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Chapter 8

“Old Is Gold?”



Nuclear Safety in the Face of Climate Change

Stéphanie Tillement

Abstract Climate objectives, as well as the recent objectives of energy sobriety and security in response to crises, have underpinned a call for the urgent development of nuclear generation capacity. At the same time, recent events have highlighted fragilities in nuclear infrastructures, both in their operation and in their design and construction. This chapter focuses on the French case to examine the conditions under which the nuclear industry can provide an appropriate response to climate change, as well as the risks and vulnerabilities associated with a nuclear revival. In particular, we analyze the two regimes at the heart of this revival: the extension and the acceleration regimes. We show that the interplay between nuclear power and climate change calls into question the social and temporal scales at which risks need to be defined and governed.

Keywords Nuclear infrastructures · Safety · Climate urgency · Time · Scales

8.1 Introduction

On May 16, 2023, the French Parliament officially passed a new law (Nuclear Acceleration Act) aimed at accelerating administrative procedures for the construction of new nuclear reactors, of the EPR2 type, as soon as 2024. Concurrently, the intended change in French nuclear safety doctrine and organization—the merger of the ASN (Nuclear Safety Authority) with the IRSN (Institute for Radiation Protection and Nuclear Safety)—was temporarily rejected.

Climate goals, as well as recent objectives of sobriety and energy security in reaction to crises, have supported a call for an urgent development of nuclear production capacity. Meanwhile, recent events have highlighted (unsuspected) fragilities in nuclear infrastructures, concerning both their operation and their design and construction. In the Summer of 2022, France had 32 out of 56 nuclear reactors shut down, a record number. This unprecedented situation has raised fears about energy security

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in a country that still had 69% nuclear power in its electricity mix in 2021. Many contingencies and disruptions have combined to lead to this situation. The COVID-19 crisis was partly responsible for delays in planned maintenance outages. Stress corrosion cracking was fortuitously discovered on safety equipment of the most recent reactors (P'4 and N4 series). This led the operator EDF to shut down 12 reactors in order to carry out extensive checks to assess whether stress corrosion was a threat to nuclear safety. Design and construction projects have been halted or significantly delayed, preventing them from compensating for the drop in production. Extreme climatic events have added to this, with a record number of heatwave days and severe drought. Low water levels in rivers used to cool the reactors led to a reduction of nuclear power production. For those who were not yet fully convinced of the acuteness of the problems to come, 2022 was a powerful reminder. Experts agree that this situation, previously considered as exceptional, will unfortunately become the norm (IPCC 2021). Anticipating and preparing for the consequences of climate change on the operation of high-hazard organizations (including nuclear power plants) has thus become urgent.

The situation of French nuclear infrastructures is an exemplary case of how economics, politics and technical and environmental contingencies interact and affect safety and climate goals. It also highlights how latent shortcomings and normalized forms of deviance (Vaughan 1997) combine with crises and their side effects. Drawing on the case of the French nuclear industry—and its long-term trajectory of operation and development—this chapter aims to open a conversation about the interplay between safety and climate change challenges when it comes to nuclear power plants. This problem can be tackled in two ways:

1. How may climate change affect the functioning of nuclear infrastructures?
2. How can nuclear technologies best contribute to climate change mitigation?

The first question involves analyzing the many imperatives that these systems should meet and how they can (or not) be articulated, in the short and long terms. In particular, it questions whether nuclear safety should always be treated in a relatively isolated way or whether this imperative could be articulated with others, such as production and security of supply, in a more integrated risk governance approach. The second question entails examining which technologies and innovation regimes (exploitation/exploration) are most likely to contribute effectively and rapidly to decarbonization and GHG reduction, in the face of the climate emergency.

8.2 From Nuclear Risks to Climate Risks: Toward a “Nuclear Renaissance”?

Civil nuclear power is emblematic of the risk society that emerged with modernization (Beck 1996; Lockie and Wong 2018). Its history has been marked by three major accidents, which have rekindled concerns about the use of nuclear technologies¹ (Perrow 2011). The most recent one, Fukushima, fell into the category of “Natech” accidents that “are seldom purely natural or technological” (Knowles 2014, cited in Verma 2021). It forcefully revealed the vulnerability of these “ultra-safe” systems to extreme climatic events, an increasingly serious threat with climate change. While experts used to consider as very low the probability of a natural disaster causing an industrial disaster, they now agree on the importance of being prepared for such a combination of natural and industrial events, in a cascading effect. The French nuclear industry did not wait for the summer of 2022 to think about the effects of climate change on the operation of nuclear facilities. The particularly critical 2003 heatwave prompted nuclear safety experts to assess the vulnerabilities to extreme weather events and ways of dealing with them. Fukushima has further reinforced this concern. Safety authorities asked operators to assess the risks induced (among others) by natural hazards on existing and future nuclear facilities and to propose measures in order to prevent or protect from them.²

On the one hand, socio-environmental changes worldwide induce new vulnerabilities that challenge traditional methods of risk calculation, management and governance. Rather than treating natural and industrial disasters as separate events, it calls for an integrated approach to these hazards, as suggested by the “Natech” accident concept. Beyond safety, these extreme climate events raise sustainability concerns, leading some researchers to consider that sustainability now includes safety (Kermisch and Taebi 2017). For example, the reduction in nuclear production capacity from May 2022 in response to drought and low water levels in rivers was mainly aimed at avoiding environmental pollution.

On the other hand, the fight against climate change has become increasingly central in the framing of nuclear issues. As François Jacq stated on December 7, 2022:

Twenty to thirty years ago there were two main issues: security of supply and cost; you needed energy and you needed it cheap. A third imperative was added, relating to the climate: decarbonisation. The whole energy issue is contained in this triptych, being understood that the mix of these different concerns varies over time. (Assemblée Nationale 2023)

While the opponents to nuclear power put forward nuclear risks and unsustainability due to nuclear waste, the nuclear industry and new ecologists tend to frame

¹ Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011).

² At the European scale, this operation was known as the “Stress tests”. Its French equivalent is “Complementary Safety Assessment” (Évaluations complémentaires de sûreté—ECS), which defined the concept of a “Hard Core” as a set of materials and organizational arrangements to ensure the control of crucial safety functions in extreme situations.

nuclear power as a “clean and green energy” and thus as a “pragmatic response to interrelated challenges of energy independence, climate change, and resource scarcity” (Ialenti 2014). The increasing concerns about global warming and the objectives of GHG emissions’ reduction opened the way to a so-called nuclear renaissance. In 2022, the European Commission officialized nuclear power’s contribution to the decarbonization of the energy mix, awarding it a “green” label.

In the world energy landscape, France is often described as an exception. It remains the most “nuclearized” country in the world considering the share of nuclear power in total electricity production. In some years, nuclear power produced more than 80% of the total electricity, which led Gabrielle Hecht to consider that “France is nuclear like nowhere else”. This production is assured by 56 pressurized water reactors (PWRs), now known as a “generation 2” technology. They were built between 1974 and the late 1990s, under the Messmer Plan that supported a massive deployment of civil nuclear power. This industry is the third largest industry in France, with 220,000 employees. Beyond these figures, the singularity of the French ecosystem pertains to its history and the network of actors on which it rests. The main French licensees, EDF and the CEA, have been present from the very beginning of the French nuclear history, contributing to a very stable nuclear ecosystem. This exceptionalism is reflected in the governance of this ecosystem, which leans on tight and complex links between operators and the State, and hence between technology and politics (Hecht 2009).

In the early 2000s, after a phase of severe slowdown—described by some parliamentarians as a “nuclear winter”—France also believed in a possible nuclear renaissance. This hope was part of an international effort to boost R&D in the civil nuclear industry, marked by the launch in 2000 of the “Generation4 International Forum” (GIF) by the American Department of Energy (DOE), along with 12 countries (including France).³ The emergence of the term “generation” during this forum was far from neutral: it supported an evolutionary reading advancing the idea of an almost linear and natural succession of ever safer, more sustainable and more efficient reactor generations. In France, this translated into the launch of the Flamanville EPR⁴ in 2007 and ASTRID⁵ in 2010, spearheading the third and fourth generations of nuclear reactors, respectively, and setting high objectives in terms of sustainability and safety. Yet, in 2019, the difficulties of the French industry became visible with two announcements a few months apart: (1) the official abandonment of the ASTRID project; (2) the severe analysis of the EPR by Jean-Martin Folz who described the project as an industrial failure (Folz 2019). These two events sounded like a major warning, tarnishing the image of the main organizations involved, primarily EDF, ex-Areva (now split between Orano and Framatome) and the CEA. This paved the way for major questions in the press and in the political and academic arenas. Was the French nuclear industry able to meet the twenty-first century’s major challenge: to give France, through its capacity to operate and build reactors, a leading role in the decarbonization of electricity production? It was no longer just a matter of knowing

³ See GIF Charter, 2001.

⁴ European Pressurized Reactor.

⁵ Advanced Sodium Technological Reactor for Industrial Demonstration.

whether the use of nuclear energy and thus the continuation of the French nuclear adventure were desirable, but whether this continuation was possible, at what price and under what conditions.

8.3 “Time Matters”

The difficulties encountered by the nuclear industry were widely commented upon. The President of the nuclear safety authority (ASN) declared in 2022 that the main source of fragility of the nuclear system was the lack of anticipation from EDF; the operators blamed the lack of long-term planning from the State; Folz evoked an unrealistic initial assessment of delays and a generalized loss of skills to explain the setbacks of the EPR. All these explanations relate to time. In the same vein, the recent *Commission of Inquiry* (Assemblée Nationale 2023) highlighted the extent to which nuclear projects are affected by the conflict between short-termism and long-termism that drastically limits the possibilities of anticipating plausible futures and planning actions (Slawinski and Bansal 2012), with huge consequences on the nuclear industry. This classical conflict translates the inter-temporal tension between “political time” (a maximum of one electoral term) and “nuclear time” (the life cycle of nuclear installations—several decades, from the decision to build a facility to its dismantling). Its major projects have faced the difficulty of resolving, in the very short term, the contradictions produced over a very long time period.

For the first time in almost 30 years, the government seems to be backing a large-scale nuclear revival, reflected in the Acceleration Act. We propose the notion of “temporal regime” as an analytical tool to explore the timing and tempo of this nuclear revival and to analyze the risks and emerging vulnerabilities it may entail. The nuclear industry’s activities fall within two main temporal regimes, anchored in two narratives: the *extension regime* and the *acceleration regime*.⁶ Both regimes respond to the climate emergency, but each refers to specific activities and carries its own risks or vulnerabilities (Table 8.1).

The extension regime is in line with the need to maintain the existing fleet, to “make it last” beyond the 40 years initially planned to meet the decarbonization objective, but also to supply electricity at an acceptable cost. This regime is based on a highly centralized and stable organization, involving the operator EDF that remains solely responsible for nuclear safety under the law, the nuclear safety authority and its technical support organization, IRSN. Safety is built through constant technical dialogue between these three players⁷. This highly stable system entails its own

⁶ The identification of these regimes is based on a careful analysis of the minutes of the meetings of the *Commission of inquiry on the loss of sovereignty and energy independence of France* (November 2022–February 2023). It also draws on the numerous formal and informal interviews held within the framework of the research projects conducted over the last ten years in relation to the nuclear sector (RESOH Chair, AGORAS project—Grant ANR-11-RSNR-0001—and NEEDS program).

⁷ The parliament finally voted to merge the ASN and IRSN in March 2024, despite strong protests. This is likely to alter the dynamics of relations and naturally calls into question the stability of the

Table 8.1 Temporal regimes of the French nuclear industry

	Acceleration regime	Extension regime
Narrative and tempo	Urgency in the face of climate change Intermittency	Maintenance/durability Stability
Goals	Decarbonization of the energy mix Innovation/competitive advantage	Energy supply at an acceptable cost Decarbonization of the energy mix
Central activity	Innovation (design and construction)	Operation (production and maintenance)
Social organization	Mostly unstable and distributed	Mostly stable and centralized
Risks and vulnerabilities	Increasing complexity → Threats both to nuclear safety and energy security Generic or systemic defaults (e.g., SCC)	Delays and cost overruns Crises → delays → Threats both to nuclear safety and energy security

vulnerabilities. “Making nuclear installations last” presupposes an army of maintenance workers who perform very substantial work within short deadlines so as not to penalize production, while guaranteeing a very high level of safety. This, of course, implies maintaining and renewing the expert knowledge and skills of these maintainers. It also calls into question the nature of the relationships involved:

- Between the licensee and contractors, as a significant proportion of maintenance activities are outsourced.
- Between occupations within organizations: maintenance work is affected by internal tensions, notably between engineering and maintenance. These tensions, linked to a different relationship to the operation of technical infrastructures and therefore to the practices and rules that underpin their maintenance, mirror those that exist between the operator and the regulator.

They point to a major potential weakness of the extension regime, i.e., the increasing complexity of the regulatory, managerial and cognitive infrastructures of maintenance activities, at the risk of a lesser understanding of the systems by those responsible for maintaining them. The challenge is to ensure that the care given to existing installations (and their partial renewal) is part of a sustainable form of innovation, i.e., toward systems that are easier to control, hence more robust.

The acceleration regime fits in with the urgency to act in the face of climate change and endorses the framing of nuclear power as a pragmatic response to the objective of decarbonized energy production. It is materialized in the recent “French

regime. The way in which safety will be affected by this change will be interesting to analyze over the coming years.

Acceleration Act” and mainly involves the development of a series of six EPR2.⁸ Unlike the extension regime, which relies on perennial organizations, the acceleration regime unfolds within projects, thus temporary organizations. The most recent projects, EPR and ASTRID, have shown the fragilities induced by largely unstable physical, managerial (planning) and regulatory infrastructures. This contributed to the difficulties in steering and running these projects. The size and complexity of the infrastructure contributed to the failure of the EPR project (Folz 2019), in particular by preventing the simultaneous pursuit of safety and industrial performance objectives. ASTRID suffered from the CEA’s pro-innovation bias, with the introduction of unplanned and unshared breakthrough innovations, making it difficult to steer and defend the project. Both projects faced the “knowledge crisis” inherent to the design profession, and particularly critical in the nuclear sector, firstly because it requires expert, distributed skills and secondly because of the intermittent nature of design and construction activities. The drop in activity following the Messmer Plan, combined with the associated illusion of overcapacity, led to an unlearning process from which the EPR and the ASTRID project (albeit to a lesser extent) suffered greatly. The inability of stakeholders (the State, the operators and the regulator) to fully acknowledge and then manage the intermittency of design and construction has contributed to the current pitfalls: projects with uncertain status, between innovation and renewal of old technologies, role conflicts between historical actors and disengagement of some. It exacerbated tensions between operators, designers and regulators, preventing them from defining clear objectives and standards, making trade-offs and evaluating performance, leading to a delegitimization of the nuclear sector.

These two regimes are clearly interdependent: acceleration and extension involve the same organizations and the same resources. All projects, be they design, construction or maintenance, are launched at the same time, which compels the nuclear industry to manage the cumulative dimension of these projects. The lack of long-term national strategic planning combined with short-termism (also denounced as an impediment for organizations to effectively address climate change issues) has deprived the nuclear system and more widely the electricity system, of its margins in terms of skills, personnel or technology, at the risk of making it more vulnerable to unforeseen events and snowballing effects. The succession of recent crises has shed light on systemic vulnerabilities. The COVID-19 crisis showed the difficulties in planning and organizing major maintenance operations on a very large scale, as well as the possible disastrous consequences of the absence of margins for nuclear safety but also security of supply in the future. The war in Ukraine highlighted the very tight coupling between nuclear plants’ availability and safety and energy supply. This

⁸ The Acceleration law also provides for the development of small modular reactors (SMRs). While the EPR2 program is still organized centrally around EDF, both operator and architect, many SMR projects are led by start-ups. Private players are emerging alongside the major historical players (EDF, Orano, CEA). If SMR projects were to be developed, they would involve a more decentralized, or at least more distributed, organization, similar to those prevailing in the USA. This would be new in France and would necessarily involve changes in safety governance. As SMRs are still in the nascent stages of development, we will not discuss them in this article.

“era of disruption” (Bansal 2019) involves new risks, which emerge from and bring into play interdependencies that go beyond the scope of a given organization (i.e., between systems, organizations and institutions). Part of these interdependencies already existed but were previously invisible or simply overlooked.

These questions are of particular importance since the lack of anticipation forces the nuclear industry to operate increasingly following a logic of speed and results in increasing production pressures, which affect both regimes. All the chain of nuclear organizations is concerned, down to the contractor that employs welders, which is asked to train experienced welders in record time (3–4 years instead of 7 years). The safety literature has demonstrated the negative effect of precipitation and speed on safety performance (Blount et al. 2005). It underlines the complexity of articulating different requirements and associated (possibly contradictory) time frames, e.g., safety with climate or performance goals. While speed is often celebrated as “a synonym of good” in the face of the “sense of urgency”, some organizations that have become famous for their rapid decision-making are now equally famous for their mistakes and disastrous consequences (e.g., NASA) (Vaughan 1997).

These movements raise very important and difficult questions about the prioritization and definition of safety in relation to other imperatives: is safety still the number one priority (as reflected in the “safety first” doctrine)? And what type of safety? Nuclear safety? The latter is one of the variables (crucial of course) in the equation to solve when deciding to invest in nuclear power and to choose the best technology. While the objective is of course to design and operate safe systems, the debate is about the level of safety that can be achieved in relation to other crucial requirements. Safety, like performance, is multi-dimensional. The example of French nuclear power shows perfectly how dealing with a nuclear safety problem may generate new risks because of the close coupling between the production means and the supply system. It includes the risk of a “blackout” and its major side effects, at the societal scale, on infrastructures, transports, health ... and thus on human lives.

One major stake is to redefine nuclear safety in its articulation with all the other types of safety, such as security of supply, environmental or ecological safety or health and safety at work and more broadly with sustainability and other forms of performance. This also requires a tight articulation between the extension and articulation regimes. These regimes raise essential questions concerning the care to be given to the existing infrastructures and the logic of innovation that should prevail in the choice of future technologies, i.e., the *exploitation* of known and mastered technologies or the *exploration* of new and disruptive solutions, in the hope for increased performance. The first approach has two major advantages, especially in the context of urgency: (1) they can be rapidly deployed; (2) they present far fewer uncertainties (notably unknown unknowns) than exploratory projects. The extension of reactors’ lifespan and the decisions to opt for a simplified design of the Flamanville EPR for EPR2 and to develop it in series, all point to a prevalence of the exploitation logic.

8.4 “Working Things Out”: Toward a Broader and Long-Term Approach

A socio-temporal lens reveals two paradoxical consequences of the long-term trajectory of the French nuclear infrastructure: it has the peculiarity of being at the same time highly institutionalized and destabilized. The extended history of reactor operation has led to very high expectations from regulators, public authorities and civil society regarding safety, reliability and industrial and economic performance. However, the discontinuous trajectory of design and construction activities over the past decades, alternating highs and lows of activity, has led to a disintegration of skills and a weakened industrial base. New reactor projects, primarily ASTRID and the EPR, have felt within this ambiguous framework of undermined organizations subject to ever-increasing requirements.

The nuclear industry’s ability to contribute positively to the fight against climate change will depend on its capacity to jointly govern different types of risk and on its degree of preparedness for emerging vulnerabilities induced by interdependencies between risks (or types of safety). This calls for a systemic approach, which is sensitive to aligning global and local scales as well as the short and long terms. It is far from simple. As put by Hecht et al. (2020), “our political systems are not at all designed to deal with these kinds of issues, especially with the election period. Everything is short-term”. Developing nuclear infrastructures to meet climatic goals while ensuring their safety means first acknowledging such inter-temporal conflicts. One way to do so is probably to devote effort to long-term vision and planning. Planning can mean restricting degrees of freedom in the short term, against greater freedom and security in the medium and long term. This meets the current debate in France around “energy” or “ecological planning” and necessarily raises the question of the organizational and socio-material conditions for “effective” planning—in the pragmatist sense of a capacity to engage in relevant actions (Lorino 2018)—able to take into account the multiple requirements and to think about their articulation, notably safety/security and climate change. Neglected in the 1990s and 2000s, in a tacit agreement between the executive and the nuclear lobby, plans and scenarios are re-emerging as central tools in the face of the “energy wall” (Assemblée Nationale 2023). However, the impact of such tools depends on how they are designed, mobilized and governed and by whom. In the face of climate change, it is probably time to open them up to new players. If public debates do not appear to be the most appropriate vehicle (in view of the most recent debate on the EPR2), Parliament could play a more important role in the governance of nuclear issues, to foster inter-organizational and inter-institutional discussions (as has been the case for nuclear waste since the 1991 Bataille law).

More importantly—and the energy sector is a striking example—safety governance arrangements have to rely on detailed knowledge and consideration of the interdependencies between the means of production (which, in the case of nuclear technologies, are high-risk organizations) and the entire energy production and supply

system. Following this, it is no longer possible to think at the level of one organization or even one industry. The governance of risk involves the inter-institutional scale. This opens new debates about the role of the Nuclear Safety Authority (ASN) (and its TSO, IRSN), its decisions and prescriptions. They have been revived very recently by the government's (strongly contested) decision to have Parliament vote to merge the ASN and IRSN, thereby challenging the strict separation between expertise and decision-making. The effects of this reform on the safety regime will be interesting to analyze in the years to come. For example, the ASN (and its TSO) have been criticized for being too zealous, for following mostly a bureaucratic logic while remaining voluntarily ignorant of the industrial realities (Finon 2023). Furthermore, while the independence of the Nuclear Safety Authority is unquestionable, the risks of a primacy of the conformity requirement over the safety requirement or the concordance between safety requirements and socio-economic issues are worthwhile topics for debate.

As Perrow forcefully showed decades ago, safety—and this is all the more true with other imperatives—is also a matter of aligning divergent interests and organizing power relationships. This social alignment work is due at several levels: at a meso-level (how organizational actors integrate and articulate the imperatives in their work and daily actions and decisions) and at a macro-level (aligning policymakers, regulators and industry actors' interests). It also means going beyond binary oppositions. For example, what would it mean, theoretically and practically, to consider safety as a dimension of performance in its own right and to handle it jointly with the other dimensions of performance, such as costs and delays? If the alignment work is fundamental to meet the challenges of safety and climate change, the work of contextualizing is just as important: the generic principles and global lessons have to be adapted to the local technopolitical context. In the continuation of Engwall's famous phrase, "no project is an island", no technology or industry is an island either. High-risk organizations—especially nuclear facilities—are not installed in a vacuum, but must fit into a system of interactions that brings into play numerous technical, political and social interdependencies, which goes far beyond the nuclear system alone and the present time. Meeting the challenges of safety and climate change is a matter of bridging scales.

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