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RESEARCH ARTICLE

Challenges in communicating the future of high-level radioactive waste disposal: What future are we talking about?

Margarita Berg*[,1], Thomas Hassel[2]

Abstract • Of the three main time horizons specified in the German Repository Site Selection Act (the year 2031, 500 years after closure and one million years), the current public discourse largely neglects the "medium term". However, many important choices will have to be made during this period. The article discusses different conceptions of time that could help to improve public understanding of the time horizons for high-level radioactive waste disposal and the decisions that still lie ahead.

Herausforderungen in der Kommunikation über die Zukunft der Entsorgung hochradioaktiver Reststoffe: Über welche Zukunft sprechen wir?

Zusammenfassung • *Von den drei wesentlichen im Standortauswahlgesetz genannten zeitlichen Horizonten (das Jahr 2031, 500 Jahre nach Verschluss und eine Million Jahre) wird die mittlere Perspektive im gegenwärtigen öffentlichen Diskurs meist vernachlässigt. Allerdings werden in diesem Zeitraum viele wichtige Entscheidungen zu treffen sein. Der Artikel diskutiert unterschiedliche Zeitkonzepte, die dabei helfen könnten, das öffentliche Verständnis für die Zeithorizonte der Entsorgung hochradioaktiver Reststoffe sowie die noch anstehenden Entscheidungen zu verbessern.*

Keywords • *conceptions of time, future studies, high-level radioactive waste disposal, science and art*

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Introductory observations

Conceptions of time are highly relevant in addressing the subject of high-level radioactive waste disposal. However, talking about the future (and especially the far future) is extremely complex, mostly hypothetical and riddled with complications and imprecisions. This article aims to determine which time horizons of the future are currently addressed in the discourse on high-level radioactive waste disposal and where communication could be improved. These deliberations were originally inspired by the site selection process in Germany but will include insights from other countries where appropriate.

Following § 1 of the German Repository Site Selection Act[1], there are three different time horizons which might be broken down into smaller sections if appropriate. Germany aims to have located a site for final storage of high-level radioactive waste by 2031, the waste is supposed to be recoverable for 500 years after the repository is closed, and the selected site must be the safest one for isolating the high-level radioactive waste from the biosphere for one million years. The goal of 2031 was set due to the expiring licences for the interim storage facilities and the need to find a final storage site before public awareness of this problem dwindles after the end of nuclear power use in Germany. Recoverability was included in the German Repository Site Selection Act due to the problems in the Asse repository for low- and

1 Repository Site Selection Act of 05. 05. 2017 (BGBl. I p. 1074), as last amended by Article 1 of the Act of 07. 12. 2020 (BGBl. I p. 2760). Available online at https://www.gesetze-im-internet.de/standag_2017/StandAG.pdf (in German), last accessed on 17. 10. 2022.

medium-level radioactive waste. It is assumed that knowledge of the storage facility will not last for more than 500 years after closure. The containers should be recoverable during that period. The one million years of safe storage is based on calculations of half-life and uncritical radiation levels (Wollenteit 2019).

This broad range of future time horizons (from a few years to one million years) poses interesting challenges for the communication on high-level radioactive waste disposal. However, two of these time horizons are currently discussed almost exclusively. News reports following the interim report on suitable subareas (BGE 2020) referred amply to the year 2031 (which local politicians in particular often described as 'a long time from now') and to the one million years (albeit in a very abstract way). Similarly, the first 'Streitgespräch' (a disputation format established by the German National Citizens' Oversight Committee) discussed mainly the next decade in the conversation itself, with the one million years brought up afterwards by a question from the audience. In contrast to the generational approach in France (see below), there have been no specific attempts to facilitate public understanding of the different time horizons in Germany so far, with the exception of a short TV documentary (Geiger 2021).

It is perhaps understandable that discussions currently focus on the year 2031, because it is reasonably soon and deals with the initial step of finding a site, and on the period of one million years, probably due to its almost fantastical scope. However, the 'medium term' of 500 years after closure is mostly neglected in the public discourse even though many important decisions will still need to be made during this period (and during the preceding, temporally unspecified period of filling and operation of the repository), e.g. concerning criteria for potential recovery, marking of the site and knowledge transfer. Therefore, it needs to be made very clear that the issue will not end in 2031 and that the selection of the site is only one step in the overall process of final storage.

Statements about the future development of a system become possible by looking into the past. The farther one can look back and understand the developments up to the present, the farther one can predict further developments in the future. Following this approach, one is able to predict changes of the host rock for about one million years. This is possible because the geological processes that took place in these rocks have largely been understood at least for the past 250 million years of earth history. This approach cannot be directly transferred to technological developments. However, humans are capable of conceiving and producing buildings or technical systems with a long durability, so that from a technical point of view as well, we can find the best possible solutions for safe final disposal, at least for the near future. Such safety promises for functional endurance of the technical system become more difficult if it is not subject to maintenance, as is the case with the final storage containers after closure of the section. In order to be able to describe the future behaviour of this system, data is needed that depicts changes in properties over time, which can then be extrapolated into the future. The quality of the data and the temporally exact system development are extremely important to keep uncertainties and insecurities in the statements on future system behaviour as small as possible. It is precisely in the consideration of the 'medium term', which appears to be the most undefined and obscure in the public discourse, that the most accurate knowledge of the system's behaviour is required.

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Furthermore, since the period of one million years is established in the German Repository Site Selection Act (with similarly long-time horizons in the equivalent laws of other countries), "engaging with such radically long-term timespans is no longer just for the astrophysicists, theologians, palaeontologists, geologists, evolutionary biologists, or archaeologists among us. It has become our collective task" (Ialenti 2014, para. 10). What might be called 'time literacy' (here understood as the ability to conceive of and discuss vastly different time horizons individually and together, without losing sight of the medium term) is an important part of empowering civil society to handle this future task in a responsible way.

Therefore, one of the first challenges of communicating the future of high-level radioactive waste disposal is to find appropriate ways to actually address all time horizons of the future that are of relevance. The article will proceed, first, to discuss why it is so difficult to communicate the time horizon of 500 years after repository closure at all, and the one million years in a concrete, meaningful way. Second, suggestions for improving communication, e.g. focussing on generational approaches, will be made.

Different conceptions of time

Apart from the obvious fact that the next decade is a lot easier to conceive of than half a millennium, the difference between the A series of time (*Modalzeit* in German) and the B series of time (*Lagezeit* in German) might help to explain why it is easier to communicate about 2031 than about '500 years from x' (x being the time when the repository is closed). The distinction between A series and B series was initially proposed by McTaggart (1908). Events in the A series are ordered in terms of past, present and future; the B series orders events in terms of "earlier than" or "later than". While in the A series, the present or the starting point of a time sequence is a necessary reference point, events in the B series can be located e.g. with the help of a calendar or a clock. '2031' is a designation according to the B theory of time, while '500 years from x', following the A theory, makes sense only with reference to the exact starting point, which is not yet known and thus makes the period in question more difficult to talk about with certainty. Arguably, 'one million years from an unspecified starting point' is also a designation according to the A series. However, the very unusualness of this long-time horizon is probably reason enough to talk about it.

Our scope of action concerning the long-term goal of safe disposal is located only at the very beginning of the overall period of one million years. Delays in the storage and closure phases would not change the fact that safe containment of the radioactive material will subsequently have to be guaranteed for one million years. Despite this fact (and although we think we have a relatively good overview of the early stages of disposal after site selection), it is difficult for us to deal with these periods because they relate to the A theory and their starting points are still unknown.

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Concerning the subject of high-level radioactive waste disposal in particular, a number of other ways to distinguish between different time horizons have been proposed. For instance, the final report of the Preservation of Records, Knowledge and Memory across Generations Initiative (RK & M) distinguishes between three timeframes: "The 'short term' refers to the period of time that ends with repository closure. This period includes both the pre-operational and the operational phases of the repository. The 'medium term' refers to the period of time with oversight activities that would follow repository closure. The 'long term' refers to the period of time with no repository oversight" (RK & M Initiative 2019, p. 49). Closure and end of oversight are the decisive points in this delineation.

Another differentiation is proposed in an article on future generations in the context of high-level radioactive waste: "We define 'close future generations' as generations who still have memory of the waste and its location, and 'remote future generations' as generations who have lost its memory" (Kermisch 2016, p. 1799). Here, the line is drawn between memory and memory loss at some unspecified point in the future.

An article on the French deep geological repository project Cigéo describes the coexistence of two forms of time in separate spheres: the manageable historical time of generations above ground and the geological time of deep storage below ground (Poirot-Delpech and Raineau 2016, p. 1826). The authors suggest that the gap between these two time horizons is apparently bridged by the Observatoire pérenne de l'environnement (OPE). This permanent observatory is tasked with monitoring the environmental conditions around the storage site and preserving biological samples, which future generations may retrieve and analyse. "The OPE thus makes the environment of the future repository, that is, its 'surface world,' an extension of the underground world: it represents the continuity between the present and the future; what is transmitted from one generation to another, and thus constantly redefined" (ibid., p. 1822). This approach (and the ones discussed in the following paragraphs) might help to address the 500-year period in particular. However, even with the work of the OPE, the actors involved in Cigéo cannot picture the very long intermediate period between the transmission of information and memory about the repository from generation to generation and the containment of the nuclear waste over geological periods: "Between the two there appears to be a horizon that cannot be represented, a sort of representational blind spot" (ibid., p. 1826).

In order to empower citizens to preserve nuclear memories, Andra, the French agency for nuclear waste management, has established memory groups (*groupes mémoires*) at all sites where it currently maintains storage facilities or projects (Andra 2021, p. 11). These groups are formed by residents who – with the help of artists – consider ways to transmit the memory of the storage sites to future generations (ibid., p. 15).

In a similar way, albeit not related to nuclear waste disposal, Bjornerud (2018, p. 176) suggests that "intergenerational commons" such as oral history projects or community gardens are needed for people of all ages to gather and become aware of their intergenerational and intertemporal entanglements with other people and the world around them.

This intergenerational approach is shared by Icelandic writer Magnason who invites his daughter to imagine the time span covered by the lives of people with whom she can feel a personal emotional bond. With her great-grandmother who was born in 1924 and her own potential great-grandchild who might live until 2186, she might personally know and influence people who are alive over a period of more than 250 years (Magnason 2021, p. 22). From such an intergenerational point of view, the perspective of 500 years suddenly does not seem that long at all.

The plethora of suggested temporal differentiations, blind spots and unknown points in time discussed in this section does not make the situation any easier, but it can perhaps serve as an invitation to think about time horizons of nuclear waste disposal in a more encompassing and creative way. Incorporating the appreciation of such different conceptions and delineations of time (and the various tasks that have to be addressed at the different stages) into communication efforts might help to improve the public's awareness and understanding of the relevant time horizons of high-level radioactive waste disposal and the important choices one can still get involved in once a site has been found and a facility has been built.

Considering the future

Another interesting aspect is that thinking and writing about the future as a sphere that can be influenced by humans is a relatively recent concept. The initial way of talking about future events considered them as something that would happen to people regardless of their own choices. The future was seen as something that comes towards people. However, at the turn from the 17th to the 18th century, a new way of addressing the future developed. In this modern conception, it is the human being who moves through time and can actively shape the empty space of the future (Hölscher 2016, p. 42). Given this relatively recent change in our consideration of the future, it is perhaps not surprising that we struggle particularly to conceive of the far future and our potential role in it.

Furthermore, it must be noted that people normally think into the future within a limited topic (e.g. climate, technology or final storage) and do not incorporate many contingencies. Issues outside the respective area of consideration are usually excluded as improbable or not mentioned at all. For the discussion in the ongoing site selection process and the legal stipulations on the scope of final disposal (up to one million years), a certain stability of other thematic strands is therefore assumed. In order not to pull the rug out from under the feet of the future planning of final disposal, the social or political development (even though it may include drastic changes) must remain constant as a basic prerequisite to develop one's own thematic strand. However, the farther we think and plan into the future, the more drastically divergent the thematic strands can become. This is illustrated in Figure 1, and it can be deduced that it seems safer to focus on shorter periods of time in the overall system in order to maintain a realistic chance of success through the still-existing proximity of the thematic strands.

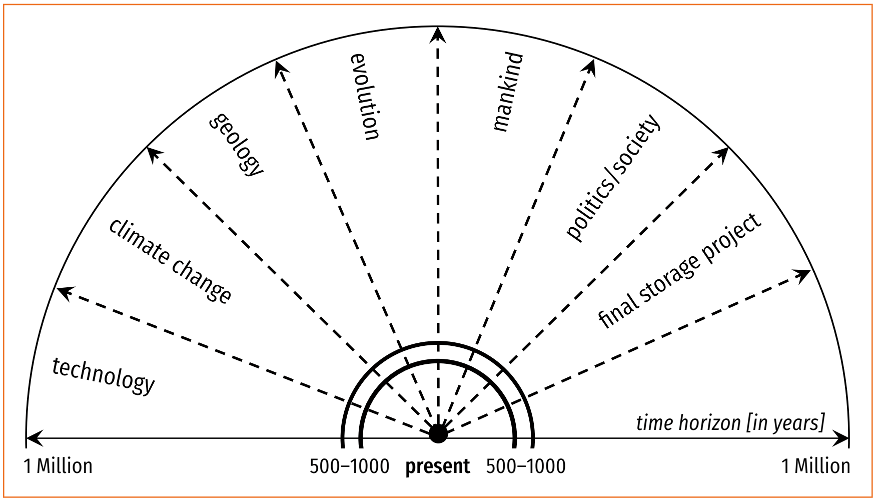

Fig. 1: Potential divergence of thematic strands from each other on the path to the future.
Source: authors' own compilation

Inspiration from other scientific disciplines and artistic approaches to time

In any case, one million years seems far removed from the years and decades of an individual human life or the centuries, maybe millennia of human societies. Even thinking hundreds of years into the future is unusual for political sciences, legal studies or engineering. However, for other disciplines, such as evolutionary biology, palaeontology or geology, considerations of thousands, millions or even billions of years are tools of the trade. Looking at the way geology in particular understands and represents time might provide some valuable insights for the communication of the time horizons of high-level radioactive waste disposal.

Geologist Marcia Bjornerud (2018, p. 163) describes her polytemporal way of looking at her surroundings: "I often feel I live not just in Wisconsin but in many Wisconsins. Even when I try not to, I can't help but sense the lingering influence of the many natural and human histories embedded in this landscape: the forests still recovering from nineteenth-century clear-cutting […]; contorted gneisses that are the surviving roots of Proterozoic mountains. The Ordovician is not a dim abstraction; I was there with students just the other day!" (The Proterozoic is a geological eon spanning the interval from 2.5 billion years to 541 million years ago, the Ordovician is a geological epoch lasting from 508 to 440 million years ago (ibid., p. 184)).

Another way to conceive the depth of time is through the collaboration of science and art. For instance, Hamburger Kunsthalle hosted an exhibition called 'Futura' in spring 2022. One exhibit, 'Perpetuum Mobile' by Nina Canell, showed a sack of cement next to a water basin agitated by ultrasonic waves. The water vapour from the basin caused the cement to harden slowly. According to the museum information, this display is supposed to trigger thinking about the irreversibility of certain processes. This installation resonated strongly with the topic of high-level radioactive waste disposal for two reasons. First, cement (as concrete) is one of the materials employed in the storage process of radioactive waste, and second, high-level radioactive waste is – at present – not fully recyclable (since only some of the materials involved can be reused and transmutation has not yet been successfully developed).

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In 2014, the US National Academy of Sciences dedicated an exhibition to the visualization of geological deep time (the depth of geological time compared to historical time). 15 artists were invited to consider the role art might play in comprehending such vast time horizons, which are way beyond the experience of individual humans and *Homo sapiens* as a species. The organizers suggested that "[u]nderstanding deep time lies, perhaps, in a combination of the rational and the intuitive" (Talasek 2014, p. 7).

In another attempt to grapple with deep time, artist Rachel Sussman has been researching and photographing living organisms older than 2,000 years, such as brain corals in the Caribbean or actinobacteria from Siberian soil samples which are at least 600,000 years old (Sussman 2014). These examples show that deep time is not only the domain of inanimate rocks but that certain living organisms might help to bridge the gap between historical time and geological time.

Another creative way of representing geological time is employed by the DeepTime Walk app (Deep Time Walk C.I.C. 2022). This app accompanies users on a 4.5 km walk through the history of the earth in a location of their choice (one metre equates to one million years) with an audio file combining scientific information and a poetic approach. Starting 4.5 billion years ago, what this Deep Time Walk makes particularly clear is the extent of time during which not very much happened, while events follow in quick succession during the last 500 metres. A similar approach is taken by representations of the history of the earth on a twelve-hour clock face. If twelve hours represent the 4.5 billion years of earth history, one second on the clock corresponds to 104,167 years and *Homo sapiens* has only been around for about three seconds (Brightmore 2022).

Instead of looking at the past, the rationale of the Deep Time Walk app and the clock face can also be used to look into the future of high-level radioactive waste disposal. Figure 2 shows a twelve-hour clock face in relation to the legal safety requirement of one million years. The figure makes very clear that our scope of action referring to the long-term goal is located only at the very beginning of the period. Even under conservative assumptions, e.g. through delays in the start of storage or in the closure phase, and with the addition of the 500-year recoverability period, we will not get beyond the first minute.

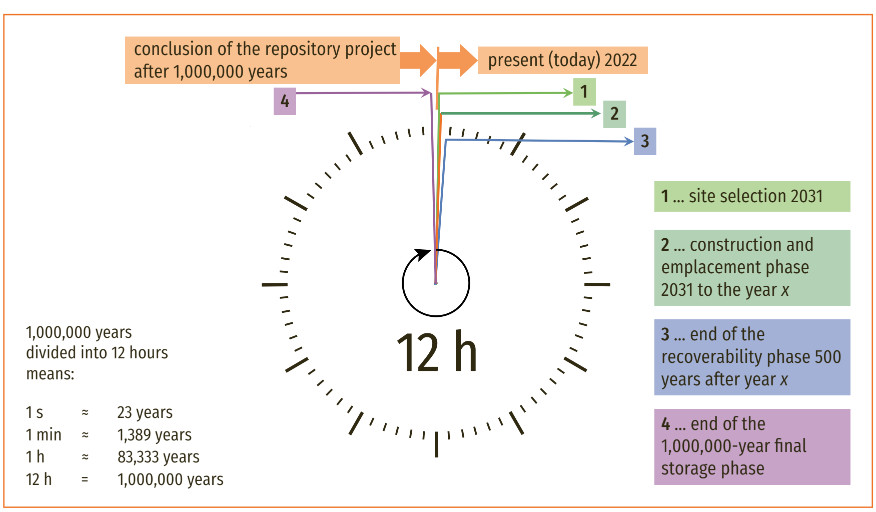

Fig. 2: Transfer of the time horizons of high-level radioactive waste disposal to a period of 12 hours.
Source: authors' own compilation

Conclusion: looking towards the future of high-level radioactive waste disposal

In the course of this article, we discussed two challenges for communicating the future of high-level radioactive waste disposal: incorporating the time horizon of 500 years after repository closure and representing one million years in a more meaningful way. For the first challenge, a number of solutions have been proposed or are already under way. Many of these suggestions focus on the transmission of knowledge from one generation to another, be it through the establishment of memory groups and the work of the OPE in France, Bjornerud's intergenerational commons or Magnason's thought-experiment. Concerning the second challenge, conceptualising one million years is likely to require creativity and leaps of imagination. Ultimately, Talasek's (2014, p. 7) proposition to combine "the rational and the intuitive" and the use of more creative visualizations might be a good place to start.

However, as long as people are not aware of the different conceptions and delineations of the time horizons involved in nuclear waste disposal, switches between them (which take place all the time and often unconsciously) can easily produce misunderstandings. 'Time literacy' is therefore essential to help people make meaningful decisions about the future.

By being aware that our genus *Homo* has only been present in the last 2.8 million years and that global climate changes were significant drivers of our evolution, the envisaged one million years of safety can be put into perspective with regard to their direct relevance for our actions today. Through the discovery of physical half-life, we have found a measure that enables us to calculate when the radioactive waste can be considered uncritical for humans in terms of its radiation. This led to the stipulation that the nuclear waste should remain isolated from the biosphere for one million years. Based on the laws of nature, this is a good way to justify the need for long-term final disposal of high-level radioactive waste.

Since we humans must subordinate ourselves to the laws of nature, without

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representing one ourselves, it is not possible to make valid predictions for events that lie so far in the future, because we often behave arbitrarily and unpredictably even in the near future. Assuming that through delays and complications, the repository might only be closed 150 years from now, the 500-year recoverability phase would extend to 650 years from now. Insofar as one could speak of stability at all, and insofar as these periods until repository closure and the end of the recoverability phase of a repository in Germany could function as a stable phase of human society, we should concentrate (in implementation and communication) on this medium term of nuclear waste disposal. We must then trust that the generations living at that time will be able to live with what we have left behind based on the best possible considerations.

Successful outcomes are likely achieved by proceeding step by step without being blinded or disillusioned by the far-away horizon of one million years or the fast-approaching year 2031. The main task – and already enough of a challenge – is therefore to plan and manage the next 650 years of high-level radioactive waste disposal in an appropriate way. After that point, the manageable historical time of generations can slowly be allowed to phase out into the geological time of deep storage, even though conceptually and imaginatively, it might never be possible to fully bridge the gap between these two time horizons.

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