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Safety and participation: citizens challenging the socio-technical divide in nuclear waste governance in Switzerland

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ABSTRACT

Since the 1990s, governments have increasingly promoted participatory nuclear waste governance that involve affected communities and encourage collaboration between experts and laypeople also in the evaluation of long-term safety and risk. However, research shows that a deep socio-technical divide persists, as expert authority continues to dominate problem framing and decision-making. As a result, citizens are often marginalized despite formal commitments to participation in radioactive-waste governance. Against this backdrop, this paper scrutinizes how the lay Safety Panel in the region of Zurich North-East (ZNO) has navigated its involvement in the techno-scientific evaluation of safety during the nuclear-waste governance process. Based on document analysis and ethnographic fieldwork, this paper traces how lay panelists have immersed themselves in the techno-scientific domain of safety and how they have come to advocate a broader consideration of safety as a socio-technical process. Strategically articulated in the course of the participatory process, this enabled the Safety Panel to challenge the institutional power relations in which safety is defined, assessed and evaluated, and to negotiate its own role in deliberating safety at the science-society interface. On this basis, this paper contributes to an inherently political understanding of safety governance, or the ways in which safety discourses can either consolidate or contest the socio-technical divide between experts and citizens in nuclear waste governance processes.

1. Introduction

Experts and citizens widely agree that geological disposal is a potential solution for the safe storage of radioactive waste for up to a million years (Schröder 2016). For its realization, science and technology are instrumental in the development of geological disposal projects and in their assessment in terms of risk and safety. And yet, disposal projects have not been only a techno-scientific concern (Bergmans et al. 2015; Landström and Bergmans, 2015). Already in the 1980s and 1990s, public resistance to disposal projects revealed the limitations of technocratic "decide-announce-defend" approaches to waste management and the dependence of such programs on public acceptance, legitimacy, and trust (Brunnengräber and Di Nucci 2019; Krütli et al. 2010). Consequently, most governments have redesigned disposal programs since the 1990s to secure the participatory involvement of affected publics in site-selection and decision-making processes (Cotton 2017; Di Nucci and Brunnengräber 2019; Kuppler 2012; see also Solomon et al. 2010; Hietala and Geysmans, 2020). This "participatory turn" entailed a greater emphasis on collaboration between laypersons and experts to support more democratic and robust decision-making in nuclear waste governance (Chilvers, 2007; Flüeler 2006; Lehtonen et al. 2022; see also Wynne 1996).

Despite the increasing acknowledgement of radioactive waste disposal as a socio-technical concern, the techno-scientific complexity of disposal projects has made the realization of public involvement challenging. Literature on participatory nuclear waste governance reveals a persistent gap between policy commitments and their practical implementation: Experts have maintained authority in problem framing (Bergmans et al. 2015; Cotton 2017; Lidskog and Sundqvist 2004); social issues have been subordinated to technical concerns (Barthe et al. 2020; Parotte and Delvenne 2015); citizens have been marginalized in scientific–technical domains (Bell 2022; Chilvers, 2007; Chilvers and Burgess 2008); and public decision-making power has often been limited to planning, procedural, and justice issues (Cotton 2018). Research on the

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politics of participation and expertise thus provides overwhelming evidence for the persistence of a "socio-technical divide" (Bergmans et al. 2015). In this sense, a technocratic culture has endured and continues to shape science–society relations and expert–citizen encounters. Across diverse governance processes, this has manifested in the discursive "framing" (Chilvers and Burgess 2008: 1881) of a lay–expert divide in terms of a "deficit model," in which only the latter are seen as holding the necessary expertise to evaluate and assess questions of risk and safety (see Chilvers, 2007; Krütli et al. 2010; Röhlig and Eckhardt 2017; Schneider 2019).

Complementing scholarship on the politics of participation and expertise, this paper scrutinizes how the lay Safety Panel in the region of Zurich North-East (ZNO) has navigated its involvement in the techno-scientific evaluation of safety within Switzerland's nuclear waste governance process. The region gained prominence in 2011 when it was listed by the National Co-operative for the Disposal of Radioactive Waste (Nagra) as one of six sites to be further investigated for the siting of a deep geological repository. To enable local participation, a so-called Regional Conference was established within the framework of the Sectoral Plan for Deep Geological Repositories (SFOE 2008), including representatives from 39 potentially affected municipalities. As an integral part of this Conference, the lay Safety Panel was created and mandated to address safety issues on behalf of the affected public, to secure knowledge transfer from science to society, and to evaluate experts' safety assessments in terms of their comprehensibility.

Against this backdrop, this paper asks: How has the lay Safety Panel in Zurich North-East navigated the techno-scientific complexity of risk- and safety-related questions since its creation? How has it approached these questions practically and conceptually? And, most importantly, how has it discursively framed risk and safety in the course of the participatory process? To address especially the latter question, this paper draws on Hajer's (1995) discourse-analytical approach. At the core of this approach is the analysis of the "argumentative struggle", in which different actors seek to define what the (environmental) problem is, what counts as valid knowledge, and which institutionalized interaction between actors appear reasonable or inevitable in addressing it. For the case study analyzed in this paper, this approach is significant in two respects. First, it draws attention to the ways in which issues of risk and safety are discoursively framed by different actors – and the lay panel in particular – over the course of the nuclear waste governance process. Safety is thus understood merely as a "multi-dimensional" (NEA 2013: 39) concept to be assessed and evaluated by experts, but as a discursive object of interpretation, negotiation, and contestation. Second, it brings into focus the extent to which the framing of risk and safety issues legitimizes a specific safety governance arrangement and, with it, the roles assigned to experts and citizens, in an either more technocratic or democratic ways.

Analyzing the Safety Panel's participatory engagment in the nuclear waste governance process along these lines privides important insights into the argumentative struggle through which the socio-technical divide between experts and citizens has been contested. Methodologically, this paper draws on document analysis and ethnographic fieldwork between spring 2019 and spring 2023. The fieldwork consisted of participant observation of Safety Panel regular meetings and sporadic attendance at Regional Conference meetings – where I was welcome as a 'guest'. Detailed field notes and official minutes of these meetings serve as the data base for the analysis of the Panel's activities during the third stage of the sitting process (based on 30 meetings held between 2018 and 2022). In addition, insights from informal discussions, participant observation during excursions, and semi-structured interviews with a selected number of panel members complement the data basis. Furthermore, meeting minutes and policy papers of the Regional Conference in Zurich North-East are used to examine the engagement of safety issues during the second stage of the SGT (protocols from meetings held between 2011 and 2018 were available online). Transcripts of interviews with panel members and key stakeholders in the Sectoral Plan provide a complementary dataset to contextualize the analysis and findings.

On this basis, this paper contributes to a better understanding of the discursive politics through which the socio-technical divide between experts and citizens, and the safety governance regime more broadly, is meaningfully framed, consolidated and contested. It is structured as follows: In section two, I provide a recent history of nuclear waste governance in Switzerland to illustrate how it is structured around a techno-scientific notion of safety, and how it has consolidated a socio-technical divide despite the participatory turn. In section three, I focus on the Safety Panel in Zurich North-East to show how its lay panelists have approached radiological hazard, risk and safety, and have framed safety in socio-political terms. In section four, I focus on the Safety Panel's engagement in the argumentative struggle about hazards, risk and safety of sites proposed for both a deep geological repository and a corresponding surface facility. This paper contributes to an inherently political understanding of safety and the ways in which safety discourses can either consolidate or contest nuclear waste governance arrangements.

2. The participatory turn in Switzerland

2.1. Safety criteria and governance

In techno-scientific terms, nuclear experts conceive of safety as a "non-event" (Hollnagel 2014) or a state in which protection against undesirable events and developments is guaranteed (see also NEA 2013). And yet, it is common knowledge among nuclear experts that "such a state rarely exists in reality" (Schröder et al. 2016: 258) and that there is no such thing as "absolute safety" (Röhlig 2024: 230). Instead, safety requires a legal or regulatory definition of what "risks are acceptable" (Eckhardt 2021: 7) – a definition that may change over time. From a scientific-technical perspective, building a safety case is then a calculative, evaluative or argumentative exercise to ensure that the statutory reference points are met (Ialenti 2020; Röhlig 2024; see also NEA 2013). It turns safety into a "dynamic non-event" that can be established on technical-scientific grounds, but that can also evolve as an object of considerable controversy (Röhlig and Eckhardt 2017).

In Switzerland, safety is enshrined as a key principle in the Swiss Federal Nuclear Energy Act and Ordinance (SNEA 2003; SNEA 2004) and applies to all categories of radioactive waste. In line with international safety standards (see IAEA 2006), the Swiss Federal Nuclear Safety Inspectorate (ENSI) defined comprehensive safety criteria in 2007, comprising thirteen criteria in four groups (HSK 2007: 18): the properties of the host rock, (2) its stability, (3) the reliability of the geological information, and (4) structural suitability (see also HSK 1993). In accordance with the "polluter pays" principle (SNEA, 2003, Art. 31), Nagra is responsible – on behalf of the nuclear power plant operators – for demonstrating that the statutory safety criteria can be met at a given site. On this basis, Nagra must propose suitable geological siting regions and sites, and submit an application for a general license (SFOE 2008: 77). To this end, Nagra has carried out research and built a safety case to justify site selection and its disposal project. In turn, the regulatory authority to assesses and decide whether safety standards are met lies with ENSI. As part of its supervisory mandate, ENSI is also responsible for regularly updating safety requirements during the Sectoral Plan process – consistent with a techno-scientific conception of safety as a "dynamic non-event".

In the search for the "safest" site for a deep geological repository in Switzerland, ENSI's thirteen safety criteria have served as decisive reference points for siting, or the safety-oriented comparison of sites across the three stages of the Sectoral Plan process (SFOE 2008: 40): In the first stage (2008–2011), Nagra identified and evaluated various sites in terms of geology and safety on the basis of the defined criteria. The main objective of the second stage was then to define at least two geological siting regions with associated siting areas for the surface facilities of a deep geological repository for high-level and low-level waste – or a combined repository to be operated by a shared surface infrastructure" (Nagra 2014a). To this end, Nagra used a quantitative preliminary safety analysis to compare the safety of various sites and proposed to focus its search on two regions – Zurich North-East and Jura East (Nagra 2014b). However, various stakeholders challenged Nagra's proposal, with the result that ENSI ultimately forced Nagra to reconsider the Northern Lägern region and keep it in the loop. In the subsequent third stage (since 2018), the safety assessment was intensified at all three sites through in-depth geological investigations – with Nagra finally proposing Northern Lägern as its preferred site in September 2022 (Nagra 2022). The demonstration of site suitability formed the basis for the general license application (SNEA 2003, Art. 13 § g) – including a techno-scientific justification for site selection and a detailed safety case – which Nagra submit for Nördlich Lägern in November 2024.

2.2. Safety and participation

The Sectoral Plan places the emphasis on safety as the key principle for siting in Switzerland and assigns responsibility for its assessment to scientific and technical experts and institutions. In parallel, it provides a regulatory framework for the participatory involvement of potentially affected communities in a variety of ways. Its participatory design reflects the government's response to the previous failure of the site selection process in central Switzerland (Wellenberg), where local vetoes in 1995 and 2002 led to the rejection of Nagra's plans for exploring sites for a small and medium-level waste repository (Krütli et al. 2010: 231-233). The failure of the Wellenberg repository project had far-reaching consequences for nuclear waste management policy and practice: On the one hand, the revised Swiss Federal Nuclear Energy Act (SNEA 2003) abolished the cantonal veto right that had secured local decision-making authority at the Wellenberg site. In turn, it shifted safety-related competence to the national level – with the possibility of an optional national referendum (Fischer 2019: 302; Kuppler 2012: 113). On the other hand, local participation was ensured through the institutionalization of a participatory mechanism to compensate for the local veto. Under the leadership of the Swiss Federal Office of Energy (SFOE), the Sectoral Plan was thus strategically designed to create local trust and social "acceptance" (SFOE 2006a: 109; 2008: 28) by involving the potentially affected siting communities and cantonal authorities.

With the Sectoral Plan, the SFOE drew on an established planning instrument for large-scale projects of national importance (Fischer 2019: 303), which provided a broad frame for the institutionalization of regional participation along the three siting stages. In parallel with Nagra's identification of six potential sites in the first stage (Nagra 2011), the SFOE defined perimeters for organizing potential "affected communities" for regional participation, and defined the rules and structures for cooperation (SFOE 2008: 24; 2011: 93; 2015: 7). With the start of the second stage in 2011, the SFOE established Regional Conferences in the six potential siting regions. The Regional Conferences are designed to be representative bodies with around 100 members, including local stakeholder representatives, civil society representatives and representatives of the German municipalities in northern Switzerland that may be affected by potential Swiss repository sites. With the start of the third stage in 2018, three of these Regional Conferences were abandoned in line with Nagra's reduction of the number of sites in its safety comparison (NTB 2015). Three regions remained in focus for the third stage, including the regions Northern Lägern, Jura East and Zurich North-East. Following Nagra's recent announcement that Northern Lägern would be prioritized for the development of a general license (Emmenegger 2026), the Regional Conferences in the other two regions were terminated – including Zurich North-East, the region in the focus of this paper in sections three and four.

Throughout the process, the Sectoral Plan has provided a regulatory framework for nuclear waste management in Switzerland that integrates participatory elements into decision-making. It has done so through what Parotte et al. (2024: 350) have captured elsewhere as "sequential opening and closing". In Switzerland, the debate has opened up in the course of the three stages of the Sectoral Plan, and partially closed with the end of each stage. To that end, participation through the Regional Conferences entailed different forms of engagement during each stage and culminated in hearings, called "consultations" in Switzerland at the end of each (Kuppler 2017: 179). Indeed, the Sectoral Plan process has not been without its controversies, for example raising the fundamental question of what participation actually means when affected citizens can talk but not decide (Fischer 2019). Nevertheless, it has still favored a "relatively conflict-free" process and negotiations between key stakeholders and potential host communities (Kuppler 2017: 178).

2.3. Safety versus participation

The Sectoral Plan has been hailed by key stakeholders as a pioneering framework for participatory and deliberative governance. Indeed, it has successfully combined a safety-oriented site comparison by experts with public participation at potential sites. However, a socio-technical divide has structured expert-citizen encounters in Switzerland. Participation has been supported only insofar as it does not undermine or compromise techno-scientific safety (Kuppler et al. 2023: 191). Local participation has focused primarily on the design and siting of surface facilities and the socio-economic impacts of deep geological repositories (SFOE 2008: 34). In order to intensify the discussion of these issues, the Sectoral Plan had initially proposed the establishment of two lay panels – one to deal with socio-economic aspects and another to site a surface facilities. Both were set up at the inaugural meeting of the Regional Conferences in 2011 and subsequently worked in their respective areas. In the course of the second stage, participation in the Regional Conferences thus focused primarily on issues related to spatial assessment and planning at the surface – issues that henceforth dominated engagement at the regional conference meetings and in the respective panels. During the second and third stages, the Panel responsible for the siting of the surface facility, referred to in this article as the Surface Panel, played a key role in enabling negotiations on potential sites through genuine participation at the level of active involvement.

While genuine participation has been realized in areas related to spatial planning and land development, safety has not been prioritized as an area for participatory engagement in the Sectoral Plan. Rather, the Sectoral Plan considers opening up the technical-scientific assessment of safety to the public only through the Technical Safety Forum (TSF), which provides information on demand. The TFS was conceived as a platform for experts from various institutions to address technical and scientific questions relating to safety and geology from the general public, communes, siting regions, interest groups, cantons and communes in neighboring countries. As a platform for expert consultation, TFS members have the task of discussing and answering questions on technical safety aspects and publishing their answers on the Internet – a

total of 169 questions have been answered by the end of 2022. By institutional design, the TFS produces consensual knowledge that is verified and approved by the various experts involved – while it is usually made transparent which expert institutions formulated which part of an answer. It reflects the belief that knowledge controversies can or must first be resolved by experts before consensus knowledge can be made available as information to the public. As a result, it tends to reify the deficit model based on the assumption that lay people lack the scientific literacy to deal with issues of technology, risk and safety (Krütli et al. 2010: 867; see also Ialenti 2020). Furthermore, it provides an example for the socio-technical divide between experts and citizens that continues to order science-society relations in Switzerland, despite the participatory turn (see also Bergmans et al. 2015).

As evident, participation in the field of safety was initially conceived in a rather technocratic way in the Sectoral Plan – with 'participation' reduced largely to the reception of information. However, as the institutionalization of regional participation progressed, calls for participatory involvement in the field of safety became more prominent. At an early stage, the SFOE responded to these demands by enabling the creation of so-called Safety Panels within the Regional Conferences in 2011 to enable lay consultation. After their creation, the Safety Panels have been mandated to look into safety issues and report back to the Regional Conferences as a basis for their comments during the staged site selection process and especially at the end of the different stages. In their constitutive document, the mandate of the Safety Panel was defined as follows: "The siting region can gather the necessary expertise from the federal authorities and the waste producers and address safety-related questions to the [Technical] Safety Forum and delegate one representative per siting region to the Safety Forum".[1] To this end, the Safety Panels were granted funding to "invite their own experts, organize information evenings and discuss technical and scientific questions relating to safety and geology".[2]

3. The ZNO safety panel

In Switzerland, "safety" is defined as a key principle guiding the siting of a nuclear waste repository (SFOE 2008). Since the beginning of the Sectoral Plan process in 2008, stakeholders involved—experts and citizens alike—have repeatedly emphasized safety as the top priority for the siting process (Kuppler 2017; Kuppler et al. 2023). While safety as a principle has thus remained largely uncontested, ambiguity persists regarding what safety actually means and how it can be achieved. Schneider (2019) has shown the coexistence of diverging conceptions of safety among stakeholders in Switzerland, revealing that they concern not only what safety is, but more fundamentally how and by whom it can be assessed, evaluated, and achieved. In this sense, respective conceptions of safety influence – or even determines – the meaning of participation, and importantly, the role citizens may play in the techno-scientific domain. Building on this line of inquiry, the remainder of this paper demonstrates how the Safety Panel in Zurich North-East has approached risk- and safety-related questions by navigating both the techno-scientific complexity of these issues and the socio-technical divide underlying the established safety governance arrangement. It shows that lay panelists have indeed managed to acquire competences necessary to engage with the techno-scientific safety domain. Furthermore, it demonstrates that the Safety Panel has strategically reframed issues of risk and safety during the siting process in socio-technical terms, thereby raising questions about how safety should be assessed and what role lay citizens may play in that process.

3.1. Worst case scenarios

Zurich North-East gained significance in November 2011 when being listed as potential site for the disposal of radioactive waste.[3] Within the Regional Conference, the Safety Panel was established to deal with safety issues on behalf of the Regional Conference. Formed at the founding Regional Conference meeting in September 2011 and staffed with fourteen members at the follow-up meeting in November 2011, the work of the lay panel proved particularly challenging. As its leader put it: "The panel is in a situation where it has an item to work on, namely safety, but no mandate like the other two existing panels. The participation process has only just begun and there are no milestones for the Safety Panel".[4] As a result, the Safety Panel had to get "fit", as the SFOE representative put it.[5] As a first formal outcome of its engagement, the Safety Panel submitted a policy paper to the Regional Conference in February 2013 to stimulate a debate on the meaning of participation in the field of safety. In the paper, the Panel defined a set of normative principles – essentially emphasizing the need for an ethical, responsible, transparent, fair and reflexive process – for a participatory process in which it had begun to work and in which it aimed to contribute "to the enhanced safety of a potential repository".[6]

In the early process, the Safety Panel had little expertise to engage with or challenge the techno-legal understanding of safety, the safety criteria or the design of the safety case. Instead, it was preoccupied with the meaning of participation in the safety domain and its own role at the science-society interface. Nevertheless, the Panel began to engage with safety and safety-related issues. An initial engagement with key documents and experts culminated in the formulation of a set of questions, which were further developed through deliberation at the panel meetings. These questions were inspired by an examination of a number of hazards that had been missing from the expert debates, which the panelists then translated into a set of worst-case scenarios. These scenarios testified the panelists' initial preoccupation with the radiological hazard associated with deep geological disposal plans, both on the surface and subsurface. As the panel members later rationalized their early focus in a presentation to a Regional Conference meeting. The Safety Panel was concerned with the question: "How dangerous is nuclear waste really?".[7] To answer this question, a technical understanding of risk as an equation (risk = damage x probability) served as a first but unsatisfactory starting point, since the probability of an event is difficult to assess and the potential damage is severe.

Instead, panelists found the metaphor of a caged tiger to be more

[1] Regional Conference Zurich North-East. 2011. 'Fachgruppe Sicherheit'. September 10, 2011.

[2] Regional Conference Zurich North-East. 2011. 'Fachgruppe Sicherheit'. September 10, 2011.

[3] Among the regions considered, Zurich North-East stands out due to its specific waste management history, also prior to the Sectoral Plan: Already in 2002, the region known locally as the Zürcher Weinland served as a reference site for Nagra's demonstration of feasibility, which provided theoretical proof of the feasibility of deep geological disposal in Opalinus clay formations – currently the most favorable host rock for deep geological disposal in Switzerland across the three sites (Emmenegger 2025). The test drillings that began in the region in 1998 thus advanced the Swiss nuclear waste disposal program but also triggered a wave of political mobilization around anti-nuclear positions and local resistance to disposal plans at the site (Adler 2023; Emmenegger 2023; Emmenegger & Luisetti 2026). For the establishment of the Regional Conference in 2011, this meant that members of critical groups were integrated from the outset and have worked together through what proponents call "constructive criticism" (Adler 2023) – an approach that maintains an anti-nuclear stance while accepting that the nuclear waste problem needs to be solved.

[4] Regional Conference Zurich North-East. 2012. 'Protokoll 3. Vollversammlung, Etappe 1'. May 1, 2012.

[5] Regional Conference Zurich North-East. 2013. 'Protokoll 6. Vollversammlung, Etappe 1'. March 26, 2013.

[6] Regional Conference Zurich North-East. 2013. 'Grundsatzpapier der Fachgruppe Sicherheit, Zürich Nordost'. January 9, 2013.

[7] Regional Conference Zurich North-East. 2019. 'Protokoll 4. Vollversammlung, Etappe 3'. August 29, 2019.

convincing in illustrating and capturing the real nuclear hazard: A tiger without a cage signifying a "great, real, immediate danger" and a tiger in a cage signifying a "low probability of harm" (RC ZNO 2018: 3).[8] It was then up to the Panel to assess the risk posed by a caged tiger, the danger posed by the claws and the protection provided by the bars of a certain thickness. In layman's terms, the metaphor of containment was a powerful one to simplify the multi-barrier system designed for deep geological disposal underground, as well as a nuclear packaging plant on the surface. And yet the essential focus of the Panel was not the cage, but the tiger inside: In its worst-case scenarios, it focused on the hazard of nuclear waste manifesting itself in the form of a completely unprotected or uncontained fuel assembly, without the fuel elements, without the cladding tubes enclosing the fuel rods, without the repository, and without the multiple layers of geological protection. While the panelists were well aware that such scenarios were unrealistic, they were arguably in line with the 'safety first' principle. As one panelist put it: "All other criteria must be subordinated to safety and risk minimization".[9]

3.2. Process safety

In parallel with its work on hazard, risk and safety issues, the Panel began to look at empirical cases to deepen its understanding of safety and risk management in practice. In the spring of 2014, panelists visited the landfill in Kölliken, where hazardous waste had been disposed of from 1978 to 1985 and where remediation work was underway due to the failure of the project (see also Seidl et al. 2017). The hazardous waste landfill was of interest as a case where a worst-case scenario had become reality, or as a failed case of risk management comparable to the nuclear waste disposal project. During the visit, panel members met with some of those responsible for the landfill, as well as with critical voices from the scientific community and the local public. The panelists learned that the authorities had ignored critical objections from local citizens during the planning phase and had allowed the landfill to open on the basis of feasibility studies by experts. Even after the landfill started operating, the authorities and the operator continued to downplay public objections, despite increasingly obvious signs of failure. In 1985, however, the landfill was shut down after the signs could no longer be ignored. An independent expert group finally provided evidence that the landfill posed serious risks to humans and the environment.

The visit to Kolliken provided important input for the preparation of the Safety Panel's first comprehensive safety report entitled "Process Safety in the Sectoral Plan for Deep Geological Repository" (RC ZNO 2015a). In the report, the Panel recalled the visit and problematized the approach to risk management. It found that the main reasons for the failure were not primarily technical, but rather institutional, since "the operators were operating under their own supervision" (RC ZNO 2015a: 7). The visit was decisive, as the panel chairman later put it: "The Kölliken case raises questions about process safety".[10] It prompted panelists to draw a number of conclusions about what went wrong and to reflect on lessons learned. As the report makes clear, the Kölliken case is not representative of a nuclear waste repository, but illustrates what happens in the "worst case" and allows lessons to be learned (RC ZNO 2015a: 6).

Following the visit to Kölliken, the Panel invited several speakers to reflect on process requirements and quality. This exercise culminated in the identification of four key criteria by which the Safety Panel rationalized its experience in Kölliken: (1) checks and balances; (2) transparency; (3) long-term planning; (4) handling of scientific evidence (RC ZNO 2015a: 12). As the report makes clear, these criteria were essentially inspired by the exchange with a scholar of nuclear waste governance – Sophie Kuppler, who at the time was developing her Ph.D. thesis on participatory and deliberative governance and has since become an established expert in the field (see Kuppler 2017). In parallel, the formulation of the criteria also reflected the Panel's analytical engagement with issues of procedural justice and "quality of the process", as was already evident in its first policy report.[11] The Safety Panel finally approved its safety report in November 2015 and presented it at the following Regional Conference meeting. Indeed, the notion of process safety was contested also within the Safety Panel and among its panelists.[12] However, it reflects a majority opinion that was deliberated and endorsed by the panelists in the respective report published in 2015.

In any case, the understanding of process safety has continued to evolve as the Panel has continued to meet and discuss, explore further comparative cases and engage with experts in relevant fields and debates – again in the third stage. As the report explicitly emphasizes, process safety does not replace the classical technical-scientific criteria for safety – but it does condition them (see RC ZNO 2015a: 3). It focuses on the following question: "How should a process be set up and run in such a way that safety is always promoted and never hindered – even if this is unpleasant and unfavorable for various actors?" (see RC ZNO 2015a: 3). In other words, the question was not whether the safety criteria are met, but how the worst case can be avoided and, importantly, what processual criteria would have to be in place to stop the siting process if the risks became unacceptable. In contrast to a techno-scientific understanding of safety, the Safety Panel built on a socio-technical understanding of safety, where safety is not only a scientific-technical but also a socio-political achievement.

As the following sections will show, such a socio-technical understanding of safety was crucial for the Safety Panel's participatory involvement in the argumentative struggle over the 'safe' disposal of nuclear waste in the region. It enabled the Panel to problematize the institutional power relations within which safety was evaluated and assessed, as well as the socio-technical divide that structured safety governance under the Sectoral Plan. In this vein, the Safety Report proved formative for the Safety Panel: it fostered the Safety Panel's critical engagement with the governance arrangement through which safety is produced and inspired call for transparency, accountability, and checks and balances. Furthermore, it prompted a reinterpretation of the Panel's role – from one focused on securing knowledge transfer from experts to citizens to one oriented towards securing democratic oversight in a techno-scientifically complex domain.

4. Safety deliberations

This section explains how the Safety Panel in the Zurich North-East region approached safety issues during the site selection process. As part of the Sectoral Plan process, the Safety Panel was tasked with reviewing and assessing safety issues on behalf of the Regional Conference so that it could comment on the step-by-step site selection process. After its creation in 2011, this took the form of comments on Nagra's safety-related site comparison in the second stage and on the preliminary selection of Northern Lägern as the site for a deep geological repository in the third stage – on which the Regional Conference was able to comment. In parallel, it materialized in negotiations on Nagra's

[8] Regional Conference Zurich North-East. 2019. 'Präsentation der Fachgruppe Sicherheit in der 4. Vollversammlung, Etappe 3'. August 29, 2019.

[9] Regional Conference Zurich North-East. 2019. 'Präsentation der Fachgruppe Sicherheit in der 4. Vollversammlung, Etappe 3'. August 29, 2019.

[10] Regional Conference Zurich North-East. 2014. 'Protokoll 12. Vollversammlung, Etappe 1'. November 15, 2014.

[11] Already in 2013, the Panel had called for the recognition of "minority positions" and emphasized the importance of participation in the field of safety (see Regional Conference Zurich North-East. 2013. 'Grundsatzpapier der Fachgruppe Sicherheit, Zürich Nordost'. January 9, 2013).

[12] The report reflected the prominent representation of anti-nuclear voices in the Safety Panel in Zurich North-East, who have long questioned the lack of "quality control" and called for the integration of "critical expertise" (SFOE 2006b: 31).

proposal for potential sites for a corresponding surface facility in Zurich North-East – which the Regional Conference could discuss, evaluate and supplement (Nagra 2014c: 1). As this section shows, worst-case scenarios and a socio-technical concept of safety served as valuable heuristics for the Safety Panel in its evaluation task. Articulated strategically in an argumentative struggle, the notion of process safety not only challenged purely technical-scientific understandings of safety, but also served as a discursive device to contest the very governance arrangement in which safety-related expertise was authorized and the socio-technical divide between experts and citizens that conditioned the work of the Safety Panel.

4.1. Surface siting

Within the Regional Conference, the Safety Panel gained importance as it had to evaluate potential surface facilities from a 'safety' perspective. To this end, the Safety Panel introduced a worst-case scenario, in line with its concern about the actual radiological hazard from nuclear waste now imagined to exist on the surface. For example, in a question submitted to the TFS by the Regional Conference, the Safety Panel asked experts to clarify the radiological risk by imagining that a "surface facility is suddenly completely without shielding and protection … no walls, no transport and storage containers, just the unprotected fuel elements without cladding tubes" (TFS 2014). This approach, however, had explosive potential when it was raised at Regional Conference meeting: They "conjure up hell", as one Regional Conference member put it, imagining events that did not happen, "even in the case of Fukushima".[13] As a moderator at the 2014 meeting made clear: "These scenarios [indeed] sometimes go beyond the limits of the imaginable, but they improve the understanding of the hazardous material".[14]

Such a scenario thus served as a basis for the Safety Panel to intervene in the debates and to consider safety at the four potential sites for a surface facility in Zurich North-East region in 2011 (Nagra 2011: 1). In particular, the potential location of a surface facility in areas with strategic groundwater was critical from a safety perspective. Commenting on an interim report of the Surface Panel at the 2014 Regional Conference meeting, the head of the Safety Panel thus highlighted that a majority of his panelists prioritized the protection of strategic drinking water aquifers. He justified this prioritization with reference to the "precautionary principle", arguing that caution was advisable and exclusion of the site in question was a must – especially in view of the uncertain knowledge base on the aquifer at the site.[15]

The Safety Panel's subsequent call for the exclusion of the site in question was in line with the 'safety first' principle, but appeared to be in fundamental conflict with the Surface Panel's approach to site selection as the process progressed. In fact, the latter also included potential groundwater aquifers among its "exclusion criteria" in the second stage, which decisively led it to conclude that none of the sites proposed by Nagra would be suitable for a facility in the Zurich North-East region (RC ZNO 2014: 1). Nevertheless, it left room for discussion about the "least unsuitable" surface sites in case the region was ultimately selected on geological grounds (RC ZNO 2014: 38) – including sites where land use priorities would not be compromised, where groundwater would not be affected, or where knowledge of the actual location of the groundwater was still unclear. Negotiations on the siting of potential surface facilities in the region were therefore able to continue in the third stage around two potential sites – one originally proposed by Nagra and another now added to the list by the Safety Panel. They remained in the loop due to a re-evaluation of the groundwater conditions at these sites (see also Nagra 2019a; 2019b). For their evaluation, the Surface Panel subsequently used a spatial planning tool that allowed it to weigh and balance the various land use interests for different realizations of a potential surface facility – with and without a repackaging facility – at the respective sites. However, such an approach forced it to remove exclusion criteria from the evaluation catalogue. Instead, it ultimately subsumed safety concerns in line with the planning logic into one of the four dimensions considered, with a weighting of 22% for "technology/logistics/safety".[16]

Spatial planning by balancing interests stood in striking contrast to the 'safety first' principle when it was brought to the surface, and in particular to the Safety Panel's call for decisive exclusion criteria. For the Safety Panel, the assessment of safety again involved a consideration of what could potentially go wrong during the transport of radioactive material or its repackaging in an appropriate facility. Taking safety seriously would then mean giving it a 100% weighting, with safety overriding all other evaluation criteria and weighted interests as an effect. The evaluation of safety aspects of surface facilities thus triggered a more fundamental controversy about the importance of safety and the role of the Safety Panel in the course of the third stage. Worst-case scenarios remained critical for the Safety Panel and inspired its call for ultimate criteria for the exclusion of sites where the actual hazard to the drinking water resource is evident or an unacceptable risk. Nevertheless, the Regional Conference closed the debate by approving the Surface Panel's planning tool – at least for the time being. The controversy subsequently had a significant impact on how the Safety Panel evaluated the Surface Panel's work. In its evaluation report, the Safety Panel assessed not only the actual risks and hazards associated with a potential surface facility, but also the decision-making process itself – in terms of process safety. In particular, it challenged the Surface Panel's decision to deviate from its initial recognition of exclusion criteria in the second stage and problematized the radical change of direction as incoherent.

The debate on potential sites for a surface facility reached a turning point in 2020, when the Regional Conference proposed "to reopen the box" and, if necessary, evaluate new surface facility sites (Nagra 2021: 2). This proposal was made possible by the progress of Nagra's hydrological research, which provided increasing certainty about the location and dynamics of groundwater in the region. As a result, an additional site was considered for future consideration in an exchange between Nagra and the Surface Panel. For the Surface Panel, the reconsideration of these new sites was now again based on the "exclusion criteria" established in the second stage, which it adapted – now prioritizing the strategic interest of drinking water supply and reducing the (safety) distance to certain land use zones (Nagra 2021: 6). Finally, it allowed a degree of consensus for one of the sites – on condition that the repackaging facility is outsourced. In its statement on the report of the Surface Panel, the Safety Panel also emphasized the importance of focusing on the hazard. In this sense, it strongly supported the Surface Panel's site selection beyond the existing aquifer as an ultimate contribution to safety. On the other hand, it remained critical of the Surface Panel's decision to reduce the distance from inhabited areas on the basis of the increased radiological risk this entails. Consideration of the actual hazard, or radiological safety, also led the Safety Panel to propose splitting the repackaging facility and moving it out of the region – a proposal shared by different stakeholder and finally adopted by Nagra in its proposal.

As this case illustrates, the controversy over the siting of a surface facility in the Zurich North-East region was crucially fueled by the consideration of radiological risks and hazards, particularly if such a facility were to be located over a strategic groundwater aquifer.

[13] Regional Conference Zurich North-East. 2014. 'Protokoll 12. Vollversammlung, Etappe 1′. November 15, 2014.

[14] Regional Conference Zurich North-East. 2014. 'Protokoll 12. Vollversammlung, Etappe 1′. November 15, 2014.

[15] Regional Conference Zurich North-East. 2014. 'Protokoll 9. Vollversammlung, Etappe 1′. December 4, 2013.

[16] Regional Conference Zurich North-East. 2019. 'Präsentation der Fachgruppe Sicherheit in der 4. Vollversammlung, Etappe 3′. August 29, 2019.

However, in line with its focus on process safety, the Safety Panel also considered the actual process by which safety concerns could be raised and considered during the process. At an early stage in the evaluation process, it did so in particular by problematizing the way in which the federal and cantonal authorities had intervened in the debate on the strategic drinking water aquifer, and in particular the top-down intervention by the former that closed the debate.[17] Similarly, the Safety Panel later questioned Nagra's closure of the debate, as the latter had excluded some of the sites after the 'reopening the box', based on a re-evaluation of the geological conditions for a repository in the region and their geographical implications for its connection to a surface access facility – accessible either by ramp or shaft. Although this appeared to be justified as Nagra's underground investigations had progressed in parallel, the Safety Panel considered it inadmissible to change the terms of the evaluation in the middle of the process without a transparent and comprehensive scientific justification. As these two issues illustrate, the consideration of process safety entailed questioning the way in which expertise was generated and authorized in the course of the process within the institutional power relations, and the subsequent closure of the debate in the Regional Conference.

4.2. Subsurface siting

For the Safety Panel in the Zurich North-East region, participation intensified from 2014 onwards, after Nagra had communicated its preliminary safety analysis of various sites and its proposal for the site selection to be carried out in the third stage – a proposal on which the Regional Conference now had to comment as part of the consultation process. In particular, Nagra proposed to prioritize the search in the Zurich North-East and Jura East regions, while keeping Northern Lägern in reserve due to technical and structural disadvantages. In the region, Nagra's proposal was sensitive as it seemed to confirm certain path dependencies in the site selection process and fueled speculation about Nagra's preoccupation with Zurich North-East as its preferred site. However, in its assessment of Nagra's safety analysis, the Safety Panel did not address these political controversies. Rather, it structured its final assessment report according to the thirteen statutory safety criteria, examining each criterion in turn (RC ZNO 2015b). The report provides evidence of the ability and capacity of laypersons to engage and immerse themselves in the techno-scientific domain. It led the Panel to evaluate and question the plausibility of various techno-scientific variables and the way in which uncertainty was rationalized by experts in their safety analysis.

In its report, the Safety Panel also included worst-case scenarios in the long-term radiation modelling in order to stimulate the debate on safety (RC ZNO 2015b). From a scientific-technical point of view, a decisive criterion for the consideration of safety is that the calculated radioactive release dose remains below the legal threshold in one million years after disposal. As a critical quantitative criterion, safety is the result of modelling the interaction of the multiple barriers incorporated in the repository design. While modelling approaches could be challenged on the basis of their assumptions or parameters – in the sense of "*Garbage in – Garbage out*" (Adamski 2014: 79, emphasis in original) – the lay panel had little expertise to do so at the time. Moreover, there was little reason to do so, since the dose calculation remained well below the actual threshold at all sites, did not differentiate between sites, and thus had no impact on Nagra's siting proposal. In its responding report, the Safety Panel therefore accepted the approach, but further suggested considering "worst-case scenarios with combinations of several unfavorable assumptions (e.g. higher erosion rates, waterway mobility, greater depth)" (RC ZNO 2015b: 10). In fact, the Safety Panel's partial intervention did not represent a contradiction to the safety case as a whole, in which worst-case scenarios would be integrated to assess safety in the long term. On the contrary, it testified to the initial immersion of the panelists in the internal logic of the safety case – an immersion that later culminated in the submission of a corresponding question to the TFS, in which the Safety Panel asked experts to unpack the modelling assumptions and their impact on knowledge production and safety assessment (see TFS 2022).

However, the Safety Panel's assessment was not purely techno-scientific, but also socio-political. In this sense, it questioned the techno-scientific language and structure of the scientific report, which made it particularly difficult for lay people to understand the "gigantic tsunami of documents" (Flüeler cit. in RC ZNO 2015b: 8). The Safety Panel based its conclusions on a series of questions designed to assess the comprehensibility of Nagra's report. It reflected its deliberate attempt to demand transparency and to hold Nagra accountable to the public, which is entitled to be informed about the technical and scientific expertise on which decision-making is based. In this vein, it emphasized that "lay people are also entitled to judge whether there is sufficient scientific knowledge to make a particular decision" – and are particularly entitled to do so in a "democratic state" (RC ZNO 2015b: 4). As underlined in the report, comprehensibility is paramount and a key condition for genuine participation, both with regard to safety-related decision-making and the scientific knowledge base on which decisions are made.

At the same time, the Safety Panel's deliberations on process safety and the parallel preparation of the corresponding report had an impact on the evaluation of Nagra's proposal in the second stage. In its assessment, for example, the Safety Panel emphasized that not only the "classical safety criteria (relating to geology, etc.)", but also "safety-oriented and safety-guaranteeing process safety" had to be taken seriously (RC ZNO 2016: 31). The corresponding call for the consideration of checks and balances and the recognition of minority opinions marked a twofold intervention in safety governance and underpinned the Safety Panel's call for the "adjustment or optimization" of the Sectoral Plan in the sense of an "adaptive process" (RC ZNO 2016: 33; see also RC ZNO 2015a: 11). On the one hand, it entailed challenging the socio-technical divide between experts and citizens and the institutional framework in which the participation of the Safety Panel was embedded and designed to function. On the other hand, it problematized institutional path dependencies and inspired a call for institutional independence in order to keep the space open for controversy, deliberation and debate. Indeed, the parallel publication of the Panel's Process Safety Report in November 2015 essentially fueled its engagement with governance issues also in the following (RC ZNO 2015a: 11).

In the course of the third stage, the Safety Panel's immersion into safety issues continued, including an engagement with geotechnical details of the ongoing geoscientific investigation (deep drilling and rock laboratory), techno-scientific aspects of the safety case (uncertainty and regulatory frameworks), and radiological risks and hazards. The Safety Panel members discussed technical and scientific issues in their meetings with experts. At the same time, they regularly opened up technical-scientific debates, focusing on legal, institutional and scientific path dependencies and unequal power relations in which expertise was developed and knowledge was authorized. However, the work of the Safety Panel came to an abrupt end when Nagra announced that it would focus on the Northern Lägern and not Zurich North-East as the most suitable site for nuclear waste disposal due to its favorable geology. The decision was generally well received by the Regional Conference: Nagra's proposal to focus on Northern Lägern, the site it had proposed to exclude from the list in the second stage, was seen as a key sign of the quality of the Sectoral Plan process (RC ZNO 2022: 2). The Safety Panel, in contrast, took a more ambivalent view of the comprehensibility of Nagra's decision. In particular, it objected that it was unable to assess whether the decision was comprehensive, as Nagra had not made the technical and scientific arguments and documentation behind the site selection available, and as Nagra's justification of the decision to the

[17] See e.g. draft meeting input "Vorschlag einer Stellungnahme der FG SI zur Analyse der Oberflächeninfrastrukturvorschläge ZNO'. November 25, 2019.

wider public did not meet the panelists' expectations.

The Safety Panel's final report on Nagra's site selection was deliberately kept short, not least because the Regional Conference in Zurich North-East was about to be dissolved – and the Safety Panel's with it. In the report, it again emphasized the importance of a "critical review of the quality of the process" (RC ZNO 2022: 5) and evaluated the exchange of information with those involved in the Sectoral Plan, including Nagra, ENSI and the SFOE. At the same time, it emphasized the importance of the exchange between experts and citizens "on an equal footing" and the "quality of cooperation", which allows "secondary opinions" to be taken into account beyond the official scope of the process (RC ZNO 2022: 6). In order to stimulate safety thinking in this direction, the Safety Panel also included a link to the OnePager with the final report, which summarizes the questions and concerns that it listed relevant for the experts to be taken seriously in their safety assessment – "irrespective of the site selection" (RC ZNO 2022: 6).

5. Conclusion

This paper has examined the Safety Panel's participatory engagement with risk- and safety-related questions in the course of the nuclear waste governance process in Zurich North-East since its creation in 2011. It has shown that lay panelists had to navigate considerable techno-scientific complexity and did through increasing immersion in the technical-scientific field of safety in order to evaluate expert's work expertise in terms of comprehensibility on behalf of the Regional Conference. The analysis has demonstrated that lay panelists did indeed acquire the competence and expertise to carry out this task, crucially through field trips and regular engagement with experts in various formats. Moving beyondwithin the techno-scientific domain, however, the Safety Panel also approached and strategically reframed safety in socio-technical terms. In the course of the participatory governance process, it did so in two main ways.

First, it shifted attention away from safety as an abstract techno-scientific principle and towards how radiological risks and hazards might manifest in worst-case scenarios and actual events. In contrast to a techno-scientific understanding of safety as a non-event, it thus promoted an examination of the actual, albeit often unrealistic, event and the question of what might happen if something went wrong in the worst case. This perspective informed the Safety Panel's approach to risk and safety at potential sites for a deep geological repository and associated surface access facilities. It provides evidence for a rather profound epistemological divergence between experts and panelists on how to categorically capture, assess and evaluate potential impacts of nuclear waste disposal in the long term: While the techno-scientific approach to safety is based on the assumption that safety can be assessed and evaluated (see Schröder et al. 2016), a focus on hazard exhibits a rather profound skepticism of human attempts to rationalize uncertainty through safety criteria and a safety case. Such skepticism is particularly strong in the face of the inevitable epistemological uncertainties associated with deep geological disposal projects. While scientific expertise has been conditioned by the statutory codification of acceptable risk in the form of techno-scientific safety criteria, the Safety Panel's focus on hazard tended to open up a debate beyond the techno-scientific domain about what constitutes acceptable risk and what it would imply in terms of precaution for technological decision making.

Second, the Safety Panel opened up political space for considering safety within the institutional arrangement in which it is defined, assessed and evaluated – what it described with the notion of 'process safety'. Central to this reframing was the Safety Panel's call to account for the socio-political context in which safety is evaluated and assessed. For the Panel, such an understanding of safety was instrumental in addressing and problematizing the institutional power relations and path dependencies of the techno-scientific exercise. Reframing safety in this way as a socio-technical process did not only challenge the techno-scientific meaning of safety, but fundamentally questioned how and by whom safety should be assessed. Articulated strategically in the argumentative struggle over safety during the siting process, a socio-technical notion of safety provided a discursive device through which the Panel could negotiate the science-society relationship and challenge the socio-technical divide structuring that relationship. It enabled the Safety Panel to critically engaging with the governance arrangement in which safety is produced and served as a normative basis for its call for transparency, accountability and control mechanisms. In turn, it allowed the Panel to challenge its own institutional design as a platform for knowledge transfer from science to society and to emphasize its critical role as a citizens' forum securing democratic oversight.

Overall, this paper contributes to an inherently political understanding of safety and the ways in which safety discourses can either consolidate or contest safety governance arrangements. It shows that safety is not only a complex techno-scientific concept, but an inherently "ambiguous" (Eckhardt 2021: 79) one. It is ambiguous because techno-scientific and socio-technical conceptions can contrast with one another, and because these diverging conceptions of safety may clash in experts-citizen encounters. Furthermore, this paper supports Schneider's (2019) finding that divergent conceptions of safety have profound implications for nuclear waste governance. It demonstrates how the Safety Panel has articulated safety in ways that inspire reflection on the specific configuration of science, society, and politics that underpins democratic decision-making. In the final meeting of the Regional Conference in Zurich North-East, the cantonal expert Thomas Flüeler highlighted that the Safety Panel's notion of "process safety" represents one of the key contributions of the Sectoral Plan process to nuclear waste governance in Switzerland and beyond.[18] His conclusion was based on his professional and scientific work at the socio-technical interface and his vision of a "social robustness" (Flüeler 2002; 2024) in the decision-making process – achieved "when most arguments, facts, social coalitions, interests and values lead to a consistent option" (Rip 1986 cit. in Flüeler 2024: 9, own translation). Yet in Switzerland, debates about safety have largely remained a domain not of *contestation*, but of *consolidation* of the socio-technical divide between experts and citizens – partly because epistemological, institutional and ideological trust in science remains widespread within the Regional Conferences and among the broader public.

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Data availability

Data will be made available on request.

[18] Regional Conference Zurich North-East. 2022. 'Protokoll 12. Vollversammlung, Etappe 3'. July 2, 2022.

References

Adamski, D., 2014. Simulation in der Fahrwerktechnik: Einführung in die Erstellung von Komponenten- und Gesamtfahrzeugmodellen. Springer, Wiesbaden.

Adler, Peter. 2023. 'Swiss Nuclear Waste Governance: Political Processes, Constructive Opposition, and the Role of Affectedness'. Unruly Natures. 2023.

Barthe, Y., Elam, M., Sundqvist, G., 2020. Technological Fix or Divisible Object of Collective Concern? Histories of Conflict over the Geological Disposal of Nuclear Waste in Sweden and France. Sci. Cult. 29 (2), 196–218. https://doi.org/10.1080/09505431.2019.1645108.

Bell, M., 2022. The Epistemic Tensions of Nuclear Waste Siting in a Nuclear Landscape. Environ. Plann. E: Nat. Space 6 (2), 841–862. https://doi.org/10.1177/25148486221117947.

Bergmans, Anne, Göran Sundqvist, Drago Kos, and Peter Simmons. 2015. 'The Participatory Turn in Radioactive Waste Management: Deliberation and the Social-Technical Divide'. J. Risk Res. Routledge. doi: 10.1080/13669877.2014.971335.

Brunnengräber, A., Di Nucci, M. R., 2019. Conflicts, Participation and Acceptability in Nuclear Waste Governance. Springer Fachmedien Wiesbaden. Doi: 10.1007/978-3-658-27107-7.

Chilvers, J., 2007. Towards Analytic-deliberative Forms of Risk Governance in the UK? Reflecting on Learning in Radioactive Waste. J. risk Res. 10 (2), 197–222.

Chilvers, J., Burgess, J., 2008. Power Relations: The Politics of Risk and Procedure in Nuclear Waste Governance. Environ. Plann. A: Econ. Space 40 (8), 1881–1900. https://doi.org/10.1068/a40334.

Cotton, M., 2017. Nuclear Waste Politics: An Incrementalist Perspective. Routledge.

Cotton, M., 2018. Environmental Justice as Scalar Parity: Lessons from Nuclear Waste Management. Soc. Justice Res 31 (3), 238–259. https://doi.org/10.1007/s11211-018-0311-z.

Di Nucci, M.R., Brunnengräber, A., 2019. Making Nuclear Waste Problems Governable (pp. 3–19). doi: 10.1007/978-3-658-27107-7_1.

Eckhardt, Anne, 2021. Sicherheit Angesichts von Ungewissheit Ungewissheiten im. Safety Case'. Literaturstudie. Zollikerberg. TRANSENS-Bericht-01- ISSN (Online) . pp. 2747 – 4186.

Emmenegger, R., 2023. Ein Mahnmal Im Zürcher Weinland: Hinkelstein Marthalen (ZH). In: Klauser, F., Landolt, S., Müller, M., Schoepfer, I. (Eds.), In 30 Tagen Durch Die Schweiz: Einblicke in Ungahnte Orte. Helvetiq, Basel, pp. 175–180.

Emmenegger, R., 2025. Nuclear Strata: Enacting Clay for the Deep Geological Disposal of Nuclear Waste in Switzerland. Environ. Plann. E: Nat. Space 8 (3), 978–1001. https://doi.org/10.1177/25148486251324935.

Emmenegger, R., 2026. Out of Sight, Out of Mind: Activism and the Scalar Politics of Nuclear Waste Governance in Switzerland. J. Pol Ecol (forthcoming).

Emmenegger, R., Luisetti, F., 2026. The Menhir: Aesthetic Politics of Radioactive Waste disposal in Northern Switzerland. Geogr. Hel 82 (2), 137–153.

Fischer, Michael. 2019. Atomfieber: Eine Geschichte Der Atomenergie in Der Schweiz. Hier und Jetzt, Verlag für Kultur und Geschichte.

Flüeler, Thomas. 2002. 'Radioaktive Abfälle in der Schweiz: Muster Der Entscheidungsfindung in Komplexen Soziotechnischen Systemen'. Doctoral Thesis, ETH Zurich. doi: 10.3929/ethz-a-004443549.

Flüeler, T., 2006. Decision Making for Complex Socio-Technical Systems: Robustness from Lessons Learned in Long- Term Radioactive Waste Governance. Springer.

Flüeler, T., 2024. Vom Bohren harter Bretter, Fester Gesteine Und von Schwierigem Perspektivenwechsel. Int. J. Nucl. Power 3, 7–22.

Hajer, M., 1995. The Politics of Environmental Discourse: Ecological Modernization and the Policy Process. Clarendon Press, Oxford.

Hietala, M., Geysmans, R., 2020. Social Sciences and Radioactive Waste Management: Acceptance, acceptability, and a Persisting Socio-technical Divide. J. Risk Res. 25 (4), 423–438. https://doi.org/10.1080/13669877.2020.1864010.

Hollnagel, E., 2014. Is Safety a Subject for Science? Saf. Sci. 67, 21–24. https://doi.org/10.1016/j.ssci.2013.07.025.

HSK, Hauptabteilung für die Sicherheit der Kernanlagen. 1993. 'Schutzziele für die Endlagerung radioaktiver Abfälle'. HSK-R-21.

HSK, Hauptabteilung für die Sicherheit der Kernanlagen. 2007. 'Sachplan geologische Tiefenlager. Herleitung, Beschreibung und Anwendung der sicherheitstechnischen Kriterien für die Standortevaluation. Schweizerische Eidgenossenschaft'. HSK. Retrieved August 19, 2024, from https://www.ensi.ch/de/wp-content/uploads/sites/2/2014/06/sachplan-geologische-tiefenlager_2007.pdf.

IAEA, International Atomic Energy Agency. 2006. 'Fundamental Safety Principles'. IAEA Safety Standards for protecting people and the environment: Safety Fundamentals No. SF-1.

Ialenti, V., 2020. Deep Time Reckoning: How Future Thinking Can Help Earth Now. MIT Press, Cambridge, London.

Krütli, P., Flüeler, T., Stauffacher, M., Wiek, A., Scholz, R.W., 2010. Technical Safety vs. Public Involvement? A Case Study on the Unrealized Project for the Disposal of Nuclear Waste at Wellenberg (Switzerland). J. Integr. Environ. Sci. 7 (3), 229–244. https://doi.org/10.1080/1943815X.2010.506879.

Kuppler, Sophie. 2012. 'From Government to Governance? (Non-) Effects of Deliberation on Decision-Making Structures for Nuclear Waste Management in Germany and Switzerland'. J. Integrat. Environ. Sci. 9(2), 103–22. doi: 10.1080/1943815X.2012.688752.

Kuppler, Sophie. 2017. Effekte Deliberativer Ereignisse in Der Endlagerpolitik: Deutschland Und Die Schweiz Im Vergleich 2010 Bis 2010. Springer. http://www.springer.com/series/12516.

Kuppler, Sophie, Anne Eckhardt, and Peter Hocke. 2023. 'Who Decides What Is Safe? Experiences from Radioactive Waste Governance in Switzerland'. In The Future of Radioactive Waste Governance, edited by M. Arentsen and R. van Est, 169–98. Springer. doi: 10.1007/978-3-658-40496-3_7.

Landström, C., Bergmans, A., 2015. Long-term Repository Governance: A Socio-Technical Challenge. J. Risk Res. 18 (3), 378–391. https://doi.org/10.1080/13669877.2014.913658.

Lehtonen, M., Prades, A., Espluga, J., Arapostathis, S. 2022. Introduction to the Special Issue "Trust, Mistrust, Distrust, and Trust-building in the nuclear sector: historical and comparative experience from Europe". J. Risk Res. 25(5), 547–561. doi: 10.1080/13669877.2022.2067892.

Lidskog, R., Sundqvist, G., 2004. On the Right Track? Technology, Geology and Society in Swedish Nuclear Waste Management. J. Risk Res. 7 (2), 251–268. https://doi.org/10.1080/1366987042000171924.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2011. 'Sachplan geologische Tiefenlager Etappe 2: Vorschläge zur Platzierung der Standortareale für die Oberflächenanlage der geologischen Tiefenlager sowie zu deren Erschliessung - Genereller Bericht'. NTB-11-01.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2014a. 'SGT Etappe 2: Vorschlag weiter zu untersuchender geologischer Standortgebiete mit zugehörigen Standortarealen für die Oberflächenanlage - Geologische Grundlagen'. NTB-14-02.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2014b. 'SGT Etappe 2: Vorschlag weiter zu untersuchender geologischer Standortgebiete mit zugehörigen Standortarealen für die Oberflächenanlage - Sicherheitstechnischer Bericht zu SGT Etappe 2'. NTB-14-01.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2014c. 'SGT Etappe 2: Standortareal ZNO-6b-Kombi im Planungsperimeter Zürich Nordost für die Oberflächenanlage eines geologischen Tifenlagers Kombi'. NTB-14-29.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2019a. 'Vorschläge zur Konkretisierung der Oberflächeninfrastruktur der geologischen Tiefenlager: Teil 1 – Einführung und Grundlagen'. NAB-19-08.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2019b. 'Vorschläge zur Konkretisierung der Oberflächeninfrastruktur der geologischen Tiefenlager: Teil 2 – Standortspezifische Vorschläge'. NAB-19-08.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2019b. 'Diskussion OFI ZNO: Begründung für die Ablehnung von ZNO-7 und OFI-15'. Fact Sheet.

Nagra, National Co-operative for the Disposal of Radioactive Waste. 2022. 'Der Standort für das Tiefenlager: Der Vorschlag der Nagra'. NTB-14-01. Mediendossier. Retrieved August 19, 2024, from https://nagra.ch/wp-content/uploads/2022/09/Bericht-zum-Standortvorschlag.pdf.

NEA, Nuclear Energy Agency. 2013. 'The Nature and Purpose of the Post-Closure Safety Cases for Geological Repositories'. OECD Publishing, Paris.

Parotte, C., Delvenne, P., 2015. Taming Uncertainty: Towards a New Governance Approach for Nuclear Waste Management in Belgium. Technol. Anal. Strat. Manag. 27 (8), 986–998. https://doi.org/10.1080/09537325.2015.1044429.

Parotte, C., Macq, H., Delvenne, P., 2024. The Efficacy Paradox Revisited: "Closing up" Commitments in Nuclear Waste Governance. Sci. Technol. Human Values 49 (2), 344–370. https://doi.org/10.1177/01622439221112459.

RC ZNO, Regional Conference Zurich North-East. 2014. 'Zwischenbericht Evaluation Standorte Oberflächenanlage'. Retrieved August 19, 2024, from https://www.zuerichnordost.ch/fileadmin/user_upload/Bibliothek/Evaluation_Standorte_Oberflaechenanlage_-_Zwischenbericht/ZNO_zwischenbericht_Standortareale.pdf.

RC ZNO, Regional Conference Zurich North-East. 2015a. 'Prozesssicherheit im Sachplan Geologisches Tiefenlager'. Report of the Safety Panel. November 13, 2015. Retrieved August 19, 2024, https://www.zuerichnordost.ch/fileadmin/user_upload/Bibliothek/Gesamtbericht_Etappe_2/Grundlagen_Gesamtbericht_8_4_Stellungnahme_UG_Prozesssicherheit.pdf.

RC ZNO, Regional Conference Zurich North-East. 2015b. 'Nachvollziehbarkeit des Eignungsvorschlag der Nagra: Bericht der Fachgruppe Sicherheit Zürich Nordost gemäss Leistungsvereinbarung 2015'. Safety Panel Report, October 28, 2015.

RC ZNO, Regional Conference Zurich North-East. 2016. 'Provisorischer Gesamtbericht der Regionalkonferenz ZNO zur Etappe 2 des Sachplanverfahrens Geologisches Tiefenlager'. Report, March 19, 2016.

RC ZNO, Regional Conference Zurich North-East. 2018. 'Ergänzender Bericht der Fachgruppe Sicherheit RK ZNO zur Etappe 2 des Sachplans geologische Tiefenlager'. Safety Panel Report. October 22, 2018.

RC ZNO, Regional Conference Zurich North-East. 2022. 'Stellungnahme des Vorstandes der RK ZNO zu Etappe 3: Nachvollziehbarkeit der Auswahl des Standortes für die Rahmenbewilligung und Bericht zur Zusammenarbeit im Rahmen der regionalen Partizipation.' Report, November 9, 2022.

Röhlig, Klaus-Jürgen. 2024. 'Der Safety Case Als Grundlage Für Entscheidungen Unter Ungewissheit'. In Entscheidungen in Die Weite Zukunft: Ungewissheiten Bei Der Entsorgung Hochradioaktiver Abfälle, edited by Anne Eckhardt, Volker Mintzlaff, and Roman Seidl, 229–52. Springer SV.

Röhlig, K.-J., Eckhardt, A., 2017. Primat Der Sicherheit: Ja, Aber Welche Sicherheit Ist Gemeint? Gaia 2, 103–105.

Schneider, Anna. 2019. 'Wissenschaft Und Gesellschaft: Kontroverse Um Partizipation Bei Der Suche Eines Geologischen Tiefenlagers in Der Schweiz'. Master's Thesis, University of Zurich.

Schröder, J., 2016. Geological Disposal of Radioactive Waste: A Long-term Socio-Technical Experiment. Sci. Eng. Ethics 22 (3), 687–705. https://doi.org/10.1007/s11948-015-9650-4.

Schröder, J., Rossignol, N., Van Oudheusden, M., 2016. Safety in Long Term Radioactive Waste Management: Insight and Oversight. Safety Sci. 85, 258–265. https://doi.org/10.1016/j.ssci.2016.02.003.

Seidl, R., Flüeler, T., Krutli, P., Moser, C., Stauffacher, M. 2017. Radioaktive Abfälle und Sonderabfälle im Vergleich. ETH Zurich.

SFOE, Swiss Federal Office of Energy. 2006a. 'Die Anwendung partizipativer Verfahren in der Entsorgung radioaktiver Abfälle'. Law and Safety Unit. February 2006.

SFOE, Swiss Federal Office of Energy. 2006b. 'Entsorgungsnachweis Projekt Opalinuston Zürcher Weinland: Bericht über die Ergebnisse des Auflageverfahrens.' June 26, 2006.
SFOE, Swiss Federal Office of Energy. 2008. 'Sectoral Plan for Deep Geological Repositories. Conceptual Part.' Retrieved August 19, 2024, from https://pubdb.bfe.admin.ch/en/publication/download/3437.
SFOE, Swiss Federal Office of Energy. 2011. 'Sectoral Plan for Deep Geological Repositories. Conceptual Part.' Revised version November 2011. Retrieved August 19, 2024, from https://www.bfe.admin.ch/bfe/de/home/versorgung/kernenergie/radioaktive-abfaelle/sachplan-geologische-tiefenlager/etappe-1.html.
SFOE, Swiss Federal Office of Energy. 2015. 'Die Anwendung partizipativer Verfahren in der Entsorgung radioaktiver Abfälle'. Regional Participation Unit. March 2015.
SNEA, Swiss Nuclear Energy Act. 2003. Nuclear Energy Act (NEA) of 21 March 2003 (Status as of 1 January 2021). SR 732.1.
Solomon, B.D., Andrén, M., Strandberg, U., 2010. Three Decades of Social Science Research on High-level Nuclear Waste: Achievements and Future Challenges. Risk, Hazards Crisis Public Policy 1 (4), 13–47. https://doi.org/10.2202/1944-4079.1036.
SNEO, Swiss Nuclear Energy Ordinance. 2004. Nuclear Energy Ordinance (NEO) of 10 December 2004 (Status as of 1 February 2019). SR 732.11.
TFS, Technical Forum Safety. 2014. 'Frage 111: Versagen der Abschirmung der OFA'. Retrieved August 19, 2024, from https://www.ensi.ch/de/technisches-forum/versagen-der-abschirmung-der-ofa/.
TFS, Technical Forum Safety. 2022. 'Frage 161: Verifizierung und Falsifizierung von Modellen'. Retrieved August 19, 2024, from https://www.ensi.ch/de/technisches-forum/verifizierung-und-falsifizierung-von-modellen/.
Wynne, B., 1996. May the Sheep Safely Graze? A Reflexive View of the Expert-lay Knowledge Divide. In: Scott, L., Szerszynski, B., Wynne, B. (Eds.), Risk, Environment and Modernity: Towards a New Ecology. Thousand Oaks/Sage Publications, pp. 44–83.