Deadly Legacy of Geological Disposal of High-level Radioactive Nuclear Waste:

100,000 years deep underground repository for future generations

TAKEMURA Noriyoshi

Faculty of Law, Toin University of Yokohama

(2017 年 3 月 18 日　受理)

I. Introduction

High-level radioactive nuclear wastes are highly dangerous and there are no facilities in the world which can permanently and safely store it. In November 2015, after more than 30 years of efforts, Finnish government firstly approved a construction of such a store, a 'deep underground repository', in Olkiluoto. Similarly, Swedish government is currently considering a license to build a facility in Forsmark. In France a nuclear-waste agency ANDRA hopes to apply for a license to build a facility in Bure in 2017 (Gibney).

Where to put a repository is the main problem. Most countries do not use deep underground stores, but store their spent nuclear fuel above ground in temporary storage facilities. In Germany, salt formations at Gorleben had been studied for decades, but the government called off the work in 2000. The United States selected a site at Yucca Mountain in Nevada in 1987, but its government wanted to scrap the idea in 2010. In Japan, United Kingdom and Canada, governments have declared plans to build deep geological repositories, but have yet to begin the thorny process of picking sites (Gibney).

At present, although researches on the ways how to get rid of nuclear waste continue, most countries agree that the permanent underground burial is the best solution (Irvine: 58–61). In this research, from a perspective of green criminology, following questions are considered: With 100,000 years deep underground nuclear waste repository, can we keep it safely without troubles and accidents for such a long time? How is the 'problematique' of high-level nuclear waste geological disposal?

II. Positive Evaluation: Safety and Necessity of Deep Geological Repository/ Disposal

1. Radioactive waste management and its safety

World Nuclear Association (WNA) explains a radioactive waste management and emphasizes its safety as follows.

WNA explains that some radioactive wastes

TAKEMURA Noriyoshi : Professor, Faculty of Law, Toin University of Yokohama. 1614 Kurogane-cho, Aoba-ku, Yokohama 225-8503, Japan

are produced in the nuclear fuel cycle, and the relatively modest cost of managing and disposing of this is part of the electricity cost. At each stage of the fuel cycle proven technologies are used to dispose radioactive wastes safely. While for low- and intermediate-level wastes these are mostly being implemented, for high-level wastes some countries await the accumulation of enough of it to warrant building geological repositories, others have encountered political delays. Unlike other industrial wastes, the level of hazard of all nuclear waste, its radioactivity diminishes with time. Each radionuclide contained in the waste has a half-life, the time taken for half of its atoms to decay and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters, making their handling easier, while those with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive wastes decay into non-radioactive elements. The more radioactive an isotope is, the faster it decays (World Nuclear Association).

Then WNA emphasizes its safety that the main objective in managing and disposing of radioactive waste is to protect people and the environment. This means isolating or diluting the waste so that the rate or concentration of any radionuclides returned to the biosphere is harmless. In order to achieve this, all wastes are practically contained and managed, some clearly need deep and permanent burial. None is allowed to cause harmful pollution from nuclear power generation. All toxic wastes need to be dealt with safely, not just radioactive wastes. In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes (World Nuclear Association; Nuclear Energy Agency/ Radioactive Waste Management Committee).

2. Geological disposal of radioactive waste and its necessity

European Commission (EC) explains a geological disposal of radioactive waste as the best way and insists its necessity as follows.

EC explains that since the development of nuclear power in the 1950s, it has been proposed for many years that the most appropriate and natural way of dealing permanently with our radioactive wastes is to return them to the ground. Careful burial in well-engineered repositories at various depths below the land surface at specially selected sites is the favored solution in every country that has decided how to handle the problem (European Commission: 4).

Then EC insists its necessity that the burial at several hundreds of meters depth in stable rock environments, ‘geological disposal’, is the option for disposal of the most hazardous radioactive wastes because it will provide permanent safety, not just for ourselves but for future times very much longer than the whole of past human history. Although we currently store all our wastes safely and make every effort to minimize the amount of radioactive waste that we produce, it is inevitable that there will always remain some wastes that have to be disposed of deep underground. The European Union has been researching geological disposal for almost 30 years and is on the verge of constructing its first deep repositories (European Commission: 4).

III. Critical Evaluation: Dangerous and Deadly Legacy of Radioactive Waste

1. Hazardous for hundreds and thousands of years and no other solution than burying the problem

If we consider that high-level radioactive nuclear wastes could continue to be hazardous for hundreds of thousands of years, and that at present there is no other solution to radioactive wastes than burying the problem, one may say that keeping and depending on nuclear power means a dangerous waste of time.

Greenpeace explains that high-level wastes, which include materials containing highly-radioactive elements, can be radioactive for hundreds of thousands of years and emit large amounts of hazardous radiation. Even a couple of minutes of exposure to high-level waste can easily result in fatal doses of radiation. Therefore it needs to be reliably stored for hundreds of thousands of years. Humankind has been on Earth for the last 200,000 years, yet it takes 240,000 years for plutonium to be considered safe. The safe and secure storage of the dangerous waste needs to be guaranteed throughout this period, which potentially spans many Ice Ages. It's no wonder that a solution for dealing with nuclear waste has still not been found (Greenpeace 2009: 4).

Then Greenpeace continues that the nuclear industry wants to bury the problem of radioactive waste by storing it in deep geological repositories. But it appears to be impossible to find suitable locations where safety can be guaranteed for the necessary timescales. Given the immense difficulties and risks associated with the storage of dangerous nuclear waste, it's not surprising that the nuclear industry tries to dump it out of sight. Despite the billions already invested in research and development for dealing with radioactive waste, new experiments are still being presented as 'solutions'. Methods that will not be ready for a long time, may never be commercially viable or do little to solve the long term waste problem (Greenpeace 2009: 5).

2. Rock solid? Scientific review of geological disposal

According to a scientific review of geological disposal of high-level radioactive, containment barriers would lead to significant releases of radioactivity, and predicting such a complex, coupled processes over the long timescale is difficult. Unless such difficulties can be resolved, a significant release of radioactivity from a deep repository could occur. The status of research and scientific evidence regarding the long-term underground disposal of highly radioactive wastes is overviewed as follows.

Wallace explains that a number of phenomena are identified that could compromise the containment barriers, potentially leading to significant releases of radioactivity: Copper or steel canisters and overpacks containing spent nuclear fuel or high-level radioactive wastes could corrode more quickly than expected; The effects of intense heat generated by radioactive decay, and of chemical and physical disturbance due to corrosion, gas generation and biomineralisation, could impair the ability of backfill material to trap some radionuclides; Build-up of gas pressure in the repository, as a result of the corrosion of metals and/or the degradation of organic material, could damage the barriers and force fast routes for radionuclide escape through crystalline rock fractures or clay rock pores; Poorly understood chemical effects, such as the formation of colloids, could speed up the transport of some of the more radiotoxic elements such as plutonium; Unidentified fractures and faults, or poor understanding of how water and gas will flow through fractures and faults, could lead to the release of radionuclides in groundwater much faster than expected; Excavation of the repository will damage adjacent zones of rock and could thereby create fast routes for radionuclide escape; Future generations, seeking underground resources or storage facilities, might accidentally dig a shaft into the rock around the repository or a well into contaminated groundwater above it; Future glaciations could cause faulting of the rock, rupture of containers and penetration of surface waters or permafrost to the repository depth, leading to failure of the barriers and faster dissolution of the waste; Earthquakes could damage containers, backfill and the rock (Wallace: 7).

Then Wallace continues that although computer models of such phenomena have undoubtedly become more sophisticated, fundamental difficulties remain in predicting the relevant complex, coupled processes (including the effects of heat, mechanical deformation, microbes and coupled gas and water flow through fractured crystalline rocks or clay) over the long timescales necessary. In particular, more advanced understanding and modelling of chemical reactions is essential in order to evaluate the geochemical suitability of repository designs and sites. The suitability of copper, steel and bentonite as materials for canisters, overpacks and backfill also needs to be reassessed in the light of developing understanding of corrosion mechanisms and the effects of heat and radiation. Unless and until such difficulties can be resolved, a number of scenarios exist in which a significant release of radioactivity from a deep repository could occur, with serious implications for the health and safety of future generations (Wallace: 7–8).

3. Deadly legacy of radioactive waste

(1) Failed solutions

We have seen many cases of failed solutions around the world.

According to Beránek *et al*., billions of euros have been spent over the past half-century on finding a solution to the nuclear waste problem. But the attempts have all been unsuccessful (Beránek *et al*.: 3).

a) Russia, USA, France, UK, Netherlands, Japan and others: Waste dumping at sea

Low level radioactive wastes had been dumped at sea for years, based on the irresponsible idea 'out of sight and out of mind'. Disintegrating barrels had brought the wastes back into the environment and dangerous substances had been accumulated in bodies of animals. In 1993, an international treaty, which bans all dumping of radioactive waste at sea, was signed (Beránek *et al*.: 3).

b) Germany: Waste dump in water floods salt layers

In Asse, Germany, an experimental radioactive waste dump had been set up in the 1960s in salt formations deep underground. A few years later it was discovered that it had started leaking water in 1988 and is currently flooding with 12,000 litres of water each day. As a result, all 126,000 barrels of waste already placed in the dump now need to be cleared out. Asse was envisaged as a pilot project for a final storage solution in the salt layers under Gorleben, but there is now serious doubt in Germany about the viability of salt layers as storage for nuclear waste (Beránek *et al*.: 3; Federal Ministry of Economics and Technology).

c) France: Unknown waste inventory

One of the largest nuclear dumps in the world, the Centre de Stockage de La Manche (CSM) in northern France had been opened in 1969 to store low-level wastes, and it was closed in 1994. It currently stores 520,000m^3 of radioactive materials from waste reprocessing and French nuclear reactors. A 1996 commission set up by the French government concluded that the site also contained long-living waste and high-level waste, and that the true inventory was effectively unknown. In 2006 it was found that contaminated water from the site had already been leaking into an underground aquifer, threatening the surrounding agricultural land (Beránek *et al*.: 3; Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) 2014).

d) USA: Seismic fault line compromises bedrock storage

In 1987, Yucca Mountain in Nevada, about 80 miles north of Las Vegas, was designated as the site for long-term disposal of radioactive wastes in the United States. However, the US Geological Survey has found a seismic fault line under the site and there are serious doubts about the long-term movements of underground water that can transport deadly contamination into the environment. As a result of these problems and billions of dollars in cost overruns, the US government stopped funding the project in early 2010. But some years later its political climate has changed again. The White House's fiscal 2018 budget plan for the Department of Energy includes 120 million dollars to restart licensing for the proposed Yucca Mountain nuclear waste dump (Beránek *et al*.: 3; Macfarlane *et al*.; Washington Reuters).

(2) New researches and challenges

Regardless of these failed solutions, and in order to overcome them, they are doing new researches and challenges. Beránek *et al*. explain the present situation in Sweden, Finland, France and Belgium. In Europe, according to the DOPAS Project, the state-of-the-art researches and full-scale experiments are currently in progress.

a) Forsmark, Sweden — Olkiluoto, Finland: Copper corrosion

In Sweden, Svensk Kärnbränslehantering AB (SKB) (Swedish Nuclear Fuel and Waste Management Company) is tasked with managing Swedish nuclear and radioactive waste in a safe way. In the spring 2011, it applied for a license to build the Spent Fuel Repository in Forsmark in Östhammar and the encapsulation plant next to Clab in Oskarshamn. The regulatory authorities are currently considering the applications, and this will take several years. According to SKB's current timetables, its construction can start on the repository in the beginning of 2020 and it can be put into operation ten years thereafter. The reason why SKB selected Forsmark is that it is a site that offers good prospects for the long-term safety of the nuclear fuel repository. The rock is stable and homogenous, with few fractures and low water flows at depth (Svensk Kärnbränslehantering AB (SKB) 2015; Svensk Kärnbränslehantering AB (SKB) 2016). Sweden plans to pack waste in cast iron inserts in copper canisters and place them in holes bored in tunnel floors, 400–500 meters deep underground, surrounded by bentonite clay. Water is expected to make the bentonite clay expand so that it fills the cavities in the surrounding granite rock which would reduce groundwater movement (Beránek *et al*.: 4).

In Finland, Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum) (producers of nuclear power-generated electricity) , being fully responsible for their own nuclear waste management, have established Posiva Oy to manage the disposal of spent nuclear fuel produced in their power plants and associated research and development work. The construction of ONKALO, an underground research facility located in Olkiluoto, began in 2004. The facilities currently completed include personel and ventilation shafts, access tunnel, and technical rooms. ONKALO enables disposal research in actual conditions. The disposal activities are scheduled to begin in about 2020 (TVO, Fortum and Posiva). Finland adopted same way of disposal as Sweden (Beránek *et al*.: 4).

According to Beránek *et al*., the copper canisters were expected to survive corrosion for at least 100,000 years, but a recent research shows that they can fail in just 1,000 years or less. The build-up of hydrogen was produced as a result of corrosion. High temperatures from the canisters could also affect the clay buffer, while groundwater flows could bring the contaminants from any compromised containers into the biosphere. Furthermore, Nordic countries will face at least one Ice Age in the coming 100,000 years, entailing extremely violent earthquakes, penetration of permafrost to the disposal depth and below, potential intrusion of water and unpredictable changes in groundwater flows (Beránek *et al*.: 4).

b) Bure, France — Dessel, Belgium: uncertainties of clay as a natural barrier

In France, L'ANDRA (Agence nationale pour la gestion des déchets) was established by la loi du 30 décembre 1991 (the December 1991 Waste

Act) as a public body in charge of the long-term management of all radioactive waste. It benefits from 20 years' experience in the preparation of projects for the implementation of a repository, and demonstrates the feasibility of deep geological disposal for HL (high-level) and IL-LL (intermediate-level long-lived) waste and the safety of its solution. It also develops various construction and handling methods and processes, for which demonstrators and pilot models were built and tested. The performance of the disposal facility and the safety it provides are constantly reassessed via a series of methods developed and designed to integrate both the existing knowledge and system analysis. The Agency has developed a methodology for the phenomenological analysis of repository situation in order to describe and analyze any phenomenon likely to occur throughout the evolution of the repository, including over the long term (ANDRA; Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) 2016).

According to Beránek *et al*., France and Belgium are exploring clay as a natural barrier, while Sweden and Finland rely on man-made barriers to prevent leakage. The waste is to be contained in simple stainless steel canisters, which can corrode much faster than the Swedish copper ones. Hence, the French/Belgium concept relies on the natural clay formation to contain radioactivity. The crucial question is whether it can be guaranteed for hundreds of thousands of years that no cracks or channels will form in the clay layers, which would cause water to leak in and out again, poisoning nearby aquifers (Beránek *et al*.: 4).

c) DOPAS Project: Full Scale Demonstration of Plugs and Seals

The Full-Scale Demonstration of Plugs and Seals (DOPAS) Project was a European Commission (EC) programme of work jointly funded by the Euratom Seventh Framework Programme and European nuclear waste management organizations (WMOs). The DOPAS Project was undertaken in the period September 2012 – August 2016. Fourteen European WMOs, and research and consultancy institutions, from eight European countries participated in the DOPAS Project. The Project was coordinated by Posiva (Finland). A set of full-scale experiments, materials research projects, and performance assessment studies of plugs and seals for geological repositories were undertaken in the course of the Project. The DOPAS Project aimed to improve the industrial feasibility of full-scale plugs and seals, the measurement of their characteristics, the control of their behavior in repository conditions, and their performance with respect to safety objectives. It also contributes to the implementation of geological disposal across Europe (The Full-Scale Demonstration of Plugs and Seals (DOPAS) Project: 3–4).

IV. Uncertainty and Complexity of Underground

1. Substantial uncertainties of geologic repository

There are substantial uncertainties in geological repository, and no guarantee that radioactive nuclides will not be released into the environment in the future. Critical problems of 'uncertainty' and 'prediction' are raised and discussed at this moment.

Macfarlane *et al*. explain that there are substantial uncertainties in the geologic repository far into the future, and there is no way to guarantee that a repository will not release radionuclides into the environment at some point in the future. As for a suitable and safe geological repository for high-level nuclear waste, there are uncertainties, some of which can be reduced by additional work and research, and some are inherent to the extrapolation of the results of models over time and space. Can geologic and hydrologic processes be adequately understood in order to make predictions about radionuclide transport over geologic periods of time, especially once thermally hot radioactive waste has perturbed the natural system? (Macfarlane *et al*.: 3, 393–394).

They continue that a variety of factors make it difficult to predict repository behavior over geologic time. The environmental and chemical conditions of the repository evolve over time. This uncertainty arises from the difficulty of predicting interactions over tens to hundreds of thousands of years brought about by introducing a thermally and radioactively hot waste package into a complex geologic environment. Furthermore, knowledge about features, events, and processes is continually in flux. Over the long term, such factors may cause substantial divergence from the original prediction, and may cause unexpected results (Macfarlane *et al*.: 394–395).

2. Models in predictions and no solution in sight

Macfarlane *et al*. insist that models of natural systems over geologic periods of time ignore the realities of the complexity of open systems over large timescales. Complex Earth systems problems, such as understanding the behavior of a repository, require the cooperation and coordination of many different values and diverse perspectives. Models of Earth systems cannot be validated because they attempt to simulate open systems, which exchange matter and energy with their surroundings. In open systems, there is no way to know all the input parameters or processes, or to assess the boundary conditions that might affect the system. For geologic timescale, it is unfeasible to anticipate all input parameters for all processes that will occur over the modeled time period (Macfarlane *et al*.: 397–398).

They continue that investigations into past reactions among minerals and fluids in rocks show that ‘equilibrium’ may be rarely reached, and therefore it is almost impossible to decipher the detailed history of a rock, let alone predict reactions into the geologic future. Geology has not advanced far enough yet to expect that it can do this. The problem is that the agency does not know all the features, events, and processes that will affect a repository over geologic timescales (Macfarlane *et al*.: 397, 399–400). According to Alley *et al*., any chosen course will be an imperfect solution. The problem is just too big, too complex, and too long. As investigations proceed, surprising should be expected and this expectation acknowledged from the outset (Alley *et al*.: 325).

3. Global Challenges

There are a number of difficulties to be solved in deep disposal of highly radioactive waste. Among four phases (construction, operation, transient and long term), especially latter two are too difficult to solve.

Pusch *et al*. explain that the transient phase is the time span with the most complex processes and interactions during repository lifetime. The waste still produces heat and the heavily distorted hydraulic and mechanical states are trying to get back to equilibrium conditions. Oxygen trapped in the system causes chemical reactions and enhances microbial activity in the repository. Analysis of all these processes demonstrates their complexity and show the problems that are faced in investigating this phase in the laboratory. Major problems are associated with time — the thermal pulse will last for several hundreds to thousands of years and re-saturation processes are delayed because of the low hydraulic conductivity of argillaceous rock. Total equilibrium will not be reached before several tens to hundred thousands of years. The long-term behavior of a repository is the most important feature for evaluating the safety conditions and performance of a repository but no experiments in underground laboratories can be conducted to simulate this phase adequately. The evident critical issues in long-term performance prediction, beyond the problems that attend development of prediction models, are: (a) the lack of actual data from laboratory experiments and field studies, and (b) incomplete understanding of the kinetics of reactions both short-term and long-term abiotic and biotic reactions (Pusch *et al*.: 297–298).

As a result, based on the research by the Greens/EFA, we can conclude as follows.

Although there are at hand basic approaches to restrict the possible impacts of the hazard potential of the waste, but that there is no option available to completely eliminate the potential hazard. There are also problems to pass the responsibility for the radioactive waste onto succeeding generations and the high degree of uncertainty when forecasting social developments (social system, safety culture, economic attitude) for more than a few decades. The alleged safety is solely based on retrospectively collected empirical data and on restricted current knowledge of the respective point of time. An exact proof of long-time safety cannot be scientifically provided today and also not within the foreseeable future according to present knowledge (The Greens/EFA: 29–30).

In addition, according to Rana, a clear demonstration about safety aspects of nuclear waste management would help in gaining public and political confidence in any possible scheme of permanent nuclear waste disposal. A common public desire is retrievability of finally disposed waste in case repository fails to isolate wastes from the live environment. But desire of retrievability is in direct contradiction with the principle of final disposal and adds serious complexities to the problem (Rana).

V. Conclusions

Although there is an international consensus among nuclear experts that nuclear waste can be safely disposed of in a geologic repository, but after many decades of effort, we have only one geologic repository licensed to receive high-level waste. The technical issues and the accompanying uncertainties related to predicting the long-term behavior of a geologic repository are and will continue to be a challenge (Macfarlane *et al*.: 4).

On the system and modelling level, as central as natural systems are to the concept of geologic disposal, one must account for the inevitable and inherent 'uncertainties' in modeling the behavior of geologic systems, particularly over long time spans (many hundreds of thousands of years) and great distances (tens of kilometers). We must face the problem of high-level nuclear waste disposal and its long-term solutions. While geologic repositories may offer the best solution, we must endeavor to understand the 'complexity' and 'uncertainty' of the multidisciplinary science that is required to support this strategy (Macfarlane *et al*.: 5).

On the policy level, a public policy is complex subject. It requires the consideration of a number of technical as well as social parameters. Policy for the high level nuclear wastes disposal is a multifaceted issue and it requires to resolve a number of inter-related problems. In situations like disposal of HLW, comprehensive evaluation of policy success is extremely important as implications of a failure can be serious for the present and future life at earth. There are stringent complications in assessment of the involved risks due to unpredictability of future geophysical events over a long time scale of more than 100,000 years (Rana).

In short, there are a number of difficulties to be solved in deep underground repository/disposal of highly radioactive waste. Among four phases (construction, operation, transient and long term), especially latter two are too difficult to solve. The state-of-the-art researches and full-scale experiments are currently in progress. However, there are substantial uncertainties in geological repository/disposal, and no guarantee that radioactive nuclides will not be released into the environment in the future. Critical problems of 'complexity' and 'uncertainty' are raised, and will continue to be discussed. The problem is just too complex and too uncertain.

[Notes]

1) This article is a part of results of 'Research on Environmental- and Eco-crimes by Progress of Scientific Technologies and Development of Societies and Measures against Them 2015–2019' supported by the Grant-in-Aid of Scientific Research by Japanese Ministry of Education, Culture, Sports, Science and Technology.
2) This article is based on the three papers. The first was titled 'Radioactive Waste Disposal into Deep Underground: Green Criminological Consideration of 'Intergenerational Environmental Crime'' and presented at the 70th Annual Meeting of the American Society of Criminology, San Francisco, CA, U.S.A., November 19–22, 2014. The second was titled 'Legacy of Deep Underground Nuclear Waste: 'Treasure Box' or 'Pandora's Box' for the Present and Future Generations?' and presented at the 16th Annual Conference of the European Society of Criminology, Münster, Germany, September 21–24, 2016. The third was titled '100,000 Years Nuclear Waste Deep Underground Repository: Can we keep it safely without troubles and accidents for such a long time?' and presented at the 72nd Annual Meeting of the American Society of Criminology, New Orleans, LA, U.S.A., November 16–19, 2016.
3) In order to do this research I joined the DOPAS 2016 Seminar and visited three sites concerning geological disposal of high-level and low-level radioactive nuclear waste. The DOPAS 2016 Seminar took place in Turk, Finland 25th–26th May 2016, with a site visit to Olkiluoto on 27th May 2016. Over 110 participants representing WMO's, TSO's regulators, university persons *etc.* from around 50 organizations and 16 countries worldwide attended the Seminar. As on-the-spot investigations, I visited Äspö Hard Rock Laboratory of SKB, Oskarshmn, Sweden on 26th August 2016, Le Centre de Meuse/Haute-Marne (CMHM) de L'ANDRA on 30th August 2016, and Le Centre de Stockage de la Manche (CSM) de L'ANDRA on 1st September 2016. I am grateful to my colleagues Ms. Johanna Hansen (Posiva), Mr. Pär Grahm (SKB), and M. Richard Poisson (L'ANDRA).

[References]

Alley, W.M., and R. Alley (2013). *Too Hot to Touch: The Problem of High-Level Nuclear Waste*. Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi, Mexico City: Cambridge University Press.

Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) (2014). *L'Andra : Tous savoir sur la gestion des déchets radioactifs*. Paris : L'Andra.

Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) (2016). *L'Andra en Meuse/Haute-Marne*. Paris : L'Andra.

ANDRA. *Andra: The deep geological disposal concepts as developed by Andra*. (www.andra.fr)

Beránek, J., R. Teure, and A. Tumer (2010). *The deadly legacy of radioactive waste: Wasting our time with nuclear power*. Amsterdam: Greenpeace International.

European Commission (2004). *Geological Disposal of Radioactive Wastes Produced by Nuclear Power ... from concepts to implementation*. EUR 21224, Luxembourg: Office for Official Publications of the European Communities.

Federal Ministry of Economics and Technology (BMWi) (ed.) (2008). *Final Disposal of High-level Radioactive Waste in Germany — The Gorleben Repository Project*. Berlin: Federal Ministry of Economics and Technology (BMWi).

Gibney, E. (2015). Why Finland now leads the world in nuclear waste storage: Other nations hope to learn from approval of the world's first deep repository for spent nuclear fuel. *Nature, News*: Explainer: 02 December 2015. (http://www.nature.com/news/why-finland-now-leads-the-world-in-nuclear-waste-storage-1.18903)

Greenpeace (2009). *Nuclear power: a dangerous waste of time*. Amsterdam: Greenpeace International.

Irvine, M. (2011). *Nuclear Power: A Very Short Introduction*. Oxford: Oxford University Press.

Macfarlane, A.M., and R.C. Ewing (eds.) (2006). *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste*. Cambridge, Massachusetts and London, England: The MIT Press.

Nuclear Energy Agency/Radioactive Waste Management Committee (2013). *The Safety Case for Deep Geological Disposal of Radioactive Waste: 2013 State of the Art: Symposium Proceedings, 7–9 October 2013, Paris, France*. Organisation de Coopération et de Développement Économiques/ Organization for Economic Co-operation and Development.

Pusch, R., R. Young, and M. Nakano (2011). *High-level Radioactive Waste (HLW) Disposal: A Global Challenge*. Southampton: WIT Press.

Rana, M.A. (2012). High-Level Nuclear Wastes and the Environment: Analyses of Challenges and Engineering Strategies. *World Journal of Nuclear Science and Technology*, 2012, 2: 89–105.

Svensk Kärnbränslehantering AB (SKB) (2015). *Spent Fuel Repository*.

Svensk Kärnbränslehantering AB (SKB) (2016). *Äspö Hard Rock Laboratory: Annual Report 2015*. Stockholm: Svensk Kärnbränslehantering AB (SKB) (Swedish Nuclear Fuel and Waste Management Co.).

The Full-Scale Demonstration of Plugs and Seals (DOPAS) Project (2016). *DOPAS Final Report: The Full-Scale Demonstration of Plugs and Seals (DOPAS) 2012–2016*. DOPAS consortium and Posiva Oy.

The Greens/EFA in the European Parliament (2010). *Nuclear Waste Management in the European Union: Growing volumes and no solution*. Hanover: intac — Beratung・Konzepte・Gutachten zu Technik und Umwelt GmbH.

TVO, Fortum, and Posiva. *Geologic disposal of spent nuclear fuel in Olkiluoto*. (www.tvo.fi, www.fortum.co, and www.posiva.fi)

Wallace, H. (2010). *Rock Solid? A scientific review of geological disposal of high-level radioactive waste*. Derbyshire: GeneWatch UK.

Washington Reuters (2017). Yucca nuclear waste site back on table. *The Japan Times*, March 17: 4.

World Nuclear Association (2015). *Radioactive Waste Management*. (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx)