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# Understanding the blind spots in the warning process during NaTech events: lessons from the Blayais Nuclear Power Plant Flood in France (1999)

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In a context of increasing industrialization, population growth in hazard-prone areas and intensification of hazard triggers, integrating NaTech risks into crisis management planning and warning processes has become more and more essential. This paper examines lessons learned from Hurricane Martin, which struck France on December 27, 1999 - causing the flooding of the Blayais Nuclear Power Plant (NPP) on the Gironde estuary. By focusing on the alert process and the coordination among actors, the study examines lessons learned beyond the dominant emphasis on technical and procedural solutions. It reconstructs the alert timeline, information flows, and decision-making chain based on reports from prefectural services, nuclear technical reports, and post-event press articles, in order to produce a “consolidated feedback”.The study shows that vulnerability arises not only from physical impacts on infrastructure but also from fragmented communication and coordination, as each actor followed its own institutional logic and corrective procedures. This fragmentation highlights dilemmas related to alerts that could have arisen, such as conflicting instructions between sheltering (to limit radiological exposure) and evacuation (due to flooding). Finally, this near-miss accident demonstrates the need for preparatory lessons-learned frameworks that capture how risk is progressively built through signal interpretation, uncertainty management, governance arrangements, and alert practices in complex NaTech crises.

*Keywords*: warning, NaTech, experience feedback, nuclear, flood, storm.

## 1. Introduction

On 27 December 1999, Hurricane Martin struck western France and caused extensive damage to life (27 deaths) and property. The storm especially caused partial inundations in the Blayais nuclear power plant (NPP), located on the Gironde estuary, leading to the loss of several safety-related systems. This event led to the activation of the national nuclear crisis organization and was classified as Level 2 on the International Nuclear Event Scale (INES). Although it did not result in any radiological release, the Blayais event, however, revealed critical vulnerabilities in the interaction between a natural hazard and a high-risk technological system.

This case study is particularly relevant in a context of intensifying climate-related hazards affecting critical infrastructures, where interactions between environmental disturbances and technological systems increasingly challenge safety management practices (Galderisi and Ceudech (2010); Krausmann et al. (2017)). Such NaTech accidents (i.e. the consequence of natural hazards on technological activities) do not fit neatly into traditional lessons learned reports (RETEX). Corrective lessons learned have proven effective in analyzing and preventing “classic” industrial accidents by identifying technical or organizational failures and reinforcing safety barriers. Their relevance is more limited, however, when applied to NaTech accidents, which arise from complex and tightly coupled configurations. From Perrow's perspective, such accidents can be considered "normal": they result from non-linear interactions within highly complex technological systems (Perrow, 1984) and from their interaction with natural hazards, as illustrated by Fukushima (Perrow (2011)). As a result, they cannot be fully prevented through the ex post correction of identified failures alone. In this context, the challenge is not only to prevent the recurrence of a given event, but also to learn how organizations cope with such situations as they unfold.

## 2. Theoretical background

While RETEX (or lessons learned feedback) is often conceived as a means to capitalize on past events and transfer actionable knowledge, the literature also shows that this objective becomes more difficult to achieve if organizations face situations characterized by uncertainty, interaction effects, and evolving conditions. Causal chains are, in fact, difficult to isolate and failures do not unfold in linear or orderly sequences (Perrow (1984)). Safety performance also relies on situated adaptations and variable practices that are difficult to capture ex post (Hollnagel (2014)). Moreover, incident investigations and lessons-learned processes often reconstruct simplified narratives after the event (Dekker (2014); Le Coze (2013)).

A long-standing contribution of organizational accident research has been to show that accidents and safety breakdowns must be understood across multiple analytical levels, including macro (institutional and regulatory environments), meso (organizational structures and coordination), and micro (situated action and sensemaking) dimensions (Vaughan (1996); Le Coze (2013)). Lessons-learned processes are therefore not neutral technical tools, but socio-institutional devices whose scope and content are shaped by organizational, regulatory, and political constraints.

From a complementary perspective, Safety-II and resilience engineering approaches emphasize that safety does not rely solely on the prevention of failures, but also on organizations' capacity to adapt to variability and manage uncertainty in practice (Hollnagel (2014)). These approaches draw attention to situated adjustments, trade-offs, and sensemaking processes that are central during crises, yet often remain weakly visible in formal lessons-learned outputs.

## 3. Materials and methods

In this study, we conducted a multi-phase analysis. Phase 1 reconstructed the event chronology to reveal the dynamics of the NaTech risk configuration. Phase 2 examined how institutional RETEX captured only part of these dynamics. Phase 3 built on this gap to develop a lessons-learned framework adapted to NaTech risks.

### 3.1. *Study site and the 1999 near-missed accident*

The Blayais NPP is located in the Gironde estuary, at 40 km northwest of the city of Bordeaux (Figure 1). The plant has four pressurized water nuclear reactors with a capacity of 900 MWe, operating in pairs (R1-R2 and R3-R4). Before the 1999 event, main studies had already identified the inadequacy of the site's flood defenses, with the dike facing the Gironde rising to approximately 5.2 m NGF and the side protections to 4.75 m NGF. Following the 1999 floods, the dike was significantly reinforced, reaching 6.20 m NGF, and supplemented by a breakwater wall rising to 8.5 m NGF (IPSN (2000), ASNR Archives). These measures directly addressed the material vulnerability identified after the event: the overflowing of protective structures by wind-driven waves.

On the evening of 27 December 1999, the tidal coefficient was 77 (average level), but the situation was aggravated by exceptionally strong winds (194 km/h) blowing in the direction of the Gironde estuary. According to the Joint Association for the Sustainable Development of the Gironde Estuary (SMIDDEST), the surge associated with the storm reached 1.55m at the mouth of the estuary (Le Verdon) and 2.25 m in Bordeaux. As a consequence, NPP's operators were confronted with a growing number of technical anomalies: several alarms were triggered intermittently; electrical disturbances affected several units (R1, R2 and R4; not R3 as this unit was in maintenance), and extreme weather conditions complicated routine surveillance and maintenance activities.

### 3.2. *Data collection and selection*

In order to analyze this event, we collected data from both primary and secondary sources. The ASNR's paper archives[a] were one of the primary sources used to locate both primary and secondary information. A total of 30 folders were analyzed between October and December 2025.

Primary materials were selected for their capacity to document the event as it unfolded, with minimal retrospective reinterpretation. These sources include operational logs, onboard journal, and shift handover produced during and immediately after the event, documenting technical anomalies, alarms, and on-site actions. These materials were systematically cross-checked to establish a chronological reconstruction of the event, from early meteorological warnings to the restoration of normal operations.

In addition to these primary sources, we collected secondary sources consisting of lessons-learned documents produced after the event by institutional actors (plant operator, nuclear safety authorities, and governmental bodies). Reports from prefectural services and nuclear safety authorities during or immediately after the event were selected to document crisis organization activation, information flows, and inter-organizational coordination. Press articles helped capture public framing and temporal narratives of the event.

### 3.3. *Data Analysis*

The next step is consistent with process-oriented qualitative analysis (Langley (1999)) and abductive reasoning, in which analytical categories emerge from systematic comparison between different representations of the same event (Tavory and Timmermans (2014)). Together, these three phases provide an empirical basis for assessing what institutional lessons-learned processes capture - and what they leave aside - when confronted with evolving and interacting risk configurations. The data analysis followed a three-step process.

#### *Phase 1 - Chronology of the near-miss accident*

The first phase consisted in reconstructing the chronology of the Blayais event from the perspective of action. Rather than starting from predefined accident categories or failure modes, the analysis focused on what actors did, perceived, and decided over time. Using operational logs, field reports, testimonies, and institutional records, the chronology was rebuilt around sequences of practices, decision points, interruptions or adjustments due to the evolution of the situation. The chronology transcription method was borrowed from Laosunthara et al. (2025).

#### *Phase 2 - Institutional lessons learned mapping*

In a second phase, we analyzed the institutional lessons-learned documents produced after the event by the plant operator, nuclear safety authorities, and governmental bodies. An analysis framework grid has been built for more objective analysis of feedback from experiences of different institutional lessons learned reports. The analysis focused on identifying recurring themes such as technical issues, procedural weaknesses, and regulatory gaps, as well as the types of corrective measures proposed, including infrastructure reinforcement, updated hazard assumptions, and revised alert and emergency procedures.

#### *Phase 3 - Gaps and lessons learned for managing NaTech risks*

The third phase of the analysis consisted of a systematic comparison between the reconstructed chronology of the event (Phase 1) and the institutional lessons-learned documents (RETEX) produced after the crisis (Phase 2). The objective of this comparison was to identify what these frameworks stabilize, and conversely, what they leave aside when confronted with a NaTech situation. By examining these mismatches, the anal-

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[a] ASNR (Autorité de Sûreté Nucléaire et de Radioprotection) Archives. Selected folders n°69397, 69398, 69399, 69400, 69401, 69402, 69493, 206223, 212898, 212903, 212904, 212905, 212906, 212907, 287477, 287479, 290379, 291836, 291837, 291840, 296096, 296098, 296128, 300082, 304332, 1094558, 1098243, 1098830, 1098833, 1098834. Accessed on October 8, November 6 and 7, and December 8 and 9, 2025. Fontenay-aux-roses (FAR), France.

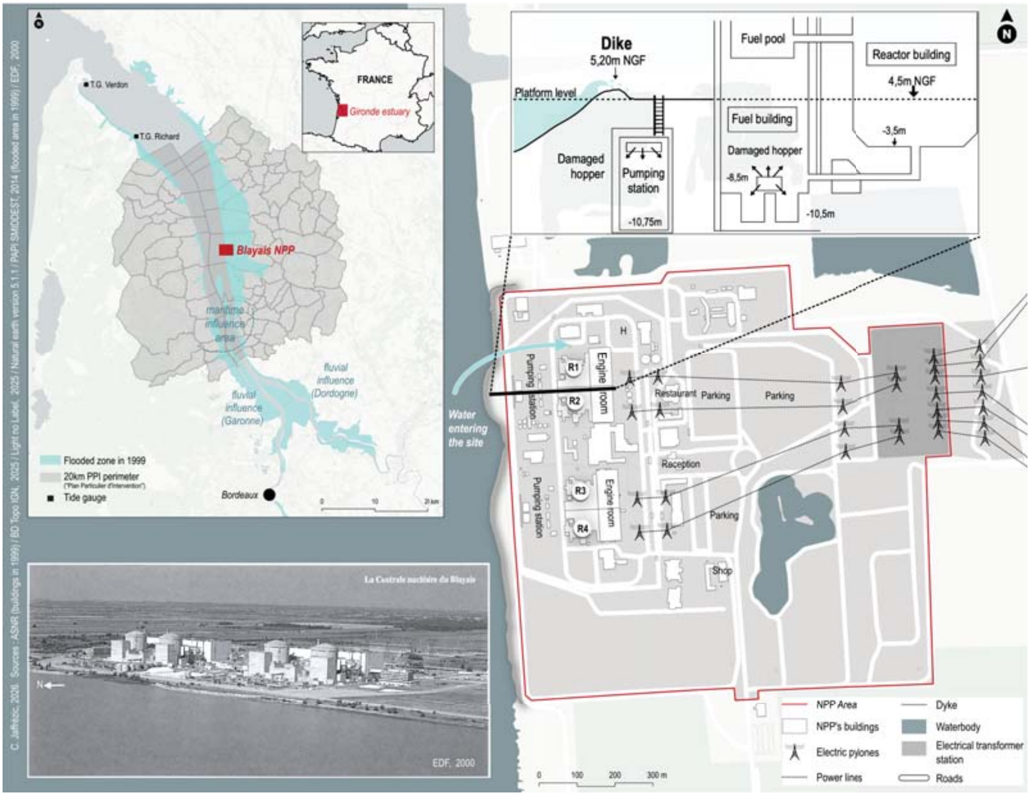


Fig. 1. Location map of the Blayais nuclear power plant

ysis makes it possible to outline the contours of an alternative lessons-learned approach, oriented toward managing interacting risks.

## 4. Main Findings

This part presents the main findings from Phase 3.

### 4.1. *The alerting process*

Analysis of the chronology of the Blayais NPP near-miss accident during the storm Martin (1999) first reveals a crisis that progressively emerged due to the overlapping of multiple disruptions, rather than a linear sequence manageable by predefined scenarios. The extreme weather conditions, the degraded access, the power outages, and the progressive water infiltration mutually limited the diagnostic and response capabilities of the various stakeholders. These disruptions did not follow an orderly escalation but overlapped and reinforced one another, reducing the margins for isolation and anticipation. Four mechanisms were then identified.

(i) Cautious weather warning: Although regional and national warnings were issued before the storm's arrival, the complexity of cyclogenesis made forecasts uncertain, forcing the warnings to be developed "in the heat of the moment" (Dedieu (2013))). A major institutional obstacle also weighed on the decision: the fear of a "false warning." [b].This mistrust led (fueled by previous events earlier in the year), during the Blayais's event, to the disregard of certain bulletins that did not reflect the exceptional nature of the event, preventing any serious consideration of the risk of

[b]Indeed, Météo-France and the Civil Security applied an informal tolerance of approximately 15% for forecast errors in order to maintain the system's credibility (Corvalan (2005); Dedieu (2009))

flooding.

(ii) Reinterpreted signs: The apparent impossibility of flooding, led to a series of delays in perceiving the danger. As an example, some signals were interpreted as routine signals. Around 09:00 p.m., high-level alarms on the water collection sump in sections 1 and 2 were treated as routine rainwater runoff events rather than signs of external flooding. This reinterpretation of the signs, in other cases, occurred under constraint, such as when at 10:00 p.m. an ICRF alarm went off in section 4 (indicating a high water level in the Gironde estuary), but it was interpreted as potentially false due to the possible submersion of a tide gauge. Here, the doubt was resolved by arguing the need not to apply the procedure in order to continue supplying the already disrupted network.

(iii) The visual isolation of the operators in the control room, coupled with the limited outdoor movement due to the wind, prevented the flooding from being perceived as a spatially coherent phenomenon. The flood diagnosis suffered from a time lag between the start of the seepage in levels R1 and R2 (10:00 p.m) and its official recognition (12:20 a.m) (Figure 2-period 3). Several concrete indicators appeared during this interval, but were difficult to analyze.

(iv) Interdependence and Failure of Warning Systems: In addition to ignored warnings, reinterpreted signs, and obstacles to field verification, the crisis revealed a dependance on formalized technical warning systems. The information feedback systems were poorly designed, relying exclusively on two tide gauges (an ultrasonic gauge at Verdon and a float gauge at the Richard station) which both failed simultaneously due to the storm. No periodic checks of these devices had been carried out since December 11, 1998 (ANSR archives, FAR/ folder no. 291840, DSIN-FAR/SD2 no. 0283/2000).

### 4.2. *Tensions between safety and continuity of service*

A second type of mismatch between Phase 1 and Phase 2 concerns the governance of crisis management - that is, the way of prioritization, hierarchy, and multi-level coordination structure decision-making in situations involving interacting risks. The reconstructed chronology shows that decisions were shaped not only by the technical condition of the nuclear installation, but also by broader system-level and organizational constraints.

At the macro level, the storm severely disrupted the national electrical grid, which became an explicit consideration in local decision-making. For instance, when a high-water ICRF alarm was detected around 10:00p.m in Unit 4, the procedure theoretically required the application of a specific instruction and the dissemination of information to other units. However, the timeline indicates that this directive was not implemented, primarily due to the choice to continue operating Unit 1 in order to maintain electricity supply to a severely disrupted power grid (Figure 2). This illustrates how continuity-of-service considerations entered the decision rationale alongside nuclear safety rules.

At the meso-organizational level, escalation toward external authorities followed thresholds designed for more conventional accident progressions. At 10:40p.m, the PCD1 (on-call duty for the management team of a pair of units) informed the DIN (the local division of ASNR) of the difficulties encountered on site, while explicitly noting that there was “no regulatory obligation” to do so at that stage (Figure 2). Similarly, although a level-1 PUI could in principle have been triggered earlier following the observation of exceptional water levels, institutional feedback documents later noted that such activation would have had little operational effect, given that access roads were already closed and reinforcements could not reach the site (ASN Archives, DSIN-GRE/ADIR, n°15/2000). Escalation decisions were therefore shaped by logistical feasibility and territorial disruption, not only by predefined procedural thresholds.

At the micro level, the chronology documents how organizational roles and perceived legitimacy structured information flows. After flooding was observed in Unit 2, the formal operational recognition occurred at 00:20am (Figure 2), and the field operator delayed informing the control room

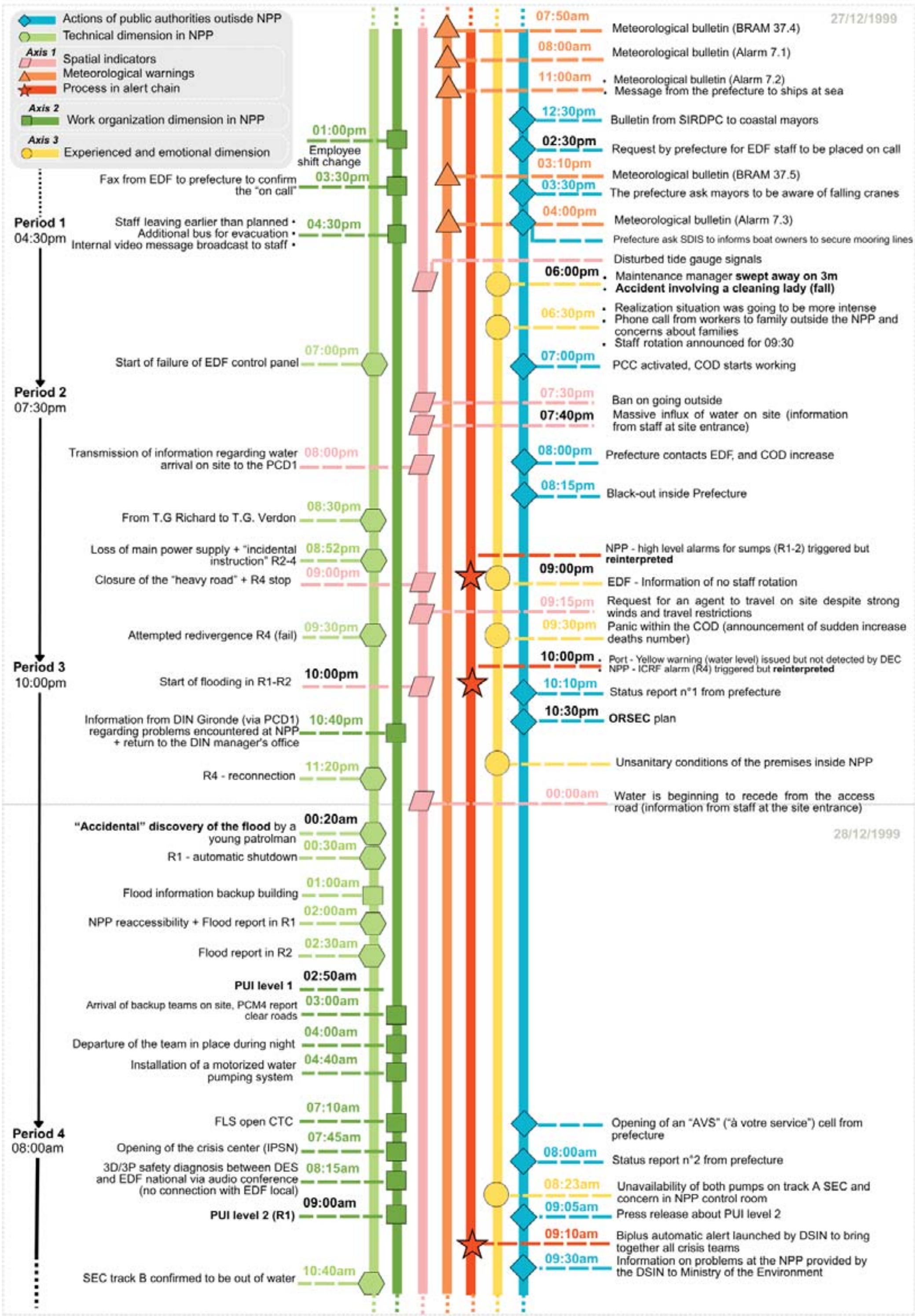


Fig. 2. Simplified timeline of the flooding of the Blayais power plant on December 27 and 28, 1999

by approximately 30 minutes, explaining that he did not feel legitimate interrupting operators already mobilized by numerous technical failures (Daniel (2017)). The issue here was not the absence of empirical information, but the way hierarchical positioning and situational norms produced an implicit hierarchy of what constituted an interruptive and legitimate alert.

### 4.3. *Experiencing a NaTech crisis beyond siloed risk framings*

The Blayais chronology documents that, during Storm Martin, actors were exposed simultaneously as workers responsible for a critical installation and as individuals affected by the same hazard as the surrounding population (weather conditions, access to the site, fatigue, stress, material constraints). However, the chronology highlights that populations are often overlooked in feedback reports. Experiential and emotional dimensions are often set aside. When populations are included, it is to report factual statements, such as to present a victim, etc. The chronology highlights this observation using the yellow axis (Figure 2). As an example, two successive incidents occurred at 6:00 p.m.: the maintenance manager was swept away 3 meters while leaving the power station, and a cleaning lady fell in section 3/4, carried away by the wind (ASNR Archives - FAR/folder no. 291840, EDF special storm issue of "C'est arrivé dans les centrales", February 2000). A rare example of an emotional engagement was reported around 6:30 p.m. : employees receive news about their families on their phones, worry about them, but communications are cut off and they resume their work (Daniel (2017)). Furthermore, events involving emotion and workers are reported mainly in secondary sources. On the forecasting side, a conference call held on December 26 at around 9 p.m. shows that the chief forecaster identified a particular cyclogenesis anticipated a possible southward trajectory,. The forecaster's judgment was supported by an analogy with a storm she had helped to predict in February 1996, illustrating how experience-based reasoning comes into play in the production of warnings in situations of uncertainty (Dedieu (2015)). On site, Daniel reports that employees do not necessarily consider official weather messages to be exceptional, because they know the region and have already experienced storms while other sensory cues, such as a continuous rumbling noise in the unit manager's office, contribute to a more embodied perception that the situation was about to become more intense (Daniel (2017)).

## 5. Discussion

Following "the storm of the century", the Blayais NPP flooding event remains one of the most significant floods ever experienced by a French nuclear installation. As such, it has generated extensive institutional feedback and analysis, which played a decisive role in the evolution of safety standards, external hazard protection measures, and regulatory frameworks. However, our analysis shows that this corrective logic captures only part of what becomes decisive in NaTech crises, where natural hazards interact with complex technological systems and organizational arrangements.

Building on Safety Science work, particularly Le Coze's call for interdisciplinary approaches to learning from accidents, this paper argues that NaTech events—understood as "normal accidents" in Perrow's sense—require lessons learned that go beyond corrective stabilization. When risk emerges from interacting, non-linear, and evolving configurations, learning cannot be reduced to failed barriers or procedural deviations alone.

Our findings highlight the interest of a multidisciplinary RETEX framework structured around three complementary axes. First, a geographical perspective draws attention to the heterogeneity of alerts and signals across spatial and organizational scales. At Blayais, the lack of resonance between external hydrological monitoring and internal plant indicators delayed collective diagnosis, showing that learning must address how signals interact rather than whether they exist.

Second, a sociological and political perspective on governance reveals how prioritization, hierarchy, and multi-level coordination shape decision-making under constraint. Decisions were influenced not only by plant conditions but also by grid stability, access limitations, and escalation thresholds, underscoring the need for RETEX that document trade-offs rather than merely assess compliance.

Third, a psychological perspective highlights the lived and emotional dimension of NaTech crises. Actors were simultaneously managers of a critical installation and individuals exposed to the natural hazard, making sensemaking, attention, and adaptation central to action. Capturing these dimensions is essential for lessons learned aimed at managing interacting risks, rather than only correcting past failures.

## 6. Conclusion

This paper contributes to research on NaTech preparedness by proposing an analytical shift in how lessons learned from such events are conceived. Using the Blayais near-miss as an empirical case, it shows that NaTech crises call not only for corrective lessons - aimed at reinforcing physical barriers, procedures, and standards - but also for lessons-learned frameworks oriented toward preparedness. Such frameworks must be capable of capturing how risk is progressively constructed through the interpretation of heterogeneous signals, the management of uncertainty, governance arrangements, and alerting practices in situations where hazards interact. By articulating the distinction between corrective learning and preparatory learning, the paper outlines a pathway for extending the lessons learned beyond their dominant focus on technical and procedural fixes. Its main contribution is therefore not the proposal of new safety devices or regulations, but the identification of what is required for lessons-learned processes to better support organizational preparedness for non-stabilized and interacting risk situations, such as those characteristics of NaTech events.

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