just take place through formal instruments such as legislation and regulation, but is also about creating and reproducing shared principles, social norms and institutions by means of public debate, negotiations, collaboration, joint vision development, etc. (Kersbergen & Waarden, 2004, pp. 151–2). In short, governance is about achieving public goods and services in a society by the interplay of public and private actors in the context of a configuration of social, economic, political and legal institutions.

Ecosystem approach

The *Cambridge Dictionary* gives two meanings of the word ecosystem as 1) "all the living things in an area and the way they affect each other and the environment", and 2) "any complicated system consisting of many different people, processes, activities, etc., especially relating to technology, and the way that they affect each other". From a biological perspective, ecosystems are composed of organisms living together in symbiotic relationships allowing them and the ecosystem they are part of to survive. The living organisms of the ecosystem are plants, animals and micro-organisms. The ecosystem is able to survive through the exchange of matter and energy between the composing organisms and their environment: soil, water and air. The social sciences, including public and business administration, have adopted the ecosystem concept as a biological metaphor to analyse the structure and organisation of (parts of) the social, political, economic and technological world, with interdependence and interaction between the constituent components as major explanations for reaching outcomes. The second definition of ecosystem in the *Cambridge Dictionary* refers to this. Adner (2017) suggests the following definition of a social science-focused ecosystem: "The ecosystem is defined by the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" (Adner 2017, p. 42). Adner's corporate business strategy-oriented paper distinguishes four dimensions of a business-oriented ecosystem. First the *alignment structure* for analysing how positions and flows in the system are organised and accepted. *Multilaterality* of dependencies as a second dimension refers to the type of dependencies in an ecosystem, which are multisided by definition. The third dimension, *set of partners*, refers to the idea that outcomes are the result of a collective of actors. The fourth and final dimension refers to what the ecosystem is heading for, in Adner's paper, a certain value proposition; the normative outcome of the ecosystem. In our framework, the goal of democratic decision-making is to achieve public values, where "public value is the combined view of the public about what they regard as valuable" (Talbot, 2011, p. 28).

1.3.2 Multi-Level Governance-Ecosystem Framework

In combination, the governance ecosystem can be conceptualised as the institutional setting in which societies deal with specific problems and challenges, which need democratic decision-making. This conceptualisation implies that in a society several governance ecosystems can be identified. A specific governance ecosystem, therefore, is demarcated by a specific public problem or challenge. In this book, the governance of long-term RWM demarcates the governance ecosystem of interest. The conceptualisation of a multi-level governance ecosystem is displayed in Fig. 1.1.

The framework consists of four mutually dependent societal domains: "politics and administration", "science and technology", "laws and regulations", and "civil society". These four domains form the alignment structure of the ecosystem, defining the positions, interactions and flows which shape decision-making and lead to outcomes. But each of the four domains is also an independent institutional setting, with its own history, structures, cultures and routines. In the

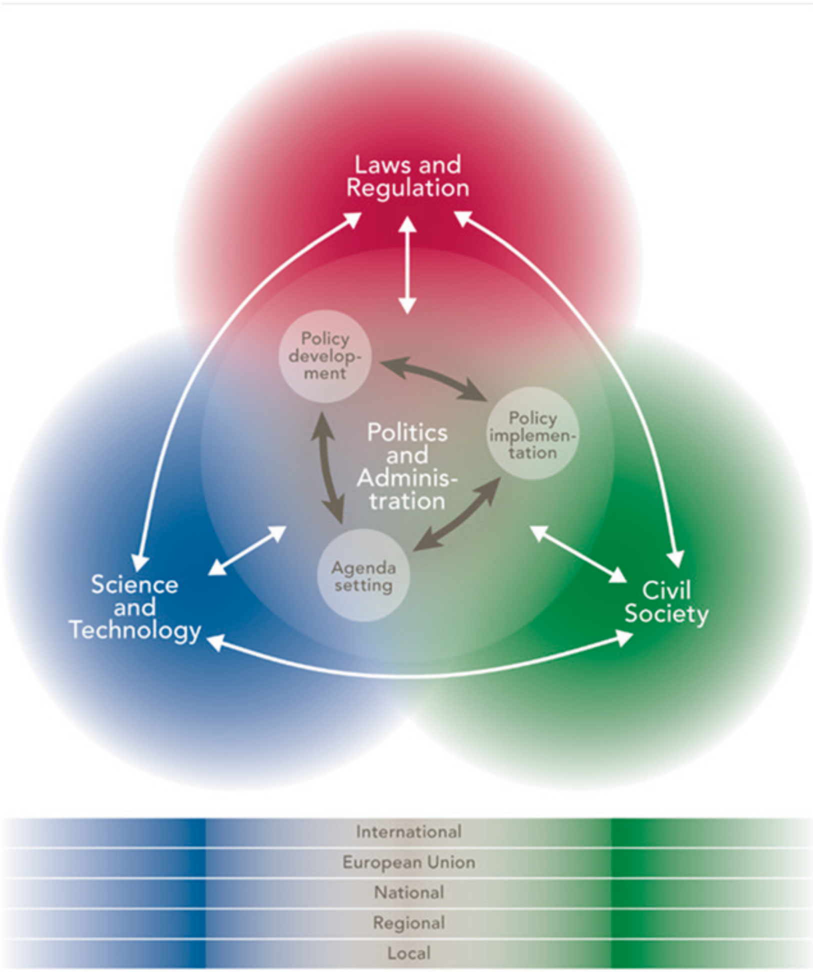

Fig. 1.1 Multi-level governance-ecosystem framework (Adapted from: Kool et al., 2017, p. 95). The figure shows both a top view and front view of the governance ecosystem, with the top view showing the four social domains and their (horizontal) interactions and the front view showing the multi-level nature of the governance ecosystem

ecosystem conceptualisation the alignment of the four domains is multilateral, meaning that all four are mutually influencing and crucial to reach outcomes. The four domains also define the set of actors carrying the interactions between the domains, and the inertia and dynamics of the decision-making processes. Below, we elaborate on the four domains and the interactions between them to provide examples that give the reader a clearer idea of the role of the various domains and the interplay between them. While the domains are distinguished analytically here, there is a strong overlap between them, as shown in Fig. 1.1, and as also appears in the ten country descriptions.

Science and technology

The safe management of risks to humans and the environment from radioactive waste is highly dependent on scientific knowledge and technological expertise, capabilities and instruments. Science and technology play at least three roles in political decision-making (cf. Beck, 1992, p. 163). First, the industrial use of science and technologies creates social benefits and risks. With regard to political decision-making, science and technology can provide practical solutions to societal problems. For example, in the case of long-term RWM, a geological storage facility is often put forward as a possible long-term option. Second, science and technology provide means to recognise and measure physical risks, but also indicate and articulate social and ethical issues related to technologies. And third, science and technology can be used to deal with risks in the best possible way. Accordingly, many technologies and scientific fields, both physical and social, may play a valuable role in the decision-making process on long-term RWM. For the physical sciences, this varies from physics, chemistry to geology, ecology and medical sciences. Here, the focus is on science and technology in the field of radioactive materials and safety. These areas of knowledge have become highly institutionalised internationally and play a central role in national legislation and regulations (see Box 1.1).

The social sciences play a less institutionalised role in the field of RWM, although more attention has been paid to this in recent decades. For example, the work of the Radioactive Waste Management Committee (RWMC), as part of the Nuclear Energy Agency (NEA) within the Organization for Economic Cooperation and Development (OECD), also covers societal aspects of nuclear waste management, in particular stakeholder involvement in decision-making on management issues. According to the NEA website: "The decision-making process for RWM, as well as for decommissioning and legacy management, is couched in a socio-political context, in which issues of public concern and stakeholder engagement must be addressed. This especially comes into play when considering final disposal and deep geological repositories" (RWMC website, 2022). In 2000, the RWMC established the Forum on Stakeholder Confidence (FSC) "to foster learning about stakeholder dialogue and ways to develop shared confidence, informed consent and acceptance of RWM solutions” (ibid.) There is thus an understanding that RWM is not just a technical issue but a socio-technical issue, which requires all kinds of social scientific knowledge, ranging from ethics and public administration to legal knowledge.

Box 1.1 Coordination of International and National Governance of Radiation Protection and Nuclear Safety

Science and technology in the field of radiation protection and nuclear safety have become organised along three pillars: radiology and radiological protection, nuclear installation safety, and radioactive waste disposal. The history of radiological protection is well-documented (Clarke & Valentin, 2008). Figure 1.2 shows how scientific knowledge feeds into recommendations at multiple levels of governance. The International Commission on Radiological Protection (ICRP) plays a central role. The ICRP was established in 1928 to study the implications and effects of the discoveries of X-ray and radioactivity (Clarke & Valentin, 2008, p. 77). The ICRP is an independent, international, non-governmental organization, with the mission to protect people, animals, and the environment from the harmful effects of ionizing radiation. Since the 1950s, epidemiological research of people being exposed to radioactivity due to radioactive fallout from atomic bomb tests in the atmosphere provides the scientific grounding of the safety standards. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)—established by the General Assembly of the United Nations in 1955 to assess and report levels and effects of exposure to ionizing radiation—published its first report on human safety and protection in 1958, and the second in 1962 (https://www.unscear.org/unscear/about_us/history.html).

With regard to nuclear safety, the radiological protection standards are translated into nuclear technologies, and technologies for the safe application of radioactive materials in medicine, food safety and non-destructive research. Research and safety guidelines of the International Atomic Energy Agency (IAEA)—an autonomous organization of the United Nations, which seeks to promote the safe, secure and peaceful use of nuclear technologies—provide the base for the global safety standards. In the European Union (EU), the safety standards have been codified through the European Union’s Directive on Nuclear Safety. The IAEA monitors and reviews the safety of operational nuclear installations globally; the Operational Safety Review Team (OSART) reviews the installations and reports on findings and recommendations.

The Organization for Economic Cooperation and Development (OECD) is the world's leading organisation with regard to the safe disposal of radioactive material and the development of scientifically grounded guidelines. The OECD's activities are organised in the Nuclear Energy Agency (NEA). Its website states that "[t]he NEA assists member countries in the development of safe, sustainable and societally acceptable strategies for the management of all types of radioactive waste". In 1975 the NEA established the Radioactive Waste Management Committee (RWMC), for supporting

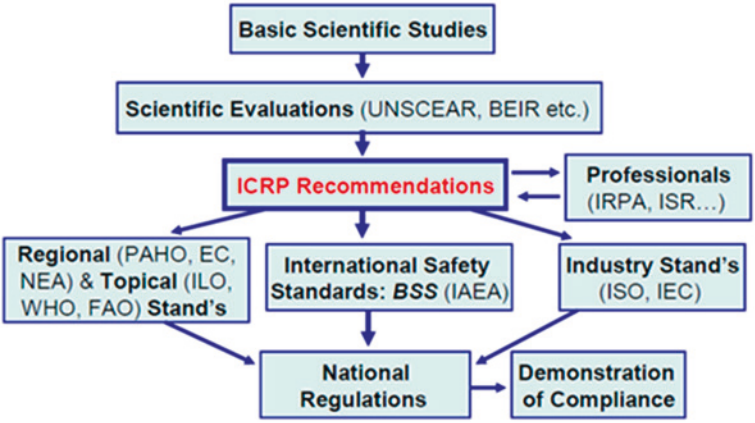

Fig. 1.2 The basis for and use of the International Commission on Radiological Protection (ICRP) recommendations on radiological protection policy. (Source: Clarke & Valentin, 2008, p. 102)

members "… in the development of safe and economically efficient management of all types of radioactive waste including spent fuel considered as radioactive waste based on the latest scientific and technological knowledge" (Nuclear Energy Agency (NEA)—Radioactive Waste Management Committee (RWMC) (oecd-nea.org)).

Civil society

Civil society includes all individuals and private organizations in a society not associated directly with the government, such as schools and universities, interest groups, professional associations, churches, cultural institutions, NGOs and businesses. This wide array of individuals and organisations represents different groups, opinions and interests, and is thought to be essential for democracy (cf. Rosanvallon, 2008). The goal of democratic decision-making is that it leads to legitimised outcomes that are valued by many members of society. If that is the case, it may increase people's trust in the decision-making processes and provide acceptability of the outcomes.

In democratic countries, periodic national, regional, and local elections are means to influence political directions. Together with the rights to express opinions, to demonstrate and to protest, people can influence political decision-making and hence political outcomes. Civil society actors in many European countries have become heavily involved in RWM issues, especially with regard to the installation of waste disposal facilities. For example, protests have been very intense in Germany in particular, but also peaked in other European countries (Thurner et al., 2017). Civil society actors can also play a role as watchdog, and for example, with the help of technical, legal or ethical experts if required critically scrutinize the information that official knowledge institutes, companies and governments produce. Because policy is often based on scientific and technical knowledge, the presence of such public counter-expertise can strongly influence public debate and political decision-making.

As indicated above, public trust or distrust and social acceptance or non-acceptance have played a major role in decision-making on long-term RWM, which has led in many countries to a 'participatory turn' in RWM governance strategy (Bergmans et al., 2014), and thus to all kinds of top-down participatory experiments, organised by public or private organizations, to involve citizens in decision-making and in the production of knowledge. The ten country studies show various inspiring examples of this.

Laws and regulations

Laws and regulations serve many purposes. Four principal ones are establishing standards, maintaining order, resolving disputes, and protecting liberties and rights. In EU countries, the laws and regulations regarding long-term RWM are based on international law and recommendations and guidelines from three international organizations (IAEA, ICRP and NEA) and European law. In the EU, the Euratom Treaty legally grounds the peaceful applications of radioactive materials and its accompanying safety standards. The Euratom Treaty is one of the fundamental treaties of the European Union and provided the legal context for Directive 2011/70/Euratom (European Council, 2011). Under the Directive, countries are obliged to develop and design a regulatory framework for the management of the country's radioactive waste. In addition to legislative frameworks regarding nuclear technology activities, there are also relevant laws and regulations in the field of environmental protection, spatial planning, and rules on public participation and access to information and the courts.

Figure 1.2 shows how rules and regulations are fed by and embedded in international scientific research, recommendations, guidelines and rules of conduct. It shows the hierarchy in the process of developing rules and regulations and their science-based grounding. The many organisations displayed in the fourth layer of Fig. 1.2 indicate the wide range of applications of radioactive material and its accompanying safety measures, mediated by many sector organizations. Protection of the workforce and protection of the environment are the two main addressees of safety standards. The internationally agreed recommended rules and regulations are translated and implemented nationally under the ratification requirements of the agreements.

A second relevant set of international input for national regulations are the agreements made in 1998 under the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, the Aarhus Convention: "In order to contribute to the protection of the right of every person of present and future generations to live in an environment adequate to his or her health and well-being, each Party shall guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters in accordance with the provisions of this Convention (Article 1). "(UN, 1998). Article 6 under 1, obliges countries to develop and design rules in accordance with the Convention for participation in radioactive waste siting and availability of information on siting matters. Annex 1 explicitly mentions disposal of radioactive waste as one of the activities covered. The Aarhus Convention provides an international legal reference for organising and designing public participation in decision making on long-term RWM.

Politics and administration

The fourth domain is that of politics and administration. Politics can be defined as the authoritative allocation of public values (Easton, 1965). The function of politics and administration is to organise democratically legitimised decision-making and to implement effective and socially acceptable policies. With regard to long-term RWM it is about effective and democratically legitimised decision-making procedures, decisions and policies. Building an effective and trust-inspiring radioactive waste governance ecosystem is an important point of attention. Time plays an important political and policy role in the governance of long-term RWM: in essence, the governance of radioactive waste is time or temporal governance (see Box 1.2).

Within the political-administrative domain we recognize three stages: 1) Agenda-setting phase, in which public issues on new developments in science and technology are identified and articulated; 2) policy development phase, in which political decisions are prepared and made; in the latter, representatives of the people play a central role, and 3) policy implementation phase, in which the above decisions are put into practice. Figure 1.1. clearly indicates that the politics and administration domain is in strong interchange and (horizontal) interaction with the other three domains. The three other domains feed political decision-making and receive the decisions taken in the politics and administration domain. In other words, strong interference, exchange of knowledge and ideas and interaction are particular features of the relationship between the politics and administration domain and the other three domains. Policy implementation includes developing, operating and maintaining the existing infrastructure of national radioactive waste processing and storage industries. Countries applying radioactive materials have established private or publicly-owned industries responsible for the logistics, processing and storage of radioactive waste in all categories.

Box 1.2 The governance of radioactive waste as time governance

Because part of the radioactive waste can remain active for hundreds of thousands of years, this waste must be managed in such a way that it does not endanger people and the environment in the distant future, but such a long period of time presents a unique governance challenge. Scientists and policymakers see geological disposal of radioactive waste as the preferred method. Laes (2016) argues that the technological and moral legitimacy of geological disposal rests on the promise that it will enable future generations in the not-so-distant-future "to forget about radioactive waste". Because time plays such an important role in the governance of RWM, in this book we pay special attention to time or temporal governance, which refers to all time-related activities that contribute to organising or preventing collective action to reach common goals, such as the safe handling of radioactive waste.

Firstly, time can be used as a governance tool for collective action. In this case, Bornemann & Strassheim (2019) speak of "governance by time". Time can be used as a resource through, for example, time management and/or time tactics (Pollitt, 2008), such as intentional delay, making promises, fixing deadlines, seizing opportunities from a crisis (cf. Carter, 2019).

To give an example, according to current policy in the Netherlands, radioactive waste is stored above ground for a period of at least a hundred years at the Central Organization for Radioactive Waste (COVRA) in Zeeland. The government wants to make a decision about long-term RWM in the Netherlands around the year 2100. An important governance question is whether this timing of the decision-making process is sensible and, if not, what would be an appropriate time schedule, and if so, how can the period up to 2100 be used wisely?

Second, because our social and political perspective on time has an important influence on how we shape governance ecosystems, our view on time is also an important object of governance. Political terms such as sustainability, intergenerational justice, reversibility of decisions and retrievability of radioactive waste have a strong time component. And if such moral guiding principles are politically embraced, they will have a strong impact on policy shaping and, in the longer term, the entire governance ecosystem. At the same time, policy proposals often contain implicit assumptions and visions about time. For example, according to Laes (2016), implementing geological disposal is aimed at realising the 'imagination of forgetting' within a few generations. Such a time governance perspective would reduce the time horizon of the radioactive waste problem from hundreds of thousands of years to several hundred years.

Interaction between the four domains

Effective and democratically legitimised governance of RWM depends on each of the four social domains. Each domain also entails a specific condition for effective democratic decision-making. The political-administrative domain requires political legitimacy and acceptance. The remaining three domains require scientific knowledge and technological feasibility, legal admissibility and social desirability and acceptance. Due to the importance of all conditions that must be met at the same time, a constructive interaction between the domains is crucial. Here, we briefly describe the (horizontal) interactions between the four domains regarding RWM in a more theoretical way. Chapter 12 will provide a comparative empirical analysis of these dynamics based on the ten country studies.

The central role of the scientific and technological domain in dealing with radioactive waste implies that science and technology also play a central role in the three other social domains. This can, for example, lead to a scientificisation of the political decision-making process. For example, in the Spanish case, Josep

Espluga-Trenc and Ana Prades state that HLW management is used by political parties to profile themselves politically, which has led to a 'nuclearization of politics'. As part of the same dynamic, the scientific and technological domain may also become politicised.

Citizens can express their support for policy, existing regulations, or technology in many ways, but they can also critically question or actively oppose their implementation in many ways. Historian Rosanvallon (2008) argues that in addition to being a voter, citizens can fulfill three more democratic roles: as a watchdog or supervisor, as a protester or restrainer, and as users of the legal system. In these three ways, citizens (individually or collectively) can give substance to their so-called democratic mistrust, which aims "to make sure that elected officials keep their promises and to find ways of maintaining pressure on the government to serve the common good" (Rosanvallon, 2008, p. 8). In the first role, citizens watch closely and critically and make themselves heard, for example through the media, when they think things are not going well. In this role it is possible to collaborate with scientists and other experts who share this critical stance. If citizens want to block a certain development, they can also go to court—the domain of law. Finally, citizens can try to ensure through protest actions that parliamentary legitimised government policy is not or cannot be implemented.

As described above, the political and administrative domain relies on science and technology to identify RWM public problems and develop solutions. National and international legislation and policy principles guide the ways in which the government can act, and which technical options can be applied. For example, French and Dutch policy both stipulate that after disposal, the radioactive waste must be retrievable, which requires certain scientific knowledge and development of technological options. In addition, the actions of the government require not only legal legitimacy, but also social support. At the same time, politicians and policymakers have a central public responsibility for good long-term RWM. They can fulfill this role by adequately stimulating and regulating the development of science and technology. In the field of radioactive waste, science and technology are highly dependent on political support and funding. The government and representatives of the people also play a central role in developing and implementing policy, legislation and regulations, and also monitor and evaluate their application. Finally, from a democratic perspective, governments have a responsibility to properly inform citizens and to involve them in decision-making processes. This is legally required due to, for example, the Aarhus Convention (UN, 1998), which became operational in 2001, and Directive 2011/70/Euratom of the European Council (2011).

In addition to the political and administrative domain, the social domain and the science and technology domain also play a role in the development of legislation and regulations. Legal frameworks and principles provide the rules on the basis of which people act and interact in a constitutional state, and aim to protect citizens against each other and the government. That is why high-quality legislation is important. In governance in general, and the drafting and implementation of legislation and regulations in particular, the interaction between various levels of government—local, regional, national and international—plays an important role. This is referred to as multilevel governance. In the field of radioactive waste governance, international bodies such as the NEA of the OECD, the IAEA of the UN, and the EU, or Euratom all play an important role.

1.4 A Reader's Guide

The following ten chapters are devoted to the governance of long-term RWM in ten EU countries. In each of those countries long-term RWM is a societal and political challenge mainly because of the country's nuclear-based production of electricity, which is by far the largest contributor to long-lived radioactive waste (European Commission, 2019, p. 15).

The first row of Table 1.1 lists the taxonomy of three types of radioactive waste according to the IAEA: low-level waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW). All countries included in the book follow this IAEA classification in one way or another. The second row lists the IAEA preferred technical option for the management, storage and disposal of each waste type. For the long-lived LLW a (near) surface storage of at least 300 years is recommended. For ILW and HLW, deep geological storage for 100,000 years and more are recommended. In all ten European countries discussed in this book, the final disposal of LLW, ILW and HLW is still work in progress. So none of the countries described (nor anywhere else in the world) has reached the operational phase of long-term final disposal as suggested by the IAEA.

Table 1.1 Taxonomy of three types of radioactive waste and suggested waste management options by the IAEA. (Source: IAEA, 2009)

Radioactive waste type	Low-level waste (LLW)	Intermediate-level waste (ILW)	High-level waste (HLW)
IAEA suggested technical option	Near surface disposal	Intermediate depth disposal	Deep geological disposal

The ten European countries included in the book are working on near surface or intermediate depth disposal options and DGD options, but the stage of development, the technological challenges and governance approach differ from country to country. The order of the chapters is mainly determined on the basis of the development phase a country is in. We start with countries that are still in a policy-making phase with regard to the final disposal of high-level radioactive waste, and end with countries that are already in the implementation phase. We therefore end with France, Sweden, and finally Finland since these three countries are clearly ahead of the other seven countries, having decided on a technology (DGD) and location, and are in the phase of developing the site for a geological disposal facility. Starting with countries that are still far from such a final solution and ending with countries closest to it, provides the reader with a rich overview of the challenges involved in the different phases of the governance of RWM.

In Chap. 2, Romy Dekker, Vincent Lagendijk, Roos Walstock and Rinie van Est describe how the Netherlands pursues a so-called 'dual strategy'—national and international—with regard to RWM. On the national level, an above-ground facility was built in the 1990s to store radioactive waste for a period of at least 100 years. By around the year 2130 a geological disposal facility is envisaged to be operational. The Netherlands also pursues an international strategy, which leaves the possibility open for collaboration with other European Union Member States to establish a shared geological disposal facility. Currently, the country's radioactive waste policy lacks a concrete step-by-step decision-making process to implement its dual strategy.

In Chap. 3, Maria Rosaria Di Nucci and Andrea Prontera explain how radioactive waste governance in Italy is characterised by complex interactions between European, national, regional and local political-territorial levels. In 2011, the European Council Directive 2011/70/Euratom (European Council, 2011) put pressure on national decision-makers to initiate an inclusive process for a suitable site for nuclear waste on the basis of socio-technical and scientific criteria. Accordingly, the nuclear waste operator SOGIN envisioned plans for the construction of a central surface repository for the temporary storage of, amongst others, HLW. Recently, after a long period of incoherent stop-and-go, local opposition to the plans and a subsequent deadlock, the mandatory search for a national site is taking shape. The national map of potentially suitable areas was released in January 2021.

In Chap. 4, Anne Bergmans, Catherine Fallon, Ron Cörvers and Céline Parotte discuss key dimensions for the future of radioactive waste governance in Belgium. They highlight elements that a diverse set of Belgian stakeholders considered of importance for a national public debate. This foresight chapter gives voices to actors who compose the current HLW governance ecosystem, from concerned citizens, scientists, policymakers, civil society representatives, and public administrators to environmental associations. These actors considered five important governance principles: a flexible and stepwise approach, practicing transparency, providing clarity about the link between participation and decision-making, ensuring monitoring and control, and robust financing.

In Chap. 5, Maria Rosaria Di Nucci and Achim Brunnengräber describe that Germany has a long tradition and history in final disposal siting, but to date its governance is still work in progress. After massive societal protest, Germany decided to restart the governance process, this time from the bottom-up. Since 2013, the Repository Site Selection Act (StandAG) opened-up new opportunities, by providing a framework for the establishment of new state institutions and a participation procedure for involving civil society and stakeholder groups. The authors maintain that the StandAG leaves many unresolved issues, but permits extensive room for manoeuvre, and represents an opportunity for new and expanded forms of participation to be pursued.

In Chap. 6, Josep Espluga-Trenc and Ana Prades describe the complex interactions between central and regional governments in Spain in the search for a location for a centralised temporary aboveground repository for, amongst others, HLW. The plan to build such an intermediate aboveground disposal facility has been the subject of numerous social and political conflicts, so that it remains a difficult issue to solve. Environmental legislation, required by European directives, requires public transparency and openness to citizen participation. The authors argue that in Spain, opening the nuclear issue from the closed circles of experts and their organisations to a broad public debate has created a "nuclearization of politics", leaving limited room for counter-expertise, as nuclear-related arguments are employed opportunistically to serve broader political aims.

In Chap. 7, Sophie Kuppler, Anne Eckhardt and Peter Hocke critically discuss the basic characteristics of the Swiss governance approach to RWM. In Switzerland, the selection procedure for a nuclear waste repository site is characterized by deliberation and debate between different governmental levels, and lay persons and experts. The usual Swiss decentralised democratic model has been amended, with more centralised coordination in the decision-making process. For example, the Swiss Parliament abolished the cantonal veto rights on deep geological disposal in favor of an optional national veto right on the general license for such a repository. Moreover, it was decided in 2008 to link the decision-making process around finding a geological disposal facility to the methodology of a Sectoral Plan, which is an established spatial planning instrument of the Swiss Confederation.

In Chap. 8, Steve Thomas argues that the United Kingdom is still several decades away from building facilities that will provide a safe, permanent home for HLW. Attempts to site new facilities have repeatedly failed. In 2007, the approach changed from one driven by identifying an ideal site then implementing it, to one that placed informed consent from the hosting community at the forefront. The author estimates the new policy as risky, and has little confidence that it will identify a site for HLW that is both technically and politically acceptable.

As indicated above, France is one of the forerunners in advancing towards implementation of a repository for HLW. In Chap. 9, Markku Lehtonen describes how the state agency responsible for RWM, Andra, plans to start the construction of the Cigéo facility in 2022, with a pilot-testing phase in 2025, and operation in 2040–2050. Although supported by most parliamentarians and key stakeholders in the region, the project continues to generate controversy and recurrent clashes between opponents and the police. To deal with public distrust, the French authorities laid down the principle of reversibility by law in 2006, as a concept that allows future generations to choose between either continuing the construction and operation of disposal through successive phases, or to re-examine the earlier choices and modify the management solutions. Moreover, the government together with the nuclear industry have institutionalised counter-expertise through the establishment of permanent and ad hoc multi-stakeholder bodies, and have set up experiments at "co-creation of knowledge" by experts and citizens holding distinct types of expertise.

In Chap. 10, Johan Swahn describes how in January 2022, the Swedish government decided to allow the construction of a geological repository for SNF (the SFL). The geological waste facility is based on the KBS-3 V concept, which has three safety barriers (bedrock granite, bentonite clay, and copper canister) designed to keep the HLW isolated from the biosphere for at least 100,000 years. But the decision was controversial and may still be found to conflict with the implementation of the Swedish environmental legislation developed since the beginning of the twenty-first century. This chapter describes the long process that has led to the decision to allow the construction of a repository for SNF, and the controversies that have arisen. The most important controversy has been the copper canister corrosion issue, which has been central in the discussions of long-term safety of the repository since 2007, as well as to the repository licence review process from 2011, until the decision in January 2022.

In Chap. 11, Jarmo Vehmas, Aleksis Rentto, Jyrki Luukkanen, Burkhard Auffermann and Jari Kaivo-oja describe that Finland plans full operation of the ONKALO geological disposal facility in 2024. The ONKALO project includes an encapsulation plant and final disposal facility based on the Swedish KBS-3 V concept (see Chap. 10). The authors identify various factors that brought Finland to a forerunner position in long-term RWM, like structural corporatism and high trust in technology, nuclear expertise and politicians. Since the potential host municipality has a veto right, the critical factor was local acceptability in the municipal council of Eurajoki, which was reached after negotiations on mutual benefits with Posiva, the company established by the nuclear power companies Fortum and TVO for nuclear waste management.

We hope that the ten European country chapters contain examples of productive ways for collective decision-making, which may provide inspiration to better democratic decision-making. Thus the concluding Chap. 12 aims to address the question: What lessons do the country studies teach us about the governance of long-term RWM? Rinie van Est and Maarten Arentsen make use of the governance ecosystem framework. They show that the governance of RWM is strongly influenced by developments in the field of nuclear energy. To emphasize the multi-level nature of RWM's governance, they reflect on the interactions between international and national governmental levels, and national, regional and local levels. Next they focus on each of the four domains of the governance ecosystem framework: politics and administration, law and regulation, science and technology, and civil society. As a result the authors identify 17 lessons that may advance the democratic decision-making process around RWM.

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