

Original Research

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Abbreviations:


ARS, Acute Radiological Syndrome; C&C, Command and Control; CBRN, Chemical, Biological, Radiological, and Nuclear; DIM, Detection, Identification, and Monitoring; ED, Emergency Department; GOR, General Organizational Responsibilities; HART, Hazardous Area Response Team; HF/E, Human Factors and Ergonomics; HPA, Health Protection Agency; HTA, Hierarchical Task Analysis; IRAS, Integrated Research Application System; MDU, Mobile Decontamination Unit; NIC, Nurse in Charge; PHE, Public Health England; PPE, Personal Protective Equipment; SARS, Severe Acute Respiratory Syndrome; WAD, Work as Done; WAI, Work as Imagined

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The Standardization of the Emergency Department Response to Chemical, Biological, Radiological, and Nuclear (CBRN) Events: Human Factors/Ergonomics Approach

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Abstract

Objective: To provide standardized recommendations for the emergency department (ED) response to chemical, biological, radiological, and nuclear (CBRN) events by combining the human factors/ergonomics method of hierarchical task analysis with the theoretical framework for Work as Imagined versus Work as Done.

Methods: Document analyses were used to represent CBRN response operational procedures. Semi-structured interviews using scenario cards were carried out with 57 first receivers (ED staff) to represent CBRN practice at 2 acute hospitals in England.

Results: Variability existed in general organizational responsibilities associated with the CBRN response. Variability was further evident in top level CBRN tasks and CBRN phases at both EDs. Operational procedures focused on tasks such as documentation, checking, and timing. CBRN practice focused on patient needs through assessment, treatment, and diagnosis.

Conclusion: The findings provide top-down and bottom-up insights to enhance the ED CBRN response through standardization. The standardized CBRN action card template embeds the choice approach to standardization. The standardized CBRN framework implements the streamlined categorization of CBRN phases. Work as Imagined versus Work as Done is a useful theoretical framework to unpack a complex sociotechnical system, and hierarchical task analysis is an effective system mapping tool in health care.

A chemical, biological, radiological, and nuclear (CBRN) event is “the exposure (or risk of exposure) of a large number of individuals to hazardous Chemical, Biological, Radiological, and Nuclear materials which may occur through a variety of means including natural, accidental, and deliberate acts.”¹ CBRN events can have a large impact on society at a number of levels, with health care systems being significantly affected. Examples of CBRN events are coronavirus disease (COVID-19), a recent global biological event,² the chemical sarin attacks in Tokyo,³ biological anthrax letters in the United States,⁴ use of radioactive polonium-210 in London,⁵ Birling Gap incident in East Sussex,⁶ and the Salisbury Novichok incident.⁷

In England, the Civil Contingencies Act (CCA)⁸ lays out responsibilities on NHS organizations to uphold civil protection and act as the foundation to emergency preparedness, response, resilience, and recovery. The emergency department (ED) is exposed to the highest risk level in health care.⁹ First receivers (ED staff) are required to care for CBRN-exposed patients, risking the danger of becoming patients themselves.¹⁰ CBRN plans (policies and procedures) are used to ensure that the requirements of the CCA⁸ and NHS England National Core Standards for Emergency Preparedness Response and Recovery¹¹ are delivered in NHS organizations.

The ED has been described as a complex sociotechnical system,¹² where groups of people such as patients, relatives, and clinicians interact with different technologies in various physical and organizational environments.^{13,14} Complex sociotechnical systems have been associated with unexpected variability in performance in which patient safety can be compromised.¹⁵

It has been reported that there is a lack of standardization with regard to NHS emergency planning, and there is an urgent need to standardize national planning, training, and evaluation of NHS staff who are expected to respond to CBRN events.¹⁶ This lack of consistency in clinical practice and processes results in variability in practice between health care organizations, departments, and even amongst clinicians, and creates challenges to responding to rare CBRN events.

Standardization aims to embed best professional practice while minimizing the risks of variation; this maximizes consistency of actions across teams, organizations, and the health system.¹⁷ Standardization can overcome variability by “setting formal rules to guide employees’

activities, which are operationalised in organisations by means of work instructions, guidelines, manuals, and work procedures”¹⁸ and is defined as “the process of developing, agreeing upon, and implementing uniform technical specifications, criteria, methods, processes, designs or practices that can increase compatibility, interoperability, safety, repeatability, and quality.”¹⁹

The scientific discipline of human factors and ergonomics (HF/E) uses an understanding of physical, psychological, and social abilities and limitations to develop systems with safe, effective, and productive interactions as (re)designed tasks, environments, and tools. It has been recommended that HF/E can be applied to redesign health care work systems and processes to improve the safety and quality of care.²⁰

One way of improving work in health care environments is to follow guidelines, policies, and procedures (Work as Imagined, WAI); this is what designers, managers, regulators, and authorities believe happen, or should happen in the workplace.^{21,22} Compliance with policies and guidelines would suggest that Work as Done (WAD; what workers actually do) is similar or identical.²¹ However, it has been suggested that absolute compliance with guidelines/procedures/policies is unrealistic because frontline staff need to improvise and adjust their work dynamically to respond to the situation and patient needs.²¹

This study aimed to provide standardized recommendations for the ED response to CBRN events by using hierarchical task analysis (HTA) to compare WAI with WAD.

Methods

HTA describes a task as a higher-level goal with a hierarchy of superordinate and subordinate tasks.²³ HTA has been suggested to be an effective way of stating how work should be organized to meet a system’s goals.²⁴

Ethics, Study Environment, and Recruitment

Ethical approval was given by the Loughborough University sub-committee (C17-22). Health Research Authority approval was granted through the Integrated Research Application System (219968). Research and Development approval was given from both hospitals.

Data were collected in England at 2 Type 1 EDs defined as “consultant led 24 hour service with full resuscitation facilities and designated accommodation for the reception of accident and emergency patients.”²⁵ ED-A served a population of 1 million residents, ED-B served a population of 600 000 residents. ED-A treated 237 000 patients, and ED-B treated 116 000 patients during the study period (2016–2017).

First receivers were approached through recruitment posters and information sheets in staff rooms. Nurses in Charge (NIC) discussed the study at a staff handover meeting a week before the researcher attended the ED. Then the researcher attended handover meetings to meet the first receivers and was available throughout the shift for those interested in participating.

Work as Imagined: Document Analysis

An exploratory document analysis of hospital CBRN policies and procedures (plans) was used to develop the preliminary HTA. Document analysis requires data to be thoroughly examined and interpreted to elicit meaning, understanding, and develop empirical knowledge.^{26,27} Applied thematic analysis was used to

underpin the pragmatic approach, as well as being applicable to practical problems in applied research.²⁸

Redacted CBRN plans for ED-A and ED-B were provided by the Lead Emergency Planning and Preparedness officer at both hospitals. The CBRN plans (2 parts) from the 2 EDs were analyzed:

Part 1: Set the scene for a CBRN event and how the ED should respond as a system within a system (hospital) and a larger system (Category 1 responder).

Part 2: First receiver action cards (n = 30).

Action cards (procedures), which are to be given to first receivers when a CBRN event occurs.

Pilot Study

To test the methods, a publicly accessible hospital CBRN plan was downloaded, analyzed, and converted into an HTA representation. The pilot exercise allowed reflection on data collection and available analysis software (eg, Human Factors Risk Manager, Microsoft PowerPoint, and Microsoft Visio). The pilot exercise allowed the formulation of a step-by-step plan for analysis, timescale planning, and familiarization with software; PowerPoint and Visio were used to provide clear and legible illustrations on 1 sheet of paper (of varying sizes), which supported the review/verification phases.

Data analysis

Data were extracted using document analysis and represented as HTAs. HTAs were analyzed with a 4-stage process:

1. Familiarization
2. Formation of superordinate tasks
3. Formation of HTAs
4. Manual analysis of HTAs, using applied thematic analysis and thematic color coding to support a comparative analysis

Human factors and ergonomics review

The HTAs were reviewed by 2 ergonomists and an academic with a clinical background (former ED nurse). Ergonomists are professionals who “seek to understand how a product, workplace or system can be designed to suit the people who need to use it.”²⁹ The review evaluated whether the HTA representations of the CBRN plans were optimal in terms of eradicating duplications. Inconsistencies were highlighted with the intention of making the HTA more logical and usable.

Work as Done: Semi-Structured Interviews

An exploratory qualitative design was used to develop the semi-structured interview proforma. Scenario cards were used to present hypothetical patients as a prompt for first receivers to “talk the researcher” through what they would do to respond to the scenario. Scenario cards have previously been used to test incident command systems in hospital-based disaster simulation exercises³⁰ and as tools for planning, improving, and handling CBRN events.³¹

The scenario cards were created from CBRN literature, observations at CBRN tabletop exercises at NHS hospitals, and Health Protection Agency (HPA) guidance.³² A Hazardous Area Response Team (HART) specialist reviewed the CBRN scenario cards to ensure that they were realistic. Three scenario cards included:

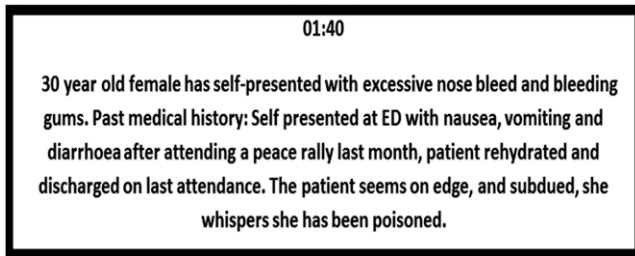


Figure 1. ARS scenario card.

1. Chemical: sarin
2. Biological: severe acute respiratory syndrome (SARS)
3. Radiological: acute radiological syndrome (ARS; Figure 1)

Pilot Study

Each scenario card was piloted with 2 participants. The pilot data allowed initial HTAs to be developed and compared.

The ease of creating the pilot HTA (Figure 2) confirmed that presenting the scenario card in the ED would provide valid and reliable insights into ED responses.

The use of scenario cards in disaster management research

Obtaining valid and reliable insights into how first receivers would respond to CBRN-exposed patients was important. CBRN events could not be anticipated ethically or created due to the life-endangering nature. Therefore, a variety of means were explored to determine the optimal method, such as software simulations, tabletop exercises and drills, and scenario cards. Scenario cards were selected because they have been reported as efficient and effective tools for planning, improving, and handling CBRN events.³¹ Scenario cards were cost-effective, not time-consuming, and allowed the continuation of patient care.

Sampling

Participants were recruited from the 2 EDs. The inclusion criteria were ages 18 years and over, more than 3 months' ED experience, ED as location of work, and belonging to first receiver staff group of allied health care professionals, doctors, medical physicists, nurses, porters, receptionists, and security staff, and employed in the ED for a minimum of 3 months on a substantive (permanent) contract.

A total of 57 participants were recruited (ED-A: 17 females and 11 males; ED-B: 13 females and 16 males). Ages ranged from 21–60 years (mean = 39 years, SD = 10). Participants were employed by the NHS in a different role or different department for an average of 12 years (SD = 8). The length of employment in the ED ranged from 3 months to 20 years (mean = 8 years, SD = 5).

Purposive sampling was used to identify and select individuals who were especially knowledgeable about, or experienced with, the phenomenon of interest.³³ A representative sample was ensured by calculating the percentage distributions of first receivers on a typical shift.

Data collection

During the first phase of semi-structured interviews, data were collected to obtain insights into WAD. Scenario cards were presented to first receivers. They were given time to read it and then asked to talk through their planned actions. Probes were used to expand on responses with “what, why, and who” questions. Field notes were made, which were later transcribed.

The second (verification) phase used the HTA developed from the first phase interview data. The verification process followed methodological guidance³⁴ to confirm the validity of the HTA representation (member checking). The verification process used the scenario card as a memory aid and explained the functions of HTA. The first receiver was then asked, “Do you think this diagram is a true representation of what you would do in a CBRN event?”—and they were prompted to discuss and amend the HTA.

Data analysis

Each transcript from the first phase (semi-structured interview) was read for familiarization to ensure complete immersion with the data. The field note and interview data were converted into HTAs (n = 57), using both Visio and PowerPoint. The HTAs were printed for manual analysis, and applied thematic analysis was used to systematically identify, organize, and code for patterns of meaning (themes) across the data set.³⁵

The synthesis of the themes provided a bottom-up perspective to standardization for WAD.

Rigor and credibility

Rigor is relevant to the reliability, validity, and reduction of bias in qualitative research.³⁶ Credibility, transferability, dependability, and confirmability^{37,38} are evidenced in Table 1.

Results

It was found that the ED response to CBRN events was different between the EDs for Work as Imagined (operational procedures) in terms of General Organizational Responsibilities (GORs). ED-A had 13 GOR themes and ED-B had 20 GOR themes, of which 13 overlapped, for themes such as decontaminate, don personal protective equipment (PPE), and isolate and contain. The HF/E review identified variance in the action cards for the following:

1. Prepare to respond to CBRN incident (ED-A and B).
2. Respond to CBRN incident (ED-A and B).
3. Initiate recovery from CBRN incident (ED-A).
4. Document CBRN incident (ED-A).

Color coding was used to illustrate the difference in the number of top-level tasks between ED-A and ED-B for the pre-incident, incident, and recovery phases (Figure 3 and Figure 4).

The pre-incident phase establishes an understanding of the potential actions required by the EDs for an effective response in liaison with other organizations such as Emergency Medical Services (EMS). The activation of the CBRN response was identical at both EDs.

The CBRN incident phase started with the notification of casualties. There was a difference in the incident phase with ED-A being more categorical in the response steps by having individual superordinate tasks such as “carry out required decontamination procedure.” ED-B combined the individual superordinate tasks under “respond to CBRN incident” and discussed specific CBRN procedures such as decontamination under “implement action pack.” An additional difference was the emphasis on documentation for operational procedures.

Both EDs stepped down from responding to the CBRN event by “initiating recovery.” At ED-A, recovery was associated with the decontamination of departmental infrastructure and the well-being of first receivers. At ED-B, recovery was a statement of ending the CBRN response.

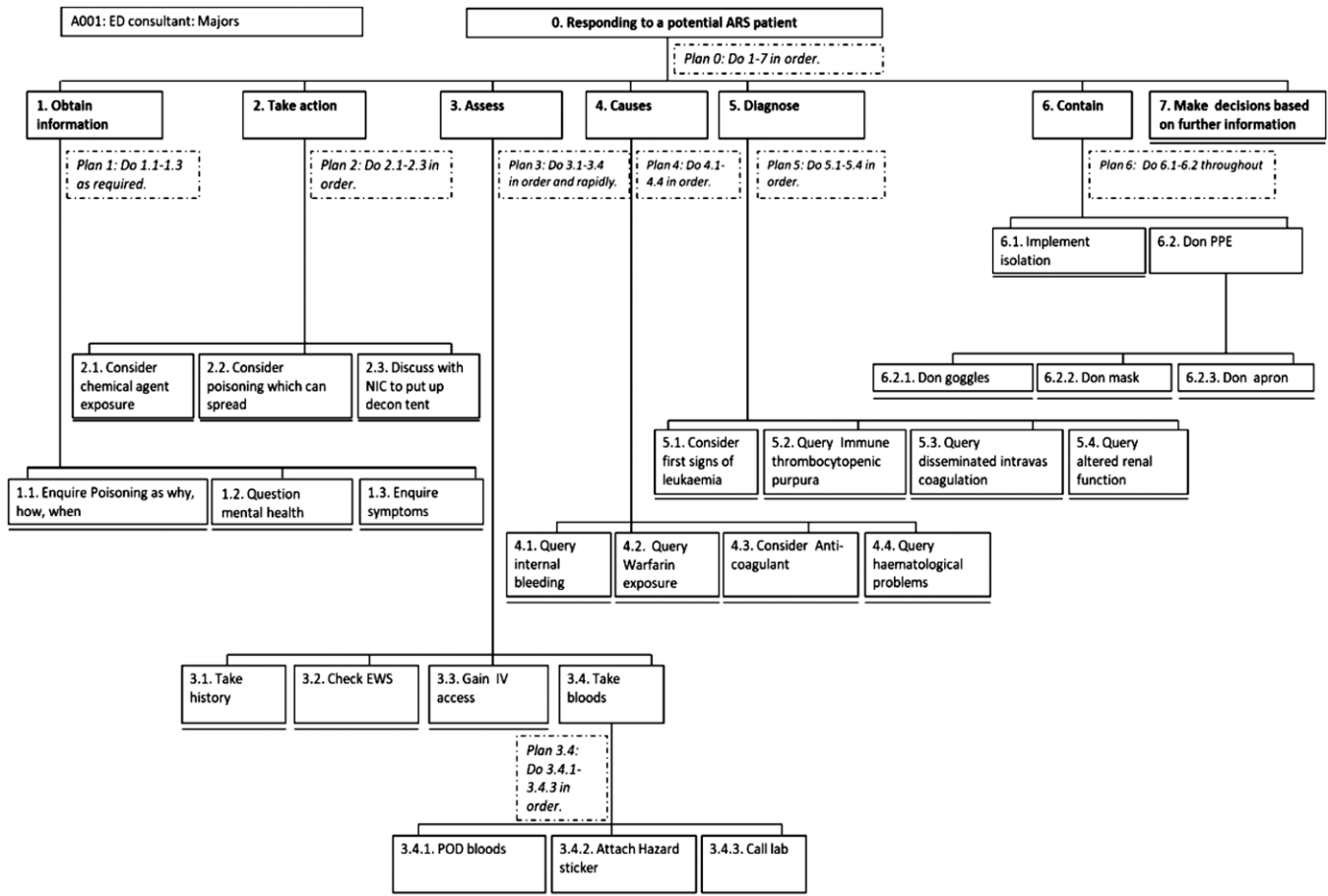


Figure 2. First receiver (ED consultant) response to ARS scenario card.

The semi-structured interviews provided insight into working practice (WAD). Nurses in Charge (NICs) at ED-A managed CBRN presentations by taking the lead while protecting their team and the environment. Nurses implemented crucial CBRN actions such as isolate and contain. There was a lack of involvement in the importance of carrying out decontamination amongst senior nurses across both EDs. Doctors made decisions at ED-B, and senior doctors additionally secured the department and managed staff. There was variability in the importance placed on key CBRN tasks for implementing PPE, decontamination, treat, and investigate (Table 2).

Similarities between WAI and WAD at both EDs were that first receivers (WAD) prioritized patients' needs (treatment, diagnosis, and patient care) compared with WAI. Senior nurses did not include decontamination in their CBRN response, even though leading the decontamination process was core to their role, based on operational procedures.

In terms of differences, WAI focused on documentation, whereas documentation was minimally discussed by first receivers at ED-B only. Additional differences were evident with most WAI action cards consisting of 3 phases at ED-A and 2 phases at ED-B. Furthermore, ED-B first receivers adhered more to WAI compared with ED-A first receivers, which was evidenced by ED-B first receivers including WAI themes in their responses to scenario cards.

The analyses of WAI and WAD provided an insight into the multi-dimensional variability across the CBRN response for first

receivers. Variability was evident through differences in the number of first receivers included in the response, having different nursing roles across EDs, and unspecified banding/experience for CBRN roles.

Limitations

Data were generated from a purposeful sample at a single point of time, giving rich data but can also be a limitation, which is common in critical care services research.³⁹ Collecting the data at a single point was planned for 2 reasons. First, CBRN events cannot be anticipated, and a real-time response was sought. Second, EDs are under extreme pressures with demand constantly exceeding capacity, in which challenges associated with overcrowding lead to stress in staff resulting in the high turnover.⁴⁰ As first receivers work varying shifts, a single point of data collection was the most appropriate to allow a quick turnaround time for verification interviews. It is important to note that the participating first receivers were a limited group, which excluded domestic employees and technicians; these individuals play a vital role in diagnostic testing and sanitization of infectious areas in the ED and should be included in future CBRN research.

Discussion and Recommendations

This study confirmed alignment between CBRN procedures and practice in the ED response to CBRN events, with actions such as

Table 1. Addressing criteria for rigorous research^{37,38}

Rigor criteria	Rigor in this research
Credibility (internal validity). Participants find the results of the study to be true.	Document analysis of HTAs was returned to CBRN leads. Scenario card HTAs were returned to a representative sample of first receivers.
Transferability (external validity). Results of the study are transferable to other similar studies.	The results of the study (HTAs) can be applied to other health care environments.
Dependability (auditability/reliability). Is the reliability achieved if the process of selecting, justifying, and applying research strategies, procedures, and methods which is clearly explained, and its effectiveness is evaluated by the researcher and confirmed by an auditor in the form of an audit trail?	An audit trail was kept throughout the study as a Trial Master File, which was reviewed by the R&D department of ED-A.
Confirmability. Findings are based on the analysis and reviewed through an auditing process. The auditor must confirm that the study findings are grounded in the data, are logical, clear, and have a high utility and explanatory power.	HTAs formulated through document analyses were reviewed by the supervisory team to confirm that they were grounded in the data, were logical, clear, and consisted of a high explanatory power.

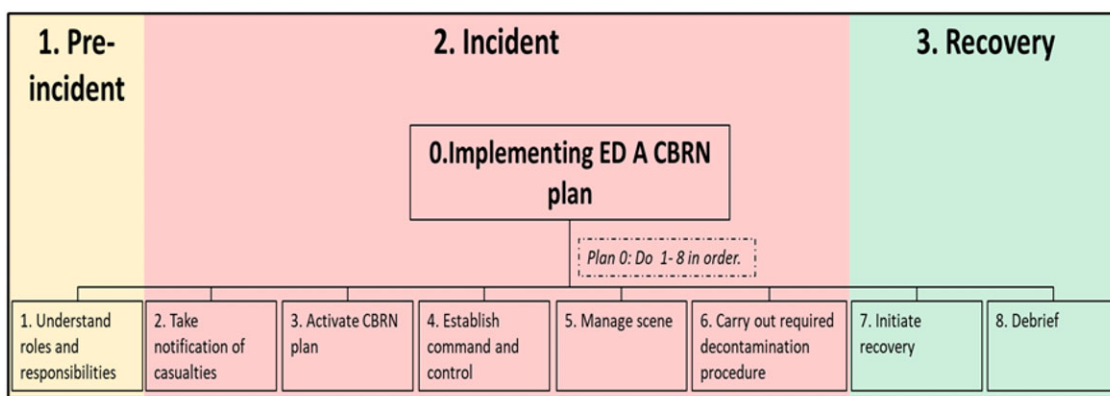


Figure 3. ED-A: GOR superordinate tasks.

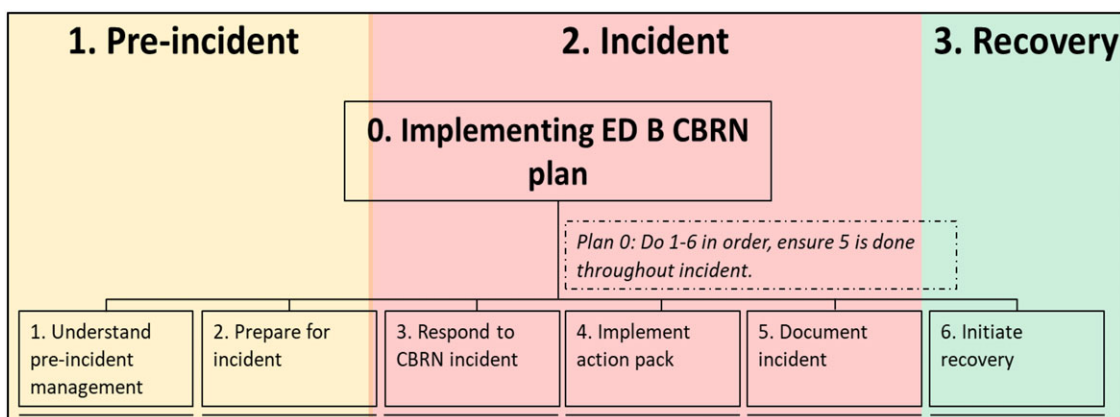


Figure 4. ED-B: GOR superordinate tasks.

isolation, escalation to senior first receivers, and activation of the CBRN plan being crucial. These actions aim to minimize the risk of secondary contamination, a known phenomenon in acute hospitals when responding to chemical events.⁴¹

Operational procedures (WAI) in the ED CBRN response differed between both EDs, in terms of general organizational responsibilities having varying phases as well as action cards consisting of varying top-level tasks.

Misalignment between CBRN procedures and practice was clear through a lack of emphasis on documentation, as evidenced through the limited discussion by first receivers. This can be explained by the busy, interruptive, and multi-tasking nature of the ED, which has been reported to delay or divert from documenting efficiently,^{42,43} as well as deviate from standardized operating procedures (SOPs).⁴⁴

CBRN operational procedures (WAI) focused on actions such as documentation, checking, timing, and providing equipment,

Table 2. Standardized main tasks in response to a CBRN presentation

ED-A	ED-B
1. Isolate and contain	1. Isolate and contain
2. Liaise and communicate	2. Liaise and communicate
3. Escalate	3. Escalate
4. Implement PPE	4. Decontaminate
5. Treat	5. Investigate

whereas CBRN practice (WAD) focused on the patients’ needs. A possible explanation is through the Prioritization of Tasks versus Prioritization of Patients’ Needs dichotomy, which includes assessment, treatment, and diagnosis. Although priority is given to minimize the number of deaths, it is advised to prioritize decontamination procedures to reduce the casualties’ exposure to CBRN materials prior to clinical treatment.⁴⁵

CBRN guidance protects responders from contamination; however, by nature, responders are known to help, as evidenced by the police officer contaminated in the Salisbury Novichok incident.⁴⁶ This explains why first receivers prioritize the needs of patients rather than follow guidance, such as keeping a paper trail of actions taken and prioritizing decontamination to minimize contamination.

Responding to a CBRN event is a complex, multifaceted, and a non-routine work situation, which consists of variability (ie, decontamination void); it is suggested that standardization can reduce the reliance on team experience to ensure a safe and effective practice.⁴⁷ The standardization of superordinate tasks for first receivers through document analyses and HF/E review introduced clarity and order across tasks, as illustrated in a standardized CBRN action card template for first receivers (Figure 5). Templates have been recommended to allow the implementation of “the choice approach” to standardization,¹⁸ which allows clinician discretion and encourages naturalistic decision-making.⁴⁸

To support effective standardization, the process needs to be well defined, described, and reproducible.⁴⁹ It is recommended that the number of phases in a CBRN event should be defined and described through superordinate tasks, which are broken down into actions that are reproducible, as shown in Table 3.

This study synthesized WAI and WAD and identified phases of the ED CBRN response in line with previous literature⁵⁰ consisting of general phases (initial response, consolidation phase, and recovery phase) for hospitals responding to major incidents (including CBRN events) and the following:

1. Evacuation
2. Triage
3. Decontamination for vulnerable individuals during CBRN emergencies⁵¹

Categorizing CBRN actions into phases allows the streamlining of an effective CBRN response, for example, by preparing for the arrival of casualties in line with previous findings^{52,53} as a means of freeing resources to deal with the surge of casualties.

There is no standardized system globally or nationally for key CBRN actions such as triage and decontamination.⁵⁴ The HF/E review resulted in CBRN GORs and action card HTAs, which flowed systematically, without repetitions, with clear allocations, and standardized phases of response. The updated HTAs were combined with the scenario card responses, and the themes aligned to give a complete integration of operational procedures (CBRN plans) and practice (first receiver responses). This forms the recommended standardized ED CBRN framework, shown in Figure 6. The standardized CBRN framework implements findings that overcome CBRN challenges associated with detection, decontamination, and diagnosis as reported previously.⁵⁵ It implements systems that are flexible, easy to follow to the available medical resources, number of casualties, and severity of injuries, encouraging its usability. The framework provides an evidence-based, simplified template to respond to a multi-faceted CBRN event.

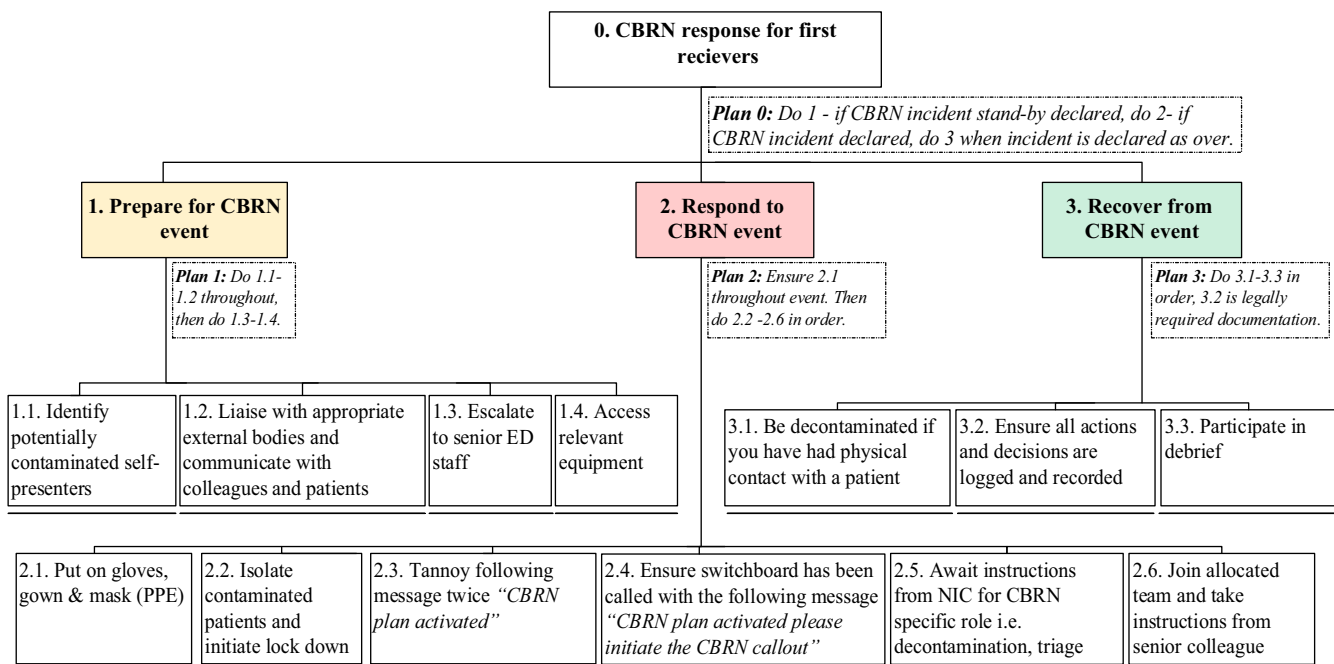


Figure 5. Standardized CBRN action card for first receivers.

Table 3. Standardized action card recommendations

Phase	Superordinate tasks	Example actions required
Pre-incident To allow first receivers to uptake a CBRN role or prepare equipment.	Prepare for CBRN event.	Access relevant equipment.
Incident To carry out actions required during the CBRN event (e.g. decontaminate).	Respond to incident.	Put on gloves, gown, and duck mask (PPE).
Recovery For documentation and debrief.	Document CBRN event.	Ensure all actions and decisions are logged and recorded.

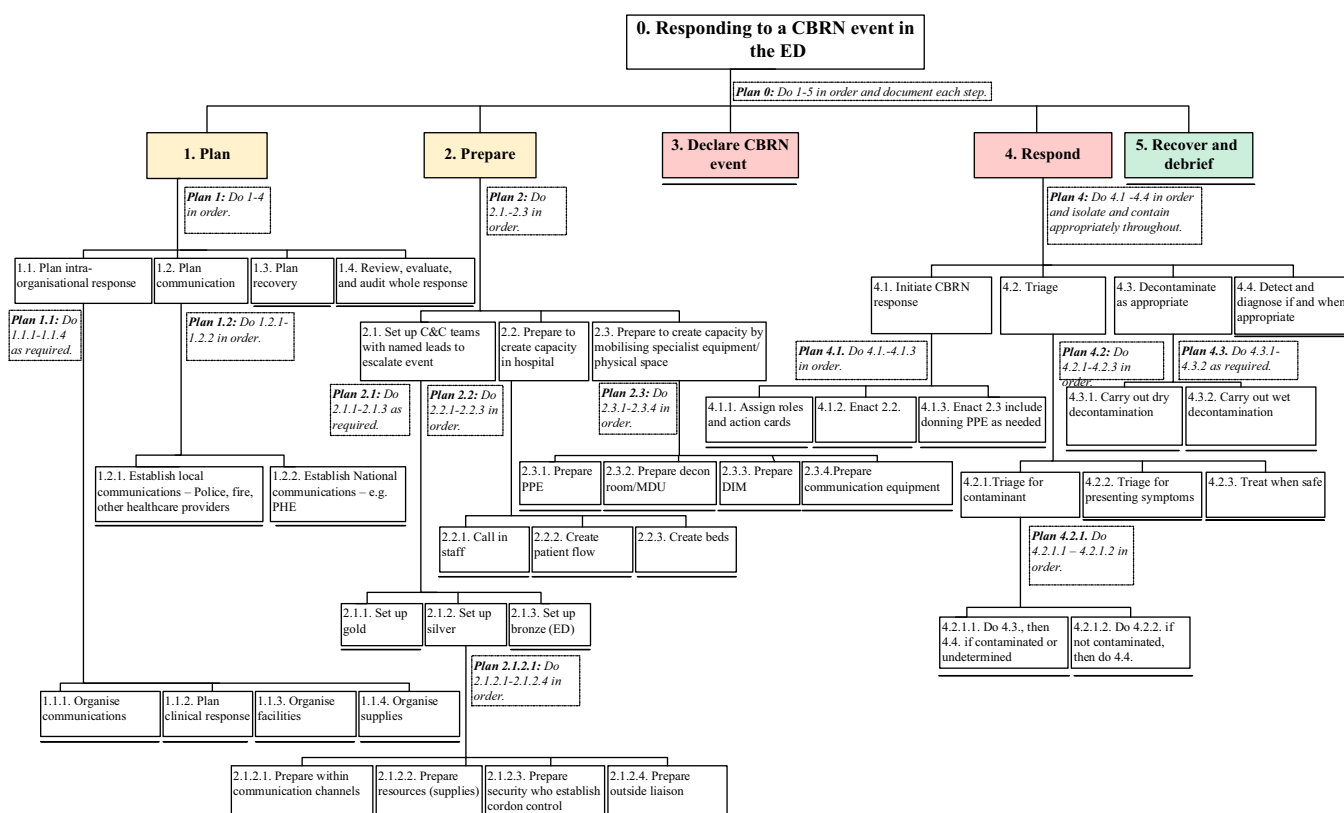


Figure 6. Standardized CBRN framework (represented as an HTA).

Conclusion

This research identified variability between WAI and WAD in the ED response to CBRN events by combining HF/E method (HTA) and theory. The findings were synthesized to provide a top-down and bottom-up insight to enhance the ED CBRN response through standardization. The standardized CBRN action card template embeds the choice approach to standardization by offering clinician discretion, which accounts for the prioritization of tasks and prioritization of patient’s needs dichotomy.

The standardized CBRN framework combines the categorization CBRN of phases, addresses challenges of detection, decontamination, and diagnosis, as well as aligning variability between operational procedures and practice. Finally, this study identified 2 key messages: WAI versus WAD is a useful theoretical framework to unpack a complex sociotechnical system, and HTA is an effective systems mapping tool in health care.

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