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RESEARCH ARTICLE

No time to waste: Exploring timeprints of radioactive waste management options in Belgium

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Abstract • Following the work of Barbara Adam (1998) and Ulrike Felt (2016), we draw particular attention to 'timeprints' in the assessment and selection of radioactive waste management (RWM) options. Using the example of Belgium, we identify four different timeprints mobilized (un)consciously by stakeholders when assessing RWM options, namely trajectorism, promise economy, radioactive waste identity, and multi-situated timeprints. We show that each of these timeprints has a significant impact on the RWM option to be considered and actively determines future radioactive waste management pathways in the form of 'tacit governance'.

***Keine Zeit zu verlieren**: Untersuchung von ‚timeprints' für die Entsorgung radioaktiver Abfälle in Belgien*

Zusammenfassung • *In Anlehnung an die Arbeiten von Barbara Adam (1998) und Ulrike Felt (2016) legen wir besonderes Augenmerk auf die zeitlichen Abläufe bei der Bewertung und Auswahl von Optionen für die Entsorgung radioaktiver Abfälle (radioactive waste management – RWM). Anhand des Beispiels Belgien identifizieren wir vier verschiedene ‚timeprints', die von den Interessenvertretern bei der Bewertung von RWM-Optionen (un)bewusst eingesetzt werden, nämlich ‚trajectorism', wirtschaftliche Versprechen, Identität radioaktiver Abfälle und ‚multi-situated timeprints'. Wir zeigen auf, dass jede dieser ‚timeprints' einen wesentlichen Einfluss auf die in Betracht zu ziehenden RWM-Optionen hat und die zukünftigen Entsorgungswege für solche Abfälle in Form einer ‚tacit governance' aktiv mitbestimmt.*

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Introduction

Time orders human actions and decisions, and is strongly entangled with questions of knowledge and control (Felt 2016). Deeply embedded in individual and collective narratives that give "feelings of stability and belonging" (Felt 2016, p. 2), time is not a straightforward physical entity. It is constructed and reflects clashes and wins that have concrete consequences for both the world we live and wish to live in. Yet, the politics of time is "all-too-easily naturalized and turned in the deep structure of taken-for-granted, unquestioned assumptions" (Felt 2016 b, p. 2).

By bringing time to the forefront of radioactive waste management (RWM) assessment and selection in Belgium, the purpose of this article is twofold. First, based on key analytical assumptions (Adam 1998; Felt 2016), it aims to highlight the framing power of time in RWM. We suggest this can help to understand the lock-in and alternatives of future RWM programs, by highlighting how temporal prints (called 'timeprints') inform the scope and impact of our current choices and designs through time. This paper is an invitation to explore RWM timeprints in different nuclear contexts. The Belgian case aims to pave the way, and, together with the political decision on high-level waste (HLW) management that has been pending for decades, it allows for a broader perspective to examine all RWM options and the potential timeprints they create, without framing the debate exclusively on the nuclear community's preferred option (geological disposal).

Concretely, we ask two questions: (1) How do geological disposal and alternative RWM options carry on and engage a particular temporal regime? (2) How do these competing temporal regimes order RWM? We rely on data collected during two rounds of online structured questionnaire submitted to 580 pre-selected Belgian stakeholders in 2019 (Parotte and Fallon 2020)[1]. We asked them to compare eight RWM options that were still being debated: geological disposal, eternal surface storage, eternal subsurface storage, storage on the site where the waste is produced, storage on the site where some waste is already temporarily stored, storage on a site to be determined, advanced nuclear technologies such as transmutation, and waiting for future generations to find a better solution (ibid., p. 13). We analyzed the implicit and explicit temporal narratives in the reasoning of Belgian respondents by adopting an interpretivist position.

In what follows, section 1 details the conceptual tools and the current state of RWM in Belgium. Section 2 describes the four identified Belgian RWM timeprints in order to highlight how each responds to its own motivations, which significantly change the option(s) to be considered. In the discussion section, we stress that every timeprint actively performs the future pathway(s) to manage HLW as a form of 'tacit governance' (Felt and Fochler 2010), understood as an implicit form of pathway orientation that performs institutions and individuals' reactivity (Espeland and Sauder 2007). We highlight the uneven consequences and conflicts between those RWM timeprints and suggest how they could potentially (re)order the RWM program. We conclude that identifying timeprints of the chosen RWM option (geological disposal or any other alternative) in each management program and considering its consequences could be an element in understanding the implementation (in)actions and their justifications.

Material and methods

To assess the temporal regime of RWM options, we mobilize three theoretical concepts: timescapes, living futures, and timeprints. Each insists on particular issues concerning the politics of time (Felt 2016), namely the situated nature of time, the relative linear sequence of time, and the persistent prints that time produces.

First, decrypting the framing power of time involves analyzing time in its relations with a particular sociotechnical environment. Barbara Adam (1998) combines 'time' with 'scape' to stress the intertwined character of multiple coexisting forms of time and their embodiment in a specific and unique context. In short, the concept of 'timescapes' fights against the universal idea of time to point out the existence of constant and situated 'temporal inconsistencies' – the challenges and tensions resulting from this simultaneous presence of different forms of time (Felt 2016 b).

To assess the temporal regime of radioactive waste management options, we mobilize three theoretical concepts: timescapes, living futures, and timeprints.

Second, Adam and Groves (2007) introduced the concept of 'living future', understood as neither predetermined nor indeterminate but embedded in everyday knowledge practices, to question the linear sequence past – present – future of a timeline. Every action contends 'a not-yet future' and an 'already there'. In this sense, time periods are strongly entangled and fictively sequenced. If the 'not yet' seems to be inaccessible to matter of facts, futures are still currently 'lived' (Adam and Groves 2007).

Finally, every action we take leaves particular prints. Adam and Groves (2007) also proposed the term 'timeprint' to question how far the impact of our present way of life extends space and matter across time. Particular knowledge practices can lead to consumption or appropriation of successors' futures (Adam and Groves 2007): future-making inevitably involves future-taking.

A responsible and ethical approach to the future implies taking this interconnection into account – our actions and their effects extend into the future present of subsequent generations – rather than acting solely from a present future perspective (Adam 2010).

With the illustrative 'temporal landscape' we have chosen, Belgium in 2019, the following sections explain how the study of 'timeprints' highlights contrasting 'living futures'. Belgium has a long history of nuclear power (beginning in the 1920s with the exploitation of uranium mines in Katanga) and with seven pressurized water reactors, the country remains highly dependent on nuclear energy production (49.7 % in 2021). Belgium deals with a relatively large amount of radioactive waste. For low-level waste (LLW), the surface disposal option was validated by the Federal government in 2006 after a participatory process launched in 1998. The long-term management strategy for HLW remains the main challenge, although the National Research Center for Nuclear Energy formally launched the preliminary research and development program on geological dis-

1 This paper focuses on a particular sample of the data collected during the Delphi survey (i.e., the responses to the questions comparing eight RWM options) to which we apply a different theoretical framework. For a full overview of the scientific report, see Parotte and Fallon (2020).

posal in 1974 and built an underground laboratory in 1980 to study this option. Two rounds of national public consultations (in 2009–2010 and in 2020) were organized to discuss the HLW program. Both the long-term waste manager (ONDRAF) and the regulatory body agency (AFCN) acknowledge geological disposal as the reference option, but public consultations and some environmental associations regularly emphasize the need for open debates on RWM (e.g. on options, framing, and the participatory process). Since 2011, successive federal governments have delayed the adoption of national program for HLW until very recently. In April 2022, the Federal Government agreed to pursue R & D activities for deep disposal in Belgium, to explore developing shared disposal facilities with interested countries, and to organize a public debate (Council of Ministers 2022).

Most Belgian stakeholders consider a promising radioactive waste management option to be 'feasible' given a predictable and manageable time horizon.

The data on which this article is based were collected in a Delphi survey that ran from April to November 2019, in a context of no political decision on a HLW program. Here, we exclusively focus on the sample responses of Belgian stakeholders relating to the comparison of eight plausible RWM options (n = 193)[2]. By following the temporal narratives (European Commission 2007) – a tacit way of sharing meaning and constituting a broader sense of direction (making and taking the future) – mobilised by Belgian respondents to compare radioactive waste management options, we identify four timeprints.

Four RWM timeprints in Belgium

Trajectorism

'Trajectorism' narrates an alignment of past, present, and future in a single pathway through which progress and economic success are collectively conceived as achievable (Felt 2016). This timeprint is particularly mobilized to assess geological disposal and future advanced nuclear technology options (e.g. transmutation), two main RWM options that have been studied for decades by the Belgian nuclear scientific communities. More than half of the respondents consider that the option of geological disposal is worth considering. While few justify why, the accumulation of scientific knowledge and the maturity of the option seem important. Respondents argued, for instance, that geological disposal is the *'most realistic' and 'appropriate'* considering knowledge accumulation, *'the only long-term solution'* which is *'permanent'*, and the *'only immediately operational final solution'*. In the more distant future, most of them plan to invest in advanced nuclear technologies. The generation of (future) scientific knowledge also seems to be an essential justification for providing *'newer and better technologies like transmutation'* that *'will provide solutions that do not exist today'*, or that *'will eventually be an alternative to geological disposal, which must be accepted until then'*.

Conversely, other respondents implicitly reject trajectorism, considering that the arguments listed above are not sufficient. They combine RWM options to keep all options open as *'for now, no option offers sufficient safeguard'* or at least they consider them as *'not mutually exclusive'*. For instance, geological disposal and transmutation may be combined due to residual waste; surface or on-site storage *'keeps options open for new technologies'* and are *'temporary solutions before geological disposal is operational in optimal conditions.'*

Both geological disposal and advanced nuclear technologies tacitly support the idea of a 'linear innovation trajectory' (Felt 2016 b), assuming that there is a cumulative path from here to there, specifically from now to tomorrow (Appadurai 2012). Envisioning one (or two) steadily unfolding direction of change, this timeprint relies on a predictable and calculable future through the projection of stabilized and upcoming knowledge (Adam 2010). It already conceives the scientific and economic living futures of RWM options, and how to debate them. For instance, without strongly supporting geological disposal, some stakeholders present it as *'a default choice'*. Trajectorism is driven by a logic of increasing returns (Arthur 1994) and the imperative to remain economically competitive: It affects what most funding is spent on, how research will (not) engage in innovation projects and closes down alternative innovation pathways (Felt 2016). Most Belgian stakeholders are aware of the closing down and monotonic process of this timeprint, and sometimes resist it by refusing the singularity of one particular RWM option.

Promise economy

This timeprint focuses on how (and what) emerging technologies can be seen as promising solutions to RW problems. Such promises work as a speculative bubble (Beckert 2016): despite the future's inescapable uncertainty, their narratives must instill confidence to create a performative fiction that attracts financial, political, and technical resources (European Commission 2007).

2 As the questionnaire was completed anonymously, quotes from respondents will not be referenced but in italics and between inverted commas.

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Hence, most Belgian stakeholders consider a promising RWM option to be *'feasible'* given a predictable and manageable time horizon. Again, geological disposal remains a relevant option in a short temporal frame: *'The problem of any alternative to geological disposal is its lengthy development time.'* In this sense, 'trajectorism' and 'promise economy' are mutually reinforcing, as promises foster a state of necessity and urgency that oppose the freedom to imagine multiple future pathways (Joly 2015). The shared multinational RWM option, which several stakeholders are combining with the geological disposal option, seems to be considered a *'highly desirable'* promise, while acknowledging that it is still in the conditional stage.

Respondents did not mention eternal surface storage or on-site storage options as a promise economy timeprint, but they are clearly divided on the promising option of transmutation. Some of them consider transmutation as a *'serious alternative to geological disposal'* to reduce the lifespan of HLW or to serve as an *'intermediate stage'* before future generations find an *'even better solution'*. The others are not convinced of its *'real added value'* for contrasting reasons that lead to other past and current pathways. One group considers transmutation to be a *'utopia'* that is not mature enough and *'too costly to be implemented as a mass technology'*. Instead, this group suggests reconsidering the reprocessing option legally abandoned in 1993 in Belgium. Another group explicitly refuses 'promise economy', either by arguing that *'we cannot continue to use possible future technological developments as an excuse to delay the decision'* or by considering them as a deferral of responsibility. As they deem that *'no option is convincing for now'*, surface and on-site storage investment should be *'the priority […] set on improving the safety of the option used now as a temporary solution'*.

This timeprint leads to contrasting imaginaries of technological progress: a progressive one based on an optimistic consideration of the role of technology in the future (in favor of different RWM options such as shared geological disposal, transmutation, and reprocessing) versus a precautionary view highlighting a more skeptical position.

Radioactive waste identity

This timeprint explores how the different ways of naming a radioactive object affect which RWM options are preferred in the future. Some respondents emphasize that a distinction should be made between waste, which is considered as *'not retrievable'*, and spent fuel, which may offer *'potential energy resources.'* Others expect that the identity of the radioactive object may change over time, for example when future innovations and knowledge could turn *'old waste into a resource.'*

With regard to the transmutation option, some stakeholders specify that it is potentially a relevant option for future waste but that it *'does not constitute a solution for current vitrified waste'*. What about the final waste that will always remain? They sustain that the leftovers not included in the current classification will influence what to consider *'as a solution in itself.'* For still others, on-site storage and subsurface storage options offer the *'important advantage'* of ensuring easy retrievability of the waste and its future use. Stakeholders in favor of geological disposal face similar debates: some consider *'passive disposal'* as a prerequisite for geological disposal, which closes the debate on the identity of the radioactive object; others argue that it would be *'fair to let future generations judge the attractiveness of waste'*. Besides, the plural identities of radioactive objects in different countries call into question the operationalization of a multinational RWM option. One respondent reminds us that, for the time being, *'there is a diversity of waste to manage but a uniqueness of storage.'*

RWM options are redefined through both temporal and competing imaginaries, as the identity of the radioactive object requires fundamentally opposing strategies in different timescapes: It can be considered either as a resource (actual or potential) that is stored before being reused, or as a byproduct that must be permanently disposed of.

Multi-situated

The multi-situated timeprint addresses the mobility of RWM options and how temporal narratives relate to different sites.

Most Belgian stakeholders strongly support the possibility of a shared multinational option, which is seen as *'technically desirable'* and as a *'potential game changer'* capable of reaching beyond the country's official borders. Some argue that it is particularly relevant for small countries: *'It is irrational to imagine a country the size of Belgium or Luxembourg developing its own program for small waste quantities.'* But for many, it is also a *'utopia'* because of the ethical and legal challenges, such as the waste ownership and responsibility through time, cost sharing between countries and generations, different political and cultural sensitivities, and waste and regulatory management systems. They raise additional concerns about risks and unfair host site selection.

The situatedness (or lack thereof) is a concern for all other RWM options, but is not regularly mentioned. For instance, stakeholders did not distinguish between on-site storage options but expressed concerns about the safety and site exposure (e.g. radiation and external threats) associated with any *of* the on-site, eternal surface storage, and subsurface storage options.

Options are presented as detached from sites, even if any innovation trajectory develops out of a complex entanglement of situated histories (Felt 2016b). They are narrated as generic despite the very situated character of the timeprint.

Discussion

This paper highlighted the RWM timeprints in a particular timescape in Belgium in 2019, and the contrasting living futures in Belgian stakeholders' narratives of long term RWM. Stakeholders mobilize implicit and explicit temporal narratives to justify actions or favor one particular solution.

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Ordering, clashes, and silences of RWM timeprints in Belgium

In this first part of the discussion, we summarize our findings on the Belgian case and underline that a hierarchy is produced among RWM options. Our results support the first of Felt's (2016) arguments about the 'politics of time': The four identified timeprints tacitly order the RWM pathways by reinforcing some and overlooking others. With 'trajectorism', both scientific and economical 'living futures' of RWM options encourage funding for geological disposal and advanced nuclear technologies. The accumulation and promise of scientific knowledge are a central rationale for the future of RWM and are primarily aligned with past and current Belgian R & D projects. Interestingly, Belgian stakeholders (even if they were not all scientists) have assimilated that geological disposal has been presented as the only option (even as a default choice). The 'promise economy' timeprint, strongly associated with a manageable time frame, reinforces an alignment of past, current, and future knowledge to also support the already funded options: geological disposal and transmutation. The radioactive waste identity timeprint emphasizes that today's waste could be tomorrow's resource and that these current uncertainties are mobilized to revive past options (e.g. reprocessing), to avoid more challenging options (e.g. shared multinational option), or to provide retrievability components to any RWM option. Finally, the multi-situated timeprint emphasizes how situatedness (or lack thereof) both supports arguments to justify and challenge a shared multinational solution (primarily associated with the geological disposal option) while it is (un)consciously kept out of the way of current on-site options and alternatives.

Our analysis confirms the second of Felt's statements (2016b): the politics of time is about clashes, inconsistencies, and silences. Aware of the uneven consideration of RWM options, some stakeholders argue, explicitly or tacitly, for control over the framing power of timeprint, and several alternative temporal narratives are proposed. Options should be combined rather than seen as mutually exclusive (e.g. transmutation should be seen as complementary to geological disposal). Improving current surface and on-site storage should be explored, even as a temporary solution before other options are sufficiently mature. The retrievability element of the RWM option should be considered as the primary criterion for eternal storage or as an additional element for geological disposal. Even options presented as 'utopian' (e.g. shared multinational or not-yet-existing technological RWM options) are brought to the fore. We interpret these attempts as a *re*-action to the tacit governance that sustains the two well-known RWM options explored for decades in Belgium: geological disposal and the transmutation option.

Last, we believe that absence of data – the silences – is an outcome in itself. We emphasize how situatedness remains secondary in the RWM timescapes: The (future) multi-situated character of any option is mostly kept out of stakeholder discourses. It is interesting to note how stakeholders silence the operational temporalities – "a nexus of political-economic forces, scheduling and regulatory pressures" (Ialenti 2021, p. 3) – related to current on-site options. The so-called 'temporary' on-site storage options are the most permanent RWM option already built, on distributed sites of nuclearized countries. Similarly, favoring the shared multinational option can be interpreted as another silence to avoid the 'scape' of our nuclear timescapes. Managing our situated waste (where it is produced) to other sites disentangles time and scape.

How to maintain the responsible entanglement of our waste? And how to ensure the reliability of any political organization over such a long-term horizon?

Choreography of RWM timeprints

This second part of the discussion extends the reflection beyond our empirical findings and discusses how this hierarchy among RWM pathways might be challenged in the future. We draw on what Felt (2016b) called 'choreography' of RWM timeprints: they are connected, overlapping, and intersecting. While every timeprint defines engagement in the RWM program and the preferred option(s) differently, they collectively shape it at the same time with uneven connections. This has implications for RWM programs, and for how accountability is addressed.

In our case, the prevalence and combination of temporal timeprints (trajectorism with promise economy) create grooves so deep that they are difficult to break out of. Strongly linked with a vision of 'manageable time for operationalization', these associations of time components mark the 'living future' in an indelible way. RWM alternatives have little space to be considered at present. Thus, it prevents disruptive innovation from occurring, it silences other ways of thinking, and it imposes thinking *with* and *for* the option of geological disposal. It can support the illusion that no further public debate is needed once a technological path is chosen, that 'matters of facts' are apolitical and latent, and thus also matter when it comes to issues of responsibility (Felt 2016b).

However, we argue that some timeprints could potentially change the game in RWM program and stress the need to test this framework in different nuclear contexts. Indeed, we speculate that the identification of timeprints could prove to be a key

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issue in RWM for several countries. First, in countries where waste and spent fuel can still be considered a resource, the identity of radioactive waste coupled with 'promise economy' can produce contrasted living futures: with or without reprocessing (opens up the debate for nuclear energy futures) and with or without retrievability (under what conditions?). Fixing all radioactive objects in waste category organizes the right to forget or to remember and engages a clear "system of *rendez-vous* into legislation; a mutual engagement in time towards the 'fair, accurate and efficient' distribution of financial responsibilities" (Saraç-Lesavre 2020, p. 443). Second, the shared multinational option has attracted more attention in recent years. Indeed, whether to reduce costs, to share knowledge, or to cope with spatial and geological constraints, several countries are willing to jointly explore this option. Eight RW operators (of which Belgium is not part) have recently institutionalized their collaboration in the European Repository Development Organization.

Combined with the trajectorism timeprint, the multi-situated timeprint challenges the 'where' question of RWM programs and reminds us that even a shared multinational option always concentrates RW somewhere. On an ethical level, we can also see it as a way of thinking about our waste located elsewhere: Once the object is removed, the time of the waste can be evacuated. However, negotiations to organize waste mobility will be another challenge. Specifically, how to maintain the responsible entanglement of our waste, how to ensure the reliability of any political organization over such a long-term horizon, and how to cope with emerging geopolitical disorders and with national dissolutions. Being highly dependent on the relationship between countries and its evolution, this challenge raises an important question about the ability of sharing timeprint to invent a collective and legitimate tradition capable of linking multinational pasts and futures.

Conclusion

There is no time to waste. Time, especially in RWM, remains "an invisible infrastructure" (Felt 2016, p. 3) that can no longer be set aside for analysis of RWM options, programs, and actions. Exploring temporal narratives, the produced timeprints and their consequences on RWM program is one way to begin. From our analysis, we draw four systematic questions to assess the framing power of time on any national RWM program: (1) What are the temporal narratives behind the RWM option selected in your country? (2) What kind of timeprints are produced with the selection and implementation of RWM option? (3) Are these RW timeprints mutually exclusive or mutually reinforcing or weakening? (4) What timeprints do we share with other nuclearized countries and how does it open up or close down RWM futures?

The analysis of the framing power of time acts reminds us that our current (non)-actions on RWM are built on a situated temporal and sociotechnical legacy, while generating latent living futures and condemning others. Consideration of the politics of time and the entangled timeprints of RWM options may nuance the nuclear community's common assumption that geological disposal is the only long-term solution because 'there is no alternative'.

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