



# Facing the Unknown: A Sociological Analysis of Non-Knowledge, Time and Procedural Dilemmas in Germany's Site Selection for Nuclear Waste

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**Abstract.** The selection for a repository site for high-level radioactive waste has experienced significant procedural delays, extending timelines into the 22nd century. This article examines these delays through a sociological lens, focusing on the interplay between non-knowledge, procedural logic, and temporal dimensions. It argues how non-knowledge, understood as a socially constructed and temporally dynamic phenomenon, creates a structural dilemma within the site selection procedure. Central to this dilemma is a tension between the procedure's scientific legitimization, which demands continuous change in social configurations of knowledge and non-knowledge, and the need for procedural closure to enable binding decisions. Results of an empirical qualitative discourse analysis (SKAD) reveal conflicting temporalities of non-knowledge that potentially undermine the procedure's capacity to conclude. Building on this, the article highlights how ongoing deferral actively shapes and constrains the futures of subsequent generations, drawing on sociological theories of temporal responsibility and the concept of timeprints. It concludes that addressing these challenges requires repositioning non-knowledge within the procedure, making explicit political decisions about acceptable unknowns, and embracing temporal responsibility beyond risk assessments. The findings underscore that delays are not merely technical or managerial issues regarding unknowns but reflect deeper socio-structural conditions demanding political and legal attention.

## 1 Introduction

After the nuclear phase-out in 2023, Germany faces the challenge of how to manage high-level radioactive waste. The aim of the site selection procedure is to identify a repository site that guarantees “the best possible safety” for people and the environment over a time horizon of one million years. However, the procedure has experienced significant delays: in 2022, the expected date for a final decision was postponed from 2031 to the period between 2046 and 2068, due among other factors, to the complexity and scope of investigations (BGE, 2022b: 11). In 2024, a Process Analysis of the Site Selection Procedure (PaSta), a scientific report on procedure planning commissioned by the Federal Office for the Safety of Nuclear Waste Management (BASE), concluded that under “ideal conditions” and taking into account all technical and public consultation and participation processes, a final decision of site selection could realistically not be expected before 2074 (Krohn et al.,

2024). This implies that the whole procedure of nuclear waste management could extend into the twenty-second century (Ott, 2024: 55). According to the latest statements, it is now even considered to completely remove any temporal deadline from Site Selection Act.

35 The disposal of radioactive waste involves a wide range of uncertainties and unknowns (Eckhardt, 2024: 207). Any strategy for the long-term management of high-level radioactive waste is confronted with the necessity of planning and providing for exceptionally long-time horizons and poses an immense decision-making challenge (Grunwald, 2024: 13). This article addresses the relationship between non-knowledge, procedure, and time as a sociological problem. It presents non-knowledge as a socially constructed and temporally dynamic phenomenon. It argues, how conflicting temporalities of non-knowledge within the procedural logic constitute a particular challenge that contributes to the observed delays. The central argument is  
40 that one specific legitimating foundation of the German site selection procedure (“science based”) generates a structural contradiction with the procedure's own immanent logic with respect to the temporal dimension of non-knowledge. The article examines how this contradiction may undermine the procedure's capacity to reach closure. This leads to a discussion about political responsibilities regarding the procedural dilemma and time.

Accordingly, this article addresses two interconnected questions: First, how does the social phenomenon of non-knowledge  
45 contribute to the observed delays? Second, what does such a socio-structural analysis of non-knowledge and the procedural logic imply for the responsibilities the procedure bears towards future generations?

To address these questions, the article first outlines the current state of discussion on procedural delays and suggestions for acceleration (Section 2). It then focuses on non-knowledge as a social-theoretical phenomenon, conceptualizing it within the context of safety and risk and highlights its constitutional relevance regarding the Site Selection Procedure (Section 3). Non-  
50 knowledge is analyzed as a product of social construction (Section 4), with a focus on its role within the social functions of procedure and legitimation. It then draws on empirical findings from a discourse analysis on the temporal dimensions of non-knowledge within the Site Selection Procedure that show a structural dilemma (Section 5). Building on the empirical findings, this article discusses sociological concepts of temporal responsibility and emphasizes that time is not merely a metric of procedural progress but fundamental to the procedure's core commitments (Section 6). Consequently, specific implications of  
55 this sociological perspective are examined and summarized in Sections 7 and 8.

## **2. Procedural Delays: Diagnosis, Critique, and Discussion**

Concerns about the procedural delays have been expressed and discussed by political decision-makers, the public, and various parts of the scientific community. In a recent position paper, the Nuclear Waste Management Commission (ESK) concludes that, accounting for all remaining steps in the approval and construction process of a future repository, the transfer of  
60 radioactive waste from interim storage to a final repository cannot realistically be expected before the end of this century. It even may not occur until the beginning of the next. Some potential consequences of such an extended delay are set out in detail in the paper, discussing potential harms for future generations but also risks regarding increasingly unstable political conditions



today (ESK, 2024). Following this conclusion, ESK is “very concerned”: alongside the challenges posed by significantly extended interim storage, questions of intergenerational justice emerge, compounded by financial uncertainties (see also  
65 “wicked financing” in Brunnengräber and Sieveking, 2024), and serious risks of knowledge and competence loss. Particularly revealing for the purposes of this article is what the paper reports about the relationship between unknowns and time: managing unknowns and uncertainties in potential site regions can generate greater consultation needs. At the same time, it cannot be ruled out that unknowns are initially not captured and must be addressed retrospectively, or that their management is “deliberately left open and deferred” (Krohn et al., 2024). All of these factors increase, in the Commission's assessment, the  
70 likelihood of a procedural failure and stand in the way of a long-term safe disposal solution, which they describe as an “unacceptable” development (ESK, 2024).

Similar concerns are raised in the academic discourse. Ethical questions have been posed about the extent to which further delays can be justified towards younger generations or those not yet born, who have never consumed or benefited from nuclear power but may be increasingly burdened with the uncertain costs and responsibilities of nuclear waste disposal (cf. Ott, 2024).  
75 The guiding principle that the procedural time must remain subordinate to the goal of “best possible safety” is increasingly called into question. As Ott (2024) argues, the risks associated with prolonged interim storage, the potential loss of expertise, and growing financial uncertainty may intensify the longer the procedure continues, potentially undermining the “best possible safety” objective that justifies the delay.

The Federal Company for Radioactive Waste Disposal (BGE) addresses reasons for delays in its 2025 annual report. Among  
80 others, they identify two key factors: first, the time required is directly proportional to the number of siting regions to be examined, given limited resources. Second, the enormous workload, the complexity of the tasks, and the large number of actors involved (both internally and externally) generate considerable uncertainty about the time required for individual tasks within the procedure itself. Despite detailed procedural planning, unavoidable uncertainties and unknowns regarding actual time requirements do remain. In conclusion, fundamental adaptations to the site selection procedure are necessary if a site is to be  
85 identified by the middle of this century (BASE, 2025a: 4).

## **2.1 Discussion on Acceleration? Shifting From a Planning to a Sociological Problem**

In recent years, discussions and proposals regarding possible actions for acceleration and adaptations have intensified, for example at the recent “Forum Endlagersuche” (BASE, 2025a; BGE, 2025; BMUKN, 2025).

One main suggestion is to merge Phase II and Phase III of the site selection procedure. One part of this proposal focuses on  
90 the redefinition of investigation processes: “Führend bei den Erkundungen ist der zu erlangende Erkenntnisstand und nicht die Umsetzung zuvor festgelegter Erkundungsmaßnahmen” (BGE, 2025: 35). Rather than focusing on specifying a process of knowledge acquisition, it is proposed to define a state of knowledge on the basis of which siting regions would be compared. However, this redefinition would require a legislative amendment. Such an adaptation would make it possible to tie the

conclusion of the procedure to a defined and relevantly marked level of knowledge, rather than to a specific knowledge-  
95 acquisition process, as a condition for proceeding to a next step (ibid.).

A further suggestion under discussion is the introduction of a so-called “abschließende vorläufige Sicherheitsuntersuchung”  
(conclusive preliminary safety investigation, in the following avSU). This is conceived as a consolidation of the  
“weiterführende vSU” (extended preliminary safety investigation) and the “umfassende vSU” (comprehensive preliminary  
100 safety investigation) and would thus be a result of merging Phase II and Phase III of the procedure. The new form of safety  
investigation would evaluate the extent to which safe containment can be expected in shorter time, while still addressing both  
the procedural purpose (§1 StandAG) and the safety requirements (§26 StandAG). This suggestion is striking, particularly in  
a discussion about time and non-knowledge: First, the question arises whether and how the same quality of investigations and  
safety guarantees can be achieved in shorter time. At the same time, on a purely linguistic level, it is an interesting suggestion  
as it combines two temporally oriented attributes that appear intuitively contradictory. On the one hand, “preliminary” opens  
105 space for subsequent revision and adaptation, in line with the requirements of §27 StandAG, that the procedure must align  
with the current state of science and technology. On the other hand, “conclusive” directs attention towards a definitive,  
procedurally final outcome. This formulation expresses a tension that, as this article seeks to show, reflects a fundamental  
contradiction within the procedure itself.

Critiques of the procedural deferral and the discussion of concrete acceleration measures demonstrate that time is recognized  
110 as a relevant and urgent problem within the procedure. However, identifying and systematically understanding the reasons for  
these delays is necessary, to adequately assess potentials for acceleration. Following this, one central question is: what is  
causing the delay? Without doubt, the answers to this question are manifold. Actors involved in the procedure explicitly  
acknowledge unknowns as one main cause of deferral. Yet this problem is currently treated primarily as a planning issue, as  
something that can be better managed through improved processes of control or more thorough investigations. This article  
115 builds on these considerations but shifts the perspective: unknowns are examined not as a planning problem, but as a  
sociological phenomenon. They are contextualized in the context of the social function and structure of the site selection  
procedure. The aim is to explain the extent to which non-knowledge may be inherent to the procedure itself, and to identify  
where adaptations are necessary to address temporal problems in a meaningful way.

To emphasize the relevance of this approach requires to first establish a conceptual understanding of non-knowledge in the  
120 context of safety, risk and decision-making from a sociological perspective. The core problem of persistent unknowns is not  
specific to radioactive waste management but constitutes a fundamental challenge of modern societies that has been widely  
discussed as a sociological phenomenon. Non-knowledge, as the following section shows, offers a more precise and productive  
framework for understanding the problem than the concepts of uncertainty and risk.



### 3. Relevance of Non-Knowledge: Decisions in the Context of Uncertainty, Risks and Unknowns

125 One influential sociological framework for analysing decision-making in the context of safety, risk, and uncertainty is the  
systems theory developed by sociologist Niklas Luhmann. From a systems-theoretical perspective, certainty is seen as an  
“empty concept” that refers to the absence of specific events (Luhmann, 1991: 91). Social action relies on the distinction  
between certainty and uncertainty as the foundation for decision-making. However, in a contingent world, this certainty can  
only ever be a socially constructed fiction, valid at a particular moment and under specific conditions (Bonß, 1995: 91). What  
130 may initially seem counterintuitive from a natural science perspective constitutes a fundamental premise within sociology of  
knowledge and social-constructivist frameworks. This insight is directly applicable to the site selection process: the site  
selection presupposes a socially negotiated and accepted understanding of what is deemed “safe enough.” In this sense,  
certainty and uncertainty are social constructs.

135 A conception of certainty always fails to recognize that there are no risk-free decisions: under complex conditions, the  
consequences of decisions are always only partially predictable or controllable. For instance, threshold values for radiation  
doses, seismic activity, or temperatures are determined with a degree of uncertainty arising from the distinction between  
knowledge and non-knowledge (Böschchen and Wehling, 2004: 123). Luhmann therefore introduces the conceptual pair of risk  
and danger. The central issue is not certainty versus uncertainty, but the attribution of responsibility: who is accountable for  
140 potential negative outcomes? Dangers are independent of human decisions and uncontrollable, such as unforeseen natural  
disasters. In contrast, risks presuppose a conscious decision made under conditions of uncertainty. They arise from human  
actions and thus entail the assignment of responsibility (Luhmann, 1991; Bonß, 1995: 53). The distinction between decision-  
makers and those affected is fundamental to whether a situation is perceived as a risk or a danger (Luhmann, 1991: 31, 117).  
This differentiation is particularly significant for the site selection procedure: does the decision to select a site constitute a risk  
145 in Luhmann’s terms?

Modern societies are characterized by the systematic transformation of dangers into calculable risks (Beck, 1986). Science and  
technology serve as central reference points for efforts to exert control and assume responsibility. Political challenges are  
increasingly framed as issues of scientific knowledge (Bogner, 2021). However, cases such as the COVID-19 pandemic, the  
150 BSE crisis, and climate change demonstrate that uncertain risks with harmful effects persist and often unfold over extended  
timeframes. From a sociological perspective, unforeseen risk experiences are particularly likely in contexts characterized by  
layered, complex uncertainties and long-term horizons, where the clear distinction between risk and danger and attribution of  
responsibility becomes increasingly blurred (Kron, 2013: 57; Beck, 2007: 210; Gross, 2016: 393).

155 This is particularly relevant in the context of radioactive waste disposal, where exceptionally long time horizons must be  
considered. It can be argued, on a theoretical level, that even the sociological concept of risk becomes analytically insufficient

when addressing the challenges of human-environment-technology interactions across vast timescales (Luhmann, 1993: 146; Wehling 2014). When geological processes, societal developments, and technological changes are projected across timeframes that exceed human imagination, the notion of calculable risk loses its analytical precision. At this point, even the concepts of risk and danger reach its socio-analytical limits, because their distinction becomes blurry. Non-knowledge, understood as a phenomenon in its own right, becomes a more precise and productive analytical lens. For this reason, this article treats non-knowledge both as a distinct phenomenon and as a relevant analytical concept.

#### 4. Non-knowledge as a Socially Constructed and Dynamic Phenomenon

The unknown is not a homogeneous phenomenon. One popular framework for distinguishing between different types of unknowns is the so-called Rumsfeld matrix, which differentiates between “known unknowns” (things we are aware that we do not know) and “unknown unknowns” (things we do not know that we do not know). A similar typology had been proposed by Smithson (1989). While its intuitive and practically useful, such typologies overlook the social processes through which certain things come to be known, become unknown, or are marked as unknowable in the first place.

Since the 1970s, a growing interdisciplinary interest in unknowns has been observed in sociology, science and technology studies or environmental sociology, a development referred to as “ignorance explosion” (Smithson, 2015). Theoretical and empirical work has increasingly recognized the social relevance of unknowns and advanced the study of their social causes and consequences (ibid.). Especially approaches in the philosophy and sociology of science have highlighted the constitutive influence of social processes on the production of both knowledge and non-knowledge (Knorr-Cetina, 2003; Gross and McGoey, 2015; Kleinman and Suryanarayanan, 2012). The terms “non-knowledge” and “ignorance” are sometimes used interchangeably and sometimes distinguished from one another. Both attempt to describe the unknown but carry partly divergent implications (Gross 2007: 743).

Within the field of ignorance studies, the term “ignorance” functions as an umbrella term referring to the boundaries and limits of knowledge and the focus often lies on the strategic usage and effects of unknowns in processes of action and decision-making (ibid.; Paul, Vanderslott, and Gross, 2022; Frickel and Kinchy, 2015; Sonnberger et al., 2024). Particularly prominent in the German literature, the term “Nichtwissen” (non-knowledge) is used to emphasize that what is not known is not simply the absence or negation of knowledge, but a socially constituted phenomenon in its own right (Wehling, 2024). From this constructivist perspective, non-knowledge is not a fixed state, but something that is collectively negotiated within a society, a group, or among specific actors. It can be framed as a risk, a resource, or an opportunity depending on the context. At the same time, the construction process of non-knowledge is hegemonic and dynamic: who participates in defining it, and on what terms, changes and shapes which types of unknowns are recognized and which remain irrelevant or invisible (Wehling, 2006: 313).



This article therefore uses the term “non-knowledge”, reconstructing it as a spectrum encompassing multiple dimensions and allowing for an analytical distinction between different forms and modes of engagement with it. Non-knowledge can be approached along three analytical dimensions: the awareness of non-knowledge, its intentionality, and its temporal stability  
190 (Wehling, 2006: 117ff.). The dimension of temporal stability is particularly significant for the present analysis. It distinguishes between “not-yet-knowledge”, referring to unknowns considered resolvable through further research, and “constitutive non-knowledge”, referring to unknowns that cannot, even in principle, be overcome. How non-knowledge is understood in temporal terms thus reflects deeper assumptions about whether, and to what extent, unknowns can be controlled and ultimately converted into knowledge in the future (Wehling, 2006: 135). Assumptions about temporal stability of non-knowledge therefore also  
195 provide insight and are closely linked to prevailing conceptions regarding future and control.

Recognizing non-knowledge as an independent phenomenon implies that an increase in knowledge does not necessarily lead to a decrease in non-knowledge. Whenever researchers gain a new insight, they simultaneously open up new unknowns. „New knowledge always leads to new horizons of what is unknown“ (Gross and McGoey, 2015: 1). The acquisition of knowledge therefore does not lead to a successive reduction of non-knowledge (Wehling, 2006: 188).

200 Focusing on non-knowledge as a socially constituted phenomenon, both epistemological and sociological approaches have highlighted the role of materiality and social practices in this constitution process (Knorr-Cetina, 2003: 5; Latour, 2008). This is examined in the context of the site selection procedure in a study by Schürkmann (2024).

#### **4.1. Social and Material Constitution of Non-Knowledge**

Schürkmann (2024) has provided an empirical study focusing on the construction and reproduction of knowledge and non-  
205 knowledge in the context of the German site selection procedure. She examines both as consequences of scientific, legal, and political actions, practices, and discourses. Non-knowledge emerges as a product of socio-material and socio-technical relations, as something that’s produced in the interaction between human actors and non-human materialities.

In this context, Schürkmann analyses the properties and functions attributed to “non-human nature”, particularly geological formations. What is assumed to be known or unknown within the site selection procedure always implies a specific  
210 understanding of the relationship between society and its geological subsurface conditions. A key finding is that socially organized time and natural, geological time intersect within the procedure and must be brought into alignment (ibid. 131).

The anticipated long-term “natural behavior” of geological formations over extended time horizons becomes a resource actively drawn upon within the procedure to pursue the long-term objective of the repository project. The same applies to technology, which functions both as an extension of geographical and scientific investigation and as a constitutive part of the  
215 repository system as a future object. Schürkmann's study applies to the specific context of German radioactive waste management what has already been established in broader social-theoretical discussions: social, and in this case especially socio-material, construction is an integral component of how knowledge and non-knowledge are interpreted and given

meaning. This dynamic is further elaborated in Wulf's (2022) empirical analysis of the Swedish repository search. She demonstrates how non-knowledge is a constitutive element of future-making processes and how the condition of "Genug-  
220 Wissen" (sufficient knowledge), a temporal stabilization of knowledge and non-knowledge interpretations, functions as an enabling condition for decision-making.

As an initial finding on a social-theoretical level, it can be stated that what counts as relevant non-knowledge, as well as the temporal expectations associated with it, is the outcome of socio-material processes of construction. Whether non-knowledge appears as a condition that can be overcome or as an unavoidable one is not only both possible and significant, but is also  
225 shaped by social interactions, dynamics, and practices.

Building on this, the site selection procedure itself can be understood as part of the social construction of non-knowledge. Non-knowledge is not merely an external condition that the procedure must manage but is also actively shaped by the procedural dynamics themselves. In fact, this dynamic is reciprocal and it is therefore necessary to ask the question in both directions: How does non-knowledge shape the procedure, and how does the procedure shape the construction of non-knowledge?  
230 Answering this question empirically requires one further theoretical step, which the following section addresses: the social function of procedures and legitimation.

## 5. On the Social Function of Legitimation and Procedural Structure

In *Legitimation durch Verfahren* (1997), Niklas Luhmann argues that modern societies secure decisions not merely through truth or authority, but through formally regulated procedures. These procedures generate trust, channel conflict, and produce  
235 binding decisions despite complexity. Their purpose is to create legitimate, collectively binding outcomes.

Accordingly, the social function of a procedure is to produce a singular, binding decision within a complex environment by absorbing uncertainty through selective steps (Luhmann, 1997). To achieve this, the procedure must clearly distinguish between procedurally relevant and irrelevant information, serving as a mechanism for complexity reduction. Consequently, the procedure is temporally bounded and allows only limited adaptability to maintain this selective function. Otherwise,  
240 constant renegotiation of what is relevant would hinder linear progress and undermine prior decisions (ibid.).

Legitimation, in Luhmann's terms, means a generalized willingness to accept decisions whose specific content is not yet known, within certain tolerance limits. Applied to the repository procedure, this means that the public, affected parties, and political actors must be able to accept the final site decision before knowing which site will be chosen. This acceptance is only possible if the conditions governing the decision-making process are themselves seen as acceptable – these conditions form  
245 the procedure's legitimating foundation. One central legitimating foundation in the German site selection procedure is to be "science based". BASE defines this as scientific criteria guiding the selection of a potential repository site and decisions grounded in scientific principles (BASE 2025b). Decisions must be supported by scientific evidence and data. A clear



distinction is made between “wissenschaftlich” (scientific), referring to how knowledge is produced, and “wissenschaftsbasiert” (science-based), referring to the content and foundation of a decision (ibid.). Alongside this, the  
250 procedure draws on additional legitimating principles: participation, transparency, self-reflection, and learning. These principles directly address Germany’s history of nuclear waste management, which had been characterized by non-transparent decision-making and top-down governance (Grunwald, 2022: 18).

The procedure and its legitimating foundations operate as forms of social practice and institutional structure that actively participate in the social construction of non-knowledge. Given the scientific basis as a legitimating foundation, non-knowledge  
255 that can be scientifically identified, documented, and justified tends to be recognized. In contrast, non-knowledge that resists scientific operationalization risks remaining invisible. Conversely, any new scientific argument introducing uncertainty is deemed procedurally relevant and must be addressed.

From this theoretical perspective, this creates potential for a structural tension in the procedure’s design. According to Luhmann’s systems theory, a social system, such as a legally regulated procedure, reproduces itself by maintaining a stable  
260 boundary between what belongs to the system and what does not. In the case of the site selection procedure, the procedure's legitimating foundation (scientific basis) threatens the stability of this boundary: it keeps the system open to new inputs where closure is required. This is not a problem that can be resolved through better management or more careful planning but is inscribed in the procedure’s logic, creating potential for structural contradiction.

The following section examines this tension empirically. It presents findings from a discourse analysis of the site selection  
265 procedure, reconstructing different dimensions of non-knowledge. The results discussed below offer a selective insight into the qualitative analysis and focus especially on the temporal dimension of non-knowledge. The empirical findings link to the theoretical considerations on procedural structure and the foundations of legitimation.

### **5.1. Structural Dilemma: Temporal Dimension of Non-Knowledge in the Site Selection Procedure**

The following section presents and discusses findings from an empirical discourse analysis. The method used, the Sociology  
270 of Knowledge Approach to Discourse (SKAD), builds on a social constructivist framework and analyses the social construction of non-knowledge as a discursive phenomenon.

#### **5.1.1. SKAD: Method and Theoretical Framework**

Drawing on the theoretical frameworks of Peter L. Berger and Thomas Luckmann (1990) and Michel Foucault's discourse theory (1991), the sociology of knowledge approach to discourse (SKAD) assumes that knowledge configurations and  
275 knowledge orders are socially constructed and institutionalized (Keller, 2010). As both an empirical method and a theoretical perspective, SKAD provides a framework for examining how discourses shape social norms and collective constructions of reality. Rooted in the sociology of knowledge, SKAD focuses on the interactions between knowledge, power, and social

practices. Discourses are understood as historically situated and context-dependent practices that actively constitute the objects they address. The analysis examines social practices, institutions, infrastructures, and actors (cf. Keller, 2010).

280 The study focused on textual materials concerning the legal and political implementation of the site selection procedure. Documents were selected through theoretical sampling (Strauss and Corbin, 1996) and included legal texts, position papers, expert reports, and technical debates by BASE, BGE, the Nuclear Waste Management Commission, the Federal Institute for Geosciences and Natural Resources, and the National Citizens' Oversight Committee.

The reconstructions presented result from an iterative analytical process that links empirical material with theoretical  
285 considerations through SKAD's qualitative-interpretive procedures. The method of analysis follows the principles of grounded theory (Strauss and Corbin, 1996). This approach enabled the reconstruction of relevant meaning-making patterns and discursive framings of non-knowledge within the procedure. Analytically, the study builds on Wehling's dimensions of non-knowledge (2006), which were extended during the analysis to include dimensions specifically identified as relevant within the procedure (for further detail, see Hirn, 2025). The following section focuses on the temporal dimension of non-knowledge.

### 290 **5.1.2. Empirical Findings: Conflicting Temporalities of Non-Knowledge**

The procedure reveals two contradictory understandings of the temporal dimension of non-knowledge. On one hand, non-knowledge is treated as stable over long periods. On the other, it is seen as unstable and subject to continuous change. Both understandings coexist within the procedure, creating conflict regarding binding decisions.

The procedural logic presupposes the finality of both the decision and non-knowledge itself, as already implicit in the very  
295 concept of a "final repository". As previously shown, legally binding procedures must progressively restrict future options in order to reach a conclusive decision (Luhmann, 1997: 47). This requires stable interpretations of what is interpreted as known and unknown. Wulf (2022: 7) captures this as a condition called "Genug-Wissen": a temporal stabilization of knowledge and non-knowledge interpretations that allows for a distinction between relevant and non-relevant non-knowledge, thereby enabling decision-making. A temporal stability of non-knowledge is reflected both in the intent of the procedure and in  
300 observable statements and actions. In the course of safety investigations, non-knowledge is often described as a state of lacking knowledge that can be resolved through the acquisition of additional knowledge. This requirement, however, stands in structural tension with one of the procedure's central source of legitimation: being "science-based." The preliminary safety analysis must reflect the current state of science and technology (§27 (2) StandAG). It implies that barriers will fulfill their function over the intended timeframe if this is predicted according to the current state of science and technology (BGE, 2022a:  
305 40). Science, however, is an ongoing process in which methods, standards, and findings continuously evolve. Against the backdrop of the procedure's long time horizons, this raises a fundamental question of which state of science and technology is "current" (cf. Hirn 2025).

### **Scientific Standards in Motion: The Case of Seismic Activity**



310 This tension is well illustrated by the discussion about the exclusion criterion of seismic activity. Following the publication of  
the “Zwischenbericht Teilgebiete” (Interim Report) and the first exclusion of siting regions, the scientific standard changed.  
A revised norm for measuring seismic activity lead to updated data and calculation methods that required a reassessment of  
seismic activity (Kaiser and Spies, 2020). Although applying the revised norm ultimately produced no changes to the inclusion  
or exclusion of potential sites, the update required an additional review and additional time (BGE, 2024b). Similar dynamics  
have been observed in debates over permissible temperature limits within the repository system (BGE, 2024a; Hirn, 2025).

315 Such cases illustrate one structural dilemma: changes in scientific standards require previously completed procedural steps to  
be reopened, not as a result of political interference, but through the normal operation of the scientific system on which the  
procedure bases its legitimacy. The linear, temporally bounded procedural logic gets disrupted. The procedure's aim of a final,  
binding decision and its legitimating foundation are conflicting regarding their respective understandings of the temporal  
dimension of non-knowledge. The result is a structural dilemma in which two defining commitments of the procedure  
320 undermine each other's fulfilment.

### **Structural Dilemma and Consequences**

Accordingly, the empirical analysis presents a second finding. The observed delays lend empirical weight to the argument  
developed here. The dominant assumption within the procedure appears to be that non-knowledge gradually dissolves as  
scientific knowledge advances, and that unknowns can, in principle, be reduced to a level at which a decision becomes  
325 acceptable. This assumption, however, does not adequately capture the contingent nature of non-knowledge. This dilemma  
risks becoming a structural obstacle to procedural closure. The tolerance thresholds described by Luhmann are rendered diffuse  
by the legitimating principle of scientific basis. This does not mean that the linear procedure is bound to fail, but it does require  
continuous and explicit judgments about what degree or what kind of unknowns are acceptable. Crucially, a temporal  
stabilization or boundary of non-knowledge does not emerge automatically from the procedure itself. In Luhmann's terms, this  
330 puts the procedure at risk of being unable to fulfill its primary function: the production of a decision within a binding  
framework.

In this context, questioning the acceptance of unknowns points in exactly the right direction, yet remains unanswered (cf.  
Eckhardt, 2024). This does not necessarily pose an insurmountable problem, and two ways of addressing it can be identified.  
The temporal stabilization of non-knowledge could either be maintained by strictly following the procedural timeline. Or it  
335 could be a (political) decision. One that clearly states which unknowns are considered acceptable and proceeds on that basis.  
In practice, however, it is the procedural timeline that has repeatedly been disrupted, revealing a pattern that is meaningful  
rather than accidental, following the perspective developed here.

This could also be interpreted as a consequence of opening the procedure to multiple actor groups. Actors from politics,  
science, and the public take on different roles and actively shape how the procedure unfolds. The participatory structure of the  
340 procedure further complicates questions of accountability. Given the complexity of finding a repository for nuclear waste, such



openness is broadly justified and reflects current approaches that emphasize institutional innovation, participatory settings, and collective knowledge production (Böschen, 2010; Paul and Haddad, 2019). At the same time, it generates precisely the kind of diffuse accountability that makes it difficult to determine who is responsible for deciding when enough is known. Nevertheless, the absence of a clear answer places considerable responsibility on decision-makers, whoever they may be at  
345 any given stage of the procedure.

## 6. From Procedural to Temporal Dilemma

The empirical analysis has shown that the temporal dimension of non-knowledge creates a structural dilemma within the site selection procedure – one that could manifest in persistent delays and can hardly be resolved through improved planning or more extensive scientific investigation alone. This points to a further, consequential question that must be addressed as a final  
350 implication of the arguments developed here: with respect to time, the central issue is whether the procedure’s objectives and its broader responsibilities are better served by reaching an imperfect decision sooner or by postponing a decision even further. The question of how non-knowledge is handled is therefore not only a procedural question: it concerns the relationship between present decisions and future possibilities.

This temporal dimension has so far remained implicit in the analysis. The following section makes it explicit. Drawing on  
355 sociological concepts of temporal responsibility, it argues that the way non-knowledge is framed and managed within the procedure actively shapes the futures available to subsequent generations and that a continued procedural extension constitutes an appropriation of those futures. The concept of “timeprints”, developed by Adam and Groves (2007), provides the analytical tools to make this dynamic visible.

### 6.1. Time as an Infrastructure of Disposal

360 In recent years, the future has become a significant topic in the social sciences, particularly in relation to political decision-making processes and energy issues (Beckert, 2016; Granjou, Walker, and Salazar, 2017: 10; Suckert, 2022). Time structures human action and is closely bound up with questions of knowledge, non-knowledge and control (Felt, 2016: 3).

The concept of timeprints is the temporal equivalent to the ecological footprint. Whereas the ecological footprint compares the spatial and material resource consumption of human activities with the Earth's regenerative capacity, timeprints draw attention  
365 to the temporal reach of actions and decisions. It highlights how certain knowledge practices – and, as this article aims to argue, certain non-knowledge practices in particular – contribute to the consumption of future potentials and thereby the appropriation of the futures of subsequent generations. In doing so, it draws attention to the fact that the human capacity to shape the future already surpasses its ability to extend care and responsibility in proportion to the long-term consequences of its actions (Adam and Groves, 2007, 2011).



370 Timeprints have already been investigated empirically in the context of radioactive waste management. Frenay and Parotte (2022) analysed the Belgian case, examining how different timeprints are mobilised, consciously or unconsciously, by actors when evaluating disposal options. Their central finding is that each of these timeprints significantly shape which disposal options are considered, thereby actively steering future waste management pathways through what they describe as “tacit governance” (Frenay and Parotte, 2022; Felt and Fochler, 2010). They argue that certain timeprints have the potential to  
375 fundamentally change the trajectory of radioactive waste management. Accordingly, a comparative study of the German case would provide valuable insights. Even without such a study, it can be established that the concept of timeprints underscores the urgency of recognizing the temporal reach of actions and, explicitly, of inactions. It demonstrates how certain non-knowledge practices can contribute to the consumption of future potentials and thereby actively constrain the possibilities available to future generations.

380 Also, different visions of the future are actively shaped through financial investments, political decisions, and socio-material practices (Adam and Groves, 2011; Hajer and Pelzer, 2018; Andersson and Keizer, 2014; Beckert, 2016). The future is consequently contested by present material and social dynamics, thereby making some futures more probable than others. These considerations also link to Schürkmann's study and empirical findings on the relationality of knowledge and non-knowledge to socio-material and socio-technical practices. The way in which the future is anticipated thus actively influences  
385 actual future developments (Andersson and Keizer, 2014; Oomen, Hoffman, and Hajer, 2021). It becomes likely that different conceptions of the future will come into conflict, which is likely to occur in the participatory repository procedure, where different actors meet.

Accordingly, a third finding becomes apparent through a temporal lens. The dynamic reveals how present actions and future consequences are mutually constitutive, showing that deferring the site selection decision is a form of future-making through  
390 inaction. This is particularly evident in the context of radioactive waste disposal, where planning must extend across time horizons of thousands to millions of years, where time constitutes an “invisible infrastructure” that cannot be overlooked in the analysis of options, programs, and policies (Felt, 2016: 3). The temporal reach of responsibility extends far beyond what risk calculations or safety analyses can capture. The concept of timeprints offers an approach to make this temporal dimension analytically accessible (Adam and Groves, 2007: 203). Applying this to the site selection procedure, the concept shows how  
395 every decision to postpone leaves a timeprint. It consumes the time and the options available to future generations.

## 7. Result: Implications for the Procedure

This article has argued that the delays in the German site selection procedure cannot be attributed only to planning failures, resource constraints, or the inherent complexity of the task. From a sociological perspective, they are at least partly structurally produced. The analysis has unfolded this problem on multiple levels: social-theoretically and empirically as a dilemma in the  
400 temporal dimension of non-knowledge within the procedure, and conceptually as a question of temporal responsibility.



The proposals regarding acceleration indicate that the problem is recognised within the procedure, yet remains unresolved. This article has sought to contribute to a more comprehensive understanding of its social and structural roots, as such understanding is a necessary precondition for developing meaningful solutions. Three implications follow from the analysis.

***Implication 1: Non-Knowledge Must Be Repositioned within the Procedure.***

405 The first fundamental implication concerns how non-knowledge is understood and treated within the procedure itself. While they are indispensable, the categories of safety and risk are insufficient for capturing the full analytical complexity of the decision-making situation. As the social theoretical analysis has shown, non-knowledge is not only a temporary deficit to be resolved through further research, but a constitutive feature of the decision itself. Conceptions of certainty and calculable risks presuppose a degree of predictability that, given the timescales involved in nuclear waste disposal, is scarcely attainable.

410 The central analytical shift this article proposes is to handle non-knowledge not as a planning problem but an irreducible element of the decision-making process. This has concrete procedural consequences. Non-knowledge must be explicitly integrated into evaluative processes, not as a residual category to be managed or eliminated before decisions can be made, but as a substantive input that shapes what decisions are possible and what responsibilities they entail. As Wulf (2022: 160) states: a right way of handling non-knowledge cannot be known. To this I would add: nor can it be derived from the existing  
415 procedural structure alone. It must be politically decided and responsibly owned. Treating non-knowledge responsibly, in this sense, does not mean deferring decisions until uncertainty dissolves. It means deciding in full awareness of the fact that unknowns remain and finding ways to build acceptance for decisions made under conditions of irreducible non-knowledge (cf. Gross, 2016). This is an issue that could be considered in current discussions of acceleration and in the course of a revision of the Site Selection Act.

420 ***Implication 2: Political Decision on Acceptance of Non-Knowledge.***

The second implication unfolds regarding the structural dilemma in the procedure and conflict regarding temporalities of non-knowledge. As the analysis has shown, the procedure currently lacks a clear and institutionally binding boundary between relevant and no longer relevant non-knowledge. This is a distinction the procedure has so far been unable to generate from within itself, allowing the structural loophole identified in Section 5 to persist.

425 Therefore, the suggestion of anchoring the procedure to a defined state of knowledge, rather than to an open-ended process of knowledge acquisition, is a step in the right direction. It holds the promise of establishing what Wulf (2022) describes as a condition of “Genug-Wissen”: a temporal stabilisation of non-knowledge interpretations that enables decision-making, rather than leaving that stabilisation to the contingencies of ongoing scientific processes. The proposal of a “conclusive preliminary safety investigation” (avSU), as an integrated outcome of merging Phase II and Phase III, points in the same direction. Whether  
430 intentionally or not, this formulation reflects precisely the dilemma this article has identified. The attempt to satisfy both decisional finality and scientific openness. “Conclusive” points towards the finality of a decision, while “preliminary”



preserves the possibility of revision, in line with §27 StandAG. Rather than treating this as a terminological inconsistency to be resolved, this article suggests reading it as a productive formulation: it names, within the legal framework itself, the tension between finality and revisability that the procedure must navigate. Both proposals, the defined state of knowledge and the avSU, share a common logic: they attempt to create a boundary between what is and what is no longer procedurally relevant, and thereby to restore the procedure's capacity to decide.

However, neither can be implemented through scientific criteria alone. Defining what state of knowledge is sufficient, or what kinds of unknowns the avSU may accept, is itself a political decision. One that requires a collective, openly justified agreement about which unknowns are acceptable and which are not. The tension between finality and revisability must be understood not only as a procedural outcome, but as a mandate for active political decision-making and the explicit assumption of responsibility. The avSU could serve as the institutional momentum to formally raise, debate and decide questions of acceptable non-knowledge through a structured deliberative process involving scientific experts, regulatory bodies, political actors, and the public. Three questions must therefore be addressed more explicitly within the procedure: who has the authority to define the required state of knowledge? On what grounds can that definition be challenged or revised? And what happens when new scientific findings emerge after the threshold has been reached? These questions are not absent from the procedure, but the way they are currently answered doesn't resolve the structural dilemma. Greater analytical precision and explicit political justification in addressing them is therefore not merely desirable, but necessary to prevent the reform proposals from reproducing the very loophole they are designed to close. This leads to a further and more fundamental question that the analysis cannot resolve but must name: how can a political institution legitimately decide, in a binding way, on what counts as acceptable non-knowledge? This is not only a procedural question but a democratic one and it points to a broader challenge that any serious engagement with the structural dilemma identified here will ultimately need to be confronted.

### ***Implication 3: Temporal Responsibility and the Limits of Deferral.***

The third implication concerns the relationship between the management of non-knowledge and the procedure's broader temporal responsibilities. The argument developed in this article suggests that non-knowledge must be taken seriously not in the sense that more knowledge is needed before decisions can be made, but in the sense that the way non-knowledge is handled has direct consequences for the procedure's ability to fulfil its own stated goals: precaution, harm prevention, and intergenerational justice (§1 (2) StandAG). Every further delay leaves a temporal imprint that constrains the options available to future generations and potentially burdens them with consequences they neither caused nor had any say in shaping. In light of the concept of timeprints, continued deferral is not a neutral act of caution, it is an active appropriation of futures that belong to others.

The central question is therefore not only whether an imperfect decision would be worse than a delayed one, but whether the continued deferral of a decision, in the face of structurally irreducible non-knowledge, can still be regarded as responsible at all.



This also means confronting an uncomfortable but necessary truth: non-knowledge can function as a legitimate justification  
465 for avoiding decisions, whether intentionally and consciously or not. As the procedure lacks an institutionally anchored  
mechanism for definitively marking non-knowledge as no longer procedurally relevant over time, there is a real risk that non-  
knowledge becomes a politically instrumentalized argument for delay. The question of which mechanisms could prevent non-  
knowledge from being used as an instrument of deferral is therefore itself an important structural challenge. Ensuring that non-  
knowledge cannot serve as a shield against politically uncomfortable decisions is not a peripheral concern. It is a precondition  
470 for the procedure for being able to fulfil its function at all.

## 8. Conclusion

The implications outlined and discussed here reveal issues that demand political and legal solutions. These are questions that  
sociology cannot answer. What it can do, and what this article has sought to contribute, is render visible the structural  
conditions under which they arise. The analysis provides a specific sociological perspective and must be read with an awareness  
475 of its limitations: both the socio-theoretical framework and the empirical findings focus only on limited dimensions of complex  
phenomena and dynamics and the results do not claim to offer an all-encompassing account. The practical management of  
non-knowledge, the dynamics of participatory governance, and the institutional conditions for political decisions regarding  
acceptable unknowns remain important areas for further (empirical) research and for developing implications on how to  
operationalize these political decisions within the procedural framework.

480 Nonetheless, what the analysis has established is that the dilemma between non-knowledge and time is not an accidental feature  
of the German site selection procedure – it is socially and structurally produced. It will not only be resolved through better  
planning, more thorough scientific investigation, or the gradual accumulation of knowledge. It requires something different:  
an explicit political discussion about acceptable non-knowledge, about defensible timeframes, and about the responsibilities  
that must be assumed in making these decisions. Deferring those discussions and concerning decisions is not a neutral position.  
485 It is a choice with consequences. Engaging seriously with these questions is a responsibility that present-day decision-makers  
owe both to future generations and to the foundational commitments of the site selection procedure itself.

## Data availability

The analysis draws on publicly available texts on the formulation and implementation of the StandAG and the site selection  
procedure, including legal documents, position papers, expert opinions, presentations, and public debates. The corpus  
490 comprises textual materials made publicly available by BASE, BGE, the Nuclear Waste Management Commission, the Federal  
Institute for Geosciences and Natural Resources, and the National Citizens' Oversight Committee.



### Author contributions

All authors contributed to the study conception and design. Conceptualization, data collection and analysis were performed and the manuscript was written by Alisa Hirn.

### 495 Competing interests

The author declares that she has no conflict of interest

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- 655