ZENITH PUBLICATIONS

OPEN ACCESS JOURNAL

AcuteFront: Journal of Emergency Intelligence & Care

Review Article

Decision Pathway for Early Hospital Response to CBRNE Incidents

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Received Date : *April 07, 2026*
Accepted Date : *May 20, 2026*
Published Date : *May 25, 2026*

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Citation: Ludovici GM, Tassi PA, Cusimano L, D'Agostino F, Malizia A. Decision Pathway for Early Hospital Response to CBRNE Incidents. Acute Front J Emerg Intell Care. 2026;1(1):1-.

Abstract

Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) incidents remain among the most demanding challenges for acute care because they combine uncertain hazard characterization, contamination risk, and time-critical decisions under resource constraints. Recent hospital focused studies show persistent gaps in preparedness, particularly in staff training, personal protective equipment, decontamination capability, and the practical execution of response procedures. At the same time, CBRNE science has increasingly moved toward integrated systems thinking, emphasizing the coordination of planning, response, recovery, lessons learned, and continuous improvement rather than isolated activities. On this basis, the present paper proposes a hospital-centered, decision driven operational framework for acute care settings. The framework organizes response around early hazard recognition, protected patient flow, contamination control, command-and-control, logistics, and continuity of essential clinical activity, with recovery and after-action review incorporated as part of the same operational pathway. Its purpose is to translate preparedness into a practical model that supports safer clinical decisions, limits secondary exposure, and strengthens institutional resilience during high consequence incidents.

Keywords: CBRNE; Emergency medicine; Hospital preparedness; Decision-making; Decontamination

Introduction

Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) events represent a distinct category of high-impact emergencies for hospitals because they can overwhelm routine clinical pathways, disrupt essential services, and expose staff and patients to secondary harm [1,2]. Unlike conventional mass casualty events, these incidents often present an initially unclear threat profile, delayed clinical evolution, and the need for immediate protective actions before the agent is fully identified [3]. In this context, emergency departments are not simply receiving units. They become the first hospital interface where clinical care, contamination control, and operational decision making must occur simultaneously [3].

Despite growing awareness, the available evidence continues to show substantial variability in hospital readiness. Systematic and survey-based studies repeatedly identify shortcomings in decontamination infrastructure, Personal Protective Equipment (PPE) availability, training frequency, and the operational translation of written plans into usable procedures. A recent systematic review of hospital preparedness measures found that decontamination, PPE, and detection were the most frequently addressed domains, while transportation, points of dispensing, and mortality management were often neglected [4-11]. In a nationwide German survey, only 12.02% of emergency departments reported the ability to properly decontaminate supine patients, and only 27.51% had appropriate PPE available. In a Jordanian national assessment, 59.1% of healthcare providers reported no hospital policy, and 76.8% had never received CBRNE specific major incident training [8,10,12].

These findings point to a broader problem than equipment shortage alone. Recent CBRNE science frameworks argue that preparedness is most effective when it is treated as an integrated system, spanning planning, incident management, recovery, lessons learned, and continuous improvement [13,14]. Similarly, recent qualitative work on hospital risk management highlights the importance of clear leadership, command-and-control, logistics, safety culture, protected communication, and structured post event review. In other words, the challenge is not only whether hospitals have a plan, but whether they can convert that plan into coherent action under uncertainty [14-16].

Against this background, the present article proposes a hospital-centered, decision-driven operational framework for CBRNE acute care response. The aim is to move beyond static preparedness checklists and to describe a practical model that links early recognition, contamination aware triage, protected clinical pathways, staff safety, continuity of care, and post event learning within a single operational logic. This paper does not aim to provide a systematic review, but rather to develop a conceptually grounded and operationally oriented framework based on current evidence and practical considerations.

The Challenge of CBRNE Incidents in Acute Care Settings

CBRNE incidents introduce a level of complexity that exceeds the boundaries of conventional emergency management. Their defining characteristic is not only the potential for mass casualties, but the simultaneous presence of contamination risk, uncertain exposure pathways, and evolving clinical presentations. These elements require hospitals to operate under conditions where diagnostic clarity is limited, while decisions must still be taken rapidly to protect both patients and healthcare personnel [13,17].

In acute care settings, the initial phase of response is particularly critical. Patients may self-present without prior field decontamination, as documented in previous incidents, effectively transferring the hazard into the hospital environment. This dynamic creates a dual responsibility: delivering immediate clinical care while preventing secondary contamination. The absence of early control measures can compromise entire departments, disrupt hospital functionality, and amplify the impact of the event [13,16,17].

The clinical management of exposed individuals is further complicated by the heterogeneity of agents and their effects. Chemical exposures may produce rapid and severe symptoms requiring immediate intervention, while biological agents can present with delayed or non-specific manifestations, increasing the risk of misclassification [13]. Radiological and nuclear exposures introduce additional challenges related to detection, long-term risk assessment, and psychological impact. Explosive events may combine trauma with potential contamination, requiring parallel management of injuries and hazard control. This convergence of clinical and environmental factors differentiates these scenarios from standard emergency pathways [13,15,16].

Operationally, hospitals must adapt to a model that integrates clinical care with safety protocols [13]. This includes the establishment of controlled zones, separation of patient flows, and the use of appropriate protective measures. However, evidence suggests that such adaptations are often incomplete or inconsistently applied. Variability in infrastructure, resource allocation, and institutional training leads to uneven response capacity across healthcare systems. In many cases, procedures exist at a theoretical level but are not fully embedded in routine practice [18,19].

Another critical aspect is the role of healthcare personnel. Staff are required to operate in high-risk environments, often with limited information about the nature of the threat. This increases cognitive load, affects decision making, and introduces the possibility of error, particularly in the early stages of response. The need to balance self-protection with patient care represents a fundamental tension in these scenarios, and it requires both technical competence and organizational support [6,7,11-13].

These challenges highlight the need for a shift in perspective. Preparedness should not be interpreted solely as the availability of equipment or written plans, but as the ability of the system to function under uncertainty [20]. This includes the capacity to recognize hazards early, to adapt workflows dynamically, and to maintain clinical effectiveness while ensuring safety. The complexity of CBRNE incidents therefore lies not only in their technical aspects, but in the interaction between clinical, organizational, and environmental factors [20,21].

Building on this understanding, the following section examines the limitations of current hospital preparedness models and the reasons why existing approaches often fail to translate into effective operational response.

Limitations of Current Hospital Preparedness Models

Although considerable efforts have been made to improve hospital preparedness for high-consequence events, existing models often show structural and operational limitations when applied to real CBRNE scenarios. These limitations do not necessarily arise from the absence of planning, but from the difficulty of translating plans into effective action under conditions of uncertainty, time pressure, and incomplete information [22-25].

A first critical issue concerns the gap between theoretical preparedness and operational capability. Many healthcare facilities report the presence of emergency plans that include hazardous material scenarios. However, evidence indicates that these plans are frequently generic, insufficiently detailed, or not fully aligned with the specific requirements of contamination management. As a result, key elements such as patient flow separation, controlled access, and decontamination procedures may not be implemented consistently when an incident occurs [15,16,22,24].

This gap is closely linked to training and familiarity with procedures. While guidelines and protocols exist, their practical application depends on repeated training, simulation, and integration into routine workflows. In many settings, training remains infrequent or focused on conventional emergencies, leaving personnel insufficiently prepared to manage contamination risks, use specialized protective equipment, or operate within structured zones [4,6,16,24,25]. This lack of operational familiarity can delay decision making and increase the likelihood of inappropriate actions during the early phase of response [26].

Infrastructure and resource constraints represent another major limitation. Effective management of contaminated patients requires dedicated spaces, appropriate ventilation systems, decontamination facilities, and adequate stocks of personal protective equipment. Studies have shown that these resources are unevenly distributed, with some hospitals lacking even basic capabilities for safe decontamination or isolation. In such conditions, the risk of secondary contamination within the facility becomes significant, potentially compromising both patient safety and staff protection [13,27,28].

Beyond material resources, organizational structure plays a central role. Existing preparedness models often rely on linear or compartmentalized approaches, where planning, response, and recovery are treated as separate phases. In practice, however, these domains overlap and interact continuously. The absence of an integrated framework can lead to fragmentation, with unclear responsibilities, inefficient communication, and delays in coordination between clinical, logistical, and safety functions [29,30].

Decision making under uncertainty is another under-addressed aspect. Traditional preparedness frameworks tend to assume a level of information that is rarely available in the initial stages of a CBRNE event [13,15,16,31]. In reality, hospitals must often act before the agent is identified, relying on incomplete data and evolving situational awareness. Without predefined decision pathways, this situation can result in inconsistent responses, variability between teams, and increased exposure risk [15,16,23,25].

Finally, current models often underestimate the importance of adaptability. Static protocols may not account for the dynamic nature of these incidents, where conditions can change rapidly and require continuous reassessment. The ability to adjust clinical pathways, reallocate resources, and modify protective measures in real time is essential, yet not always supported by existing preparedness structures [13-16,24,25].

Taken together, these limitations suggest that improving preparedness requires more than expanding resources or updating protocols. It requires a shift toward models that integrate clinical and operational functions, support decision making in uncertain environments, and enable adaptive responses. On this basis, the following section introduces a decision-driven operational framework designed to address these gaps and provide a more coherent approach to hospital response [13,25].

A Decision-Driven Operational Framework for CBRNE Response

Based on the limitations identified in current preparedness models, an effective hospital response to CBRNE incidents requires a shift toward a structured yet adaptive decision framework. The proposed model is designed to support early-phase management, when uncertainty is highest and the consequences of delayed or inappropriate actions are most significant. Rather than relying on linear protocols, the framework is organized around critical decision points that guide clinical and operational priorities in real time [13,23,32].

The first component is early hazard recognition. At the time of patient presentation, the nature of the threat is often unknown. Recognition therefore relies on a combination of clinical patterns, exposure history, and situational awareness [33]. Clusters of patients with similar symptoms, unexplained toxidromes, or atypical clinical evolution should trigger a precautionary approach. In this phase, the objective is not definitive diagnosis, but the rapid identification of potential risk and the activation of protective measures [13,26,33].

Following recognition, the model prioritizes immediate protective actions. These include the implementation of basic contamination control measures, restriction of access to clinical areas, and early use of appropriate PPE. The goal is to reduce the risk of secondary exposure before the hazard is fully characterized. This step represents a critical transition from routine care to contamination-aware management [6,8,13,34].

The next decision concerns patient stratification and flow management. Patients must be rapidly categorized based on clinical severity and contamination risk and directed through separate pathways. The definition of controlled zones allows the hospital to maintain functional integrity while limiting cross-contamination. Dedicated routes for contaminated and non-contaminated patients, as well as clear entry and exit points, are essential to ensure both safety and operational continuity [35-39].

Decontamination is integrated within this flow rather than treated as an isolated procedure. The timing and extent of decontamination depend on clinical stability and exposure characteristics. In unstable patients, life-saving interventions may take priority, while still applying measures to limit contamination spread. In stable patients, structured decontamination pathways can be applied before entry into clean clinical areas. This approach requires coordination between clinical teams and support personnel to ensure that procedures are both effective and feasible [6,8,13,15,16,23].

In parallel, command-and-control functions must be activated to coordinate the response. A clear leadership structure supports communication, resource allocation, and decision consistency across units. The integration of clinical, logistical, and safety components allows the hospital to operate as a unified system rather than as independent departments. This coordination is essential to manage evolving information and to adapt strategies as the situation develops [13-16].

Continuity of essential clinical activity represents another core element of the framework. While managing contaminated patients, hospitals must preserve their capacity to treat other emergencies. This requires the protection of clean areas, the maintenance of critical services, and the allocation of dedicated teams to avoid disruption of routine care. The balance between response and continuity is a key indicator of system resilience [6,8,15,24].

The final component of the framework extends beyond the acute phase and includes recovery and learning processes. Post-event evaluation, structured review of actions taken, and identification of critical issues allow the system to evolve. This feedback loop transforms individual events into opportunities for improvement, strengthening preparedness for future incidents [13,15,16].

Overall, the framework is not intended as a rigid protocol, but as a decision-oriented structure that supports consistent and adaptive responses. By linking early recognition, protective actions, patient flow, decontamination, coordination, and recovery within a single operational logic, it provides a practical tool for translating preparedness into effective clinical management.

Building on this operational model, the following section examines its implications for emergency medicine practice and its potential integration into routine acute care systems.

Operational Implications for Emergency Medicine

The implementation of a decision-driven framework has direct implications for emergency medicine practice, particularly in the organization of emergency departments and the management of early patient presentations. In this context, the emergency department represents the primary operational interface where clinical assessment, risk containment, and system coordination must occur simultaneously [13,36].

One of the main implications concerns triage processes. Conventional triage models are primarily designed to prioritize patients based on clinical severity, without accounting for contamination risk. In CBRNE scenarios, triage must integrate both dimensions. Patients should be assessed not only in terms of urgency of care, but also in relation to potential exposure and the risk of secondary contamination. This requires rapid classification into contamination-aware categories and the immediate direction of patients toward appropriate pathways [13-16,23].

Closely related to triage is the management of patient flow. The separation between contaminated and non-contaminated pathways is essential to preserve the functionality of the department. This separation must be established early and maintained throughout the response. It includes physical organization of spaces, controlled access points, and clear internal routing. Even in resource-limited settings, simplified forms of flow separation can significantly reduce cross-contamination and improve overall safety [13,15,23].

Staff protection is another central element. Healthcare personnel must be able to operate safely while maintaining clinical effectiveness. This involves not only the availability of personal protective equipment, but also familiarity with its correct use and limitations. The ability to rapidly transition from standard practice to protected care conditions depends on training, role definition, and clear procedural guidance. Without these elements, protective measures may be applied inconsistently, increasing both exposure risk and operational inefficiency [13].

The framework also influences decision-making processes at the clinical level. In the early phase of an incident, diagnostic certainty is often limited. Emergency physicians must therefore rely on structured decision points that support action under uncertainty. This includes adopting precautionary approaches when indicated, prioritizing containment over definitive diagnosis, and adjusting management strategies as new information becomes available. The ability to operate within this dynamic environment is a key competency in CBRNE scenarios [13,15,16,23,37].

Another relevant aspect is resource management. Emergency departments must balance the allocation of personnel, equipment, and space between contaminated patients and routine clinical activity. The presence of predefined roles and coordination mechanisms facilitates this process, allowing resources to be redirected without compromising essential services. This is particularly important during prolonged or large-scale events, where sustained operational capacity becomes critical [38-40].

Communication plays a fundamental role across all phases of response. Internally, clear and consistent communication supports coordination between clinical teams, support services, and leadership. Externally, communication with prehospital services, public health authorities, and other institutions ensures alignment of actions and information flow. Ineffective communication can lead to duplication of efforts, delays, and increased risk, while structured communication enhances both efficiency and safety [10,17].

Finally, the integration of recovery and post-event evaluation into emergency practice allows for continuous improvement. After-action reviews, identification of critical issues, and feedback from personnel contribute to refining procedures and strengthening preparedness. This process should be considered an integral part of emergency medicine in high-consequence scenarios, rather than an optional activity [13-16,41,42,43].

These implications highlight that managing CBRNE incidents is not an additional task layered onto routine practice, but a transformation of how emergency care is organized under specific conditions. The following section discusses the broader significance of this approach, its limitations, and directions for future development [14,42].

Discussion

The present work proposes a decision-driven operational framework aimed at improving hospital response to CBRNE incidents within acute care settings. The rationale for this approach emerges from a consistent finding across the literature: Preparedness is frequently present at a conceptual level, but its translation into effective operational response remains limited.

Existing studies highlight recurring deficiencies in training, infrastructure, and resource availability. However, the analysis conducted in this paper suggests that these elements, while important, are not sufficient on their own. The critical issue lies in how hospitals manage uncertainty, integrate multiple functions, and maintain coherence between clinical and organizational processes during the early phase of response [13-16,23,42].

In this context, the proposed framework aligns with broader developments in CBRNE science, which emphasize integrated systems, interdisciplinary coordination, and continuous improvement. These models underline the need to move beyond isolated components of preparedness and to consider response as a dynamic process that connects planning, action, and recovery. The decision-driven approach presented here reflects this perspective by focusing on operational continuity rather than static preparedness [13,14,42-44].

A central contribution of the framework is the emphasis on early decision points. In real-world scenarios, hospitals are required to act before complete information is available [6,8,13]. The ability to initiate protective measures, organize patient flow, and activate coordination structures under uncertainty is therefore a key determinant of outcome [44]. By structuring response around sequential decision nodes, the model provides a practical mechanism to support consistent actions across teams and reduce variability in practice [35].

Another relevant aspect concerns the integration of clinical care and contamination control. Traditional approaches often treat these domains separately, leading to fragmented responses. The proposed framework instead considers them as interdependent components of the same process. This integration allows hospitals to maintain clinical effectiveness while minimizing secondary exposure, which is particularly important in environments where resources and space are limited [18-20,24].

The discussion also highlights the importance of adaptability. CBRNE incidents are inherently dynamic, and response strategies must evolve as new information becomes available. Static protocols may fail to capture this variability, whereas a decision-oriented structure supports continuous reassessment and adjustment. This adaptability is closely linked to communication, leadership, and organizational culture, all of which influence how effectively the system responds to change [14,42].

At the same time, several limitations must be acknowledged. The framework is conceptual and has not been validated through prospective studies or real-world implementation. Its applicability may vary depending on local resources, infrastructure, and institutional organization. In addition, the variability of CBRNE scenarios means that no single model can fully address all possible conditions. For these reasons, the framework should be interpreted as a flexible guide rather than a prescriptive solution [13-16].

Future research should focus on testing the model in simulation environments and, where possible, in real incident settings. The integration of decision-support tools, digital systems, and real-time data analysis may further enhance its applicability. In parallel, efforts should be directed toward standardizing training and improving interoperability between hospitals and external response systems [14,42].

Overall, the findings suggest that improving hospital response to CBRNE incidents requires a shift in perspective. Rather than expanding existing preparedness measures, there is a need to reorganize them within a coherent operational structure that supports decision making, coordination, and adaptation.

Conclusions

CBRNE incidents challenge hospitals to operate beyond conventional emergency models, requiring the simultaneous management of clinical care, contamination risk, and system resilience. Current preparedness approaches, although necessary, are often insufficient to ensure effective response under real-world conditions.

This paper proposes a decision-driven operational framework that links early recognition, protective actions, patient flow management, coordination, and recovery within a single structure. By focusing on how decisions are made and implemented during the acute phase, the model aims to bridge the gap between preparedness and operational performance.

The framework is intended as a practical contribution to emergency medicine, offering a structured yet adaptable approach to managing complex scenarios. Its value lies in supporting consistent actions under uncertainty, reducing exposure risk, and preserving the functionality of healthcare systems.

Further validation is required to assess its effectiveness across different contexts. However, adopting a decision-oriented perspective may represent a necessary step toward improving hospital resilience and ensuring safer and more efficient responses to high-consequence events.

Deceleration

Ethics approval and consent to participate

The informed consent was waived because of the retrospective nature of this study.

Authors' contributions

Conceptualization: GML; Data curation: GML, AM; Formal analysis: PAT, FDA; Investigation: GML, PAT; Methodology: GML; LC; Project administration: AM; Resources: GML; Supervision: AM; Validation: AM; Visualization: GML; Writing–original draft: FDA; Writing–review and editing: all authors.

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