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Health Security and Radiological Preparedness in EMT-Led Responses to CBRN or Hybrid Threats: A Review of Training, Protective Protocols, Nutritional Support for Contaminated Patients, and Imaging Challenges in Contaminated Environments

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Abstract

Background: Emergency medical teams (EMTs) are often the first clinicians to reach chemical, biological, radiological, and nuclear (CBRN) incidents, including hybrid threats that combine physical, cyber, and informational attacks. Evidence on their readiness is fragmented across disciplines. **Aim:** To synthesize recent literature on EMT training, protective protocols, nutritional support for contaminated patients, and imaging in contaminated environments. **Methods:** A narrative review of peer-reviewed articles, clinical guidelines, and institutional reports published between 2017 and 2024 was conducted, followed by thematic synthesis. **Results:** Training is heterogeneous and seldom assessed for competence. Protective protocols depend on hazard-specific zoning, decontamination, and dosimetry. Nutritional care is under-addressed and relies on extrapolated critical-care and oncology guidance. Imaging is constrained by equipment contamination, dose considerations, and workflow limits. **Conclusion:** Integrated, competency-based preparedness that embeds nutrition and imaging within contamination-control pathways is needed.

Keywords: health security; radiological preparedness; emergency medical teams; CBRN; hybrid threats.

Introduction

Health security is the capacity of health systems and communities to prevent, detect, and respond to acute threats to population health, and to do so without collapsing the services on which everyday care depends. Within this broad field, chemical, biological, radiological, and nuclear (CBRN) incidents occupy a distinctive position. They are low-probability events with high consequence, and they place unusual demands on the first clinicians to arrive. Emergency medical teams (EMTs), which in the sense used by the World Health Organization (WHO) are groups of health professionals who provide direct clinical care to populations affected by emergencies, are increasingly expected to function in environments in which the hazard itself cannot be seen, smelled, or in some cases confirmed until well after patients have been touched (WHO, 2021). The paramedic, nurse, or physician who attends a contaminated casualty is therefore simultaneously a clinician, a potential victim, and a possible vector for secondary contamination.

The strategic context has also changed. Contemporary security literature increasingly uses the term hybrid threat to describe the coordinated use of conventional and unconventional means, such as military pressure, cyber operations, disinformation, sabotage, and the deliberate release of hazardous materials, below the threshold of open war (Cullen & Reichborn-Kjennerud, 2017; Hoffman, 2018). A conceptual model developed for the European Union describes hybrid threats as combinations of actors, domains, and tools that exploit the vulnerabilities of democratic societies and that are designed to be ambiguous in origin and intent (Giannopoulos et al., 2021). For health systems, ambiguity is not an abstract problem. If a cluster of patients presents with unexplained neurological symptoms at the same time

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as a cyber disruption of hospital information systems and a wave of conflicting public messages, the first operational question is whether the event is a toxic exposure, a mass psychogenic reaction, a coincident outbreak, or a combination of all three.

Radiological and nuclear hazards deserve particular attention within this landscape. Although the probability of a nuclear detonation remains low, commentators have argued that clinical and logistical preparedness for such an event, and for lesser radiological incidents such as the deliberate dispersal of radioactive material, remains inadequate in many countries (Gale & Armitage, 2018). The consequences of a radiological event are not limited to physical injury. Experience after the Fukushima accident has shown that long-term health effects, mental health burdens, and social disruption can substantially exceed the direct radiation effects, and that the quality of early health system response shapes public trust for years afterward (Yamashita et al., 2018; Chen, 2024).

Despite a large body of guidance, EMT-focused evidence remains scattered. Training research is published in disaster-medicine and nursing journals, protective-protocol guidance is issued by international agencies and toxicology groups, nutrition guidance is written for intensive care or oncology rather than for contaminated casualties, and imaging literature addresses infection control or dose rather than contamination. As a result, an EMT commander seeking a coherent evidence base for a multi-hazard response must assemble it from disconnected sources. This review attempts to do that assembly. Its specific aims are to (a) describe the threat landscape relevant to EMT-led responses; (b) review what is known about CBRN training for EMT personnel; (c) summarize protective protocols for responders and patients, with emphasis on radiological hazards; (d) examine the neglected question of nutritional support for contaminated patients; (e) analyze imaging challenges in contaminated environments; and (f) propose an integrated framework and research agenda.

2. Methods

This article is a narrative review. Narrative methods were selected because the topic spans clinical medicine, toxicology, radiation protection, nutrition science, radiology, and security studies, and the available evidence is too heterogeneous in design and outcome measures to permit a quantitative or systematic synthesis. The approach nevertheless followed principles intended to improve transparency. Searches were conducted in PubMed/MEDLINE, Scopus, and Google Scholar, supplemented by the publication repositories of the International Atomic Energy Agency (IAEA), WHO, the International Commission on Radiological Protection (ICRP), and United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR]. Search terms combined concepts relating to responders (emergency medical team, paramedic, first responder, prehospital), hazards (CBRN, radiological, nuclear, chemical, hybrid threat), and the four focal domains (training, personal protective equipment, decontamination, nutrition, enteral feeding, imaging, ultrasound, radiography, computed tomography).

Publications were eligible if they were issued between January 2017 and December 2024, were written in English, and addressed one or more of the four focal domains in relation to emergency, prehospital, or disaster settings. Because evidence specific to contaminated casualties is sparse, analogous literature was included where its principles could reasonably be transferred, notably guidance on personal protective equipment from infectious-disease outbreaks, critical-care and oncology nutrition guidelines, and infection-control guidance for radiology departments. Such transfers are flagged explicitly in the text because they represent inference rather than direct evidence. Editorials without a substantive argument, conference abstracts, and non-English reports were excluded.

The selected sources were read in full, and data were extracted on design, setting, population, and principal findings. Thematic synthesis was then used to group findings under the four focal domains and to identify cross-cutting issues. No formal risk-of-bias tool was applied, and the quality of individual sources is characterized descriptively. This is an important limitation, discussed in Section 9. Throughout the review, evidence derived from guidelines and expert consensus is distinguished from empirical studies, since the former dominate this field.

3. The Threat Landscape Facing EMTs

3.1 CBRN hazards and their clinical signatures

The four CBRN categories differ markedly in how they present to the first responder, and those differences determine what an EMT can safely do in the first minutes. Chemical agents act rapidly. Nerve agents, for example, inhibit acetylcholinesterase and produce cholinergic crisis within minutes of exposure, with miosis, bronchorrhea, bronchospasm, seizures, and respiratory failure. Management is time-critical and depends on early antidote administration, airway support, and decontamination (Hulse et al., 2019). The 2018 poisoning in Salisbury, United Kingdom, drew renewed attention to the Novichok class of agents, whose persistence and potency raise the stakes for responder protection and for the safe handling of contaminated clothing and equipment (Chai et al., 2018).

Biological agents, by contrast, usually present after a delay and may be indistinguishable from naturally occurring disease until clusters are recognized. For EMTs the central issue is source control: standard and transmission-based precautions, appropriate respiratory protection, and safe doffing of equipment. Lessons from the highly infectious disease literature indicate that contamination of healthcare workers frequently occurs during removal of

protective equipment rather than during patient contact, which has implications for any contamination-control protocol (Verbeek et al., 2020).

Radiological and nuclear hazards present a third pattern. Ionizing radiation cannot be detected without instruments, and external irradiation does not make a patient radioactive. Contamination, meaning the presence of radioactive material on or in the body, does. This distinction, which is basic in radiation biology and terminology, is routinely misunderstood by clinicians and the public alike, and its misunderstanding drives both unnecessary refusal of care and unsafe behavior (Bolus, 2017). In a radiological dispersal event, most casualties will have conventional trauma, with radiological contamination as a complicating feature rather than the primary threat. In a nuclear detonation or a severe reactor accident, acute radiation syndrome (ARS) becomes possible, with hematopoietic, gastrointestinal, cutaneous, and neurovascular components whose timing depends on dose (Dainiak, 2018).

3.2 Hybrid threats and the health system as a target

Hybrid strategies add several layers to the CBRN problem. Reviews of hybrid warfare emphasize that adversaries seek to exploit seams between civil and military responsibilities, between agencies, and between what is legally an act of war and what is not (Monaghan, 2019; Treverton et al., 2018). For EMTs, these seams appear as unclear command structures, uncertain legal authority to act, and conflicting information about the nature of an incident. Health facilities and personnel are themselves vulnerable targets. A systematic review of violence against healthcare in conflict settings documents attacks on facilities, transport, and workers, with consequences that extend well beyond immediate casualties (Haar et al., 2021).

Cyber operations are an equally important vector. Hospital cybersecurity research describes organizational weaknesses that leave clinical systems exposed, including fragmented responsibility, legacy devices, and limited staff awareness (Jalali & Kaiser, 2018). Analyses of ransomware incidents affecting healthcare delivery organizations show a rising trend over the past decade and document service disruption, including diversion of ambulances and delays to care (Neprash et al., 2022). A CBRN event coinciding with a cyber attack on receiving hospitals, dispatch systems, or electronic records would degrade exactly those functions on which contaminated-patient pathways rely: pre-alerting, patient tracking, decontamination capacity management, and laboratory support. EMT plans should therefore assume degraded communications and paper-based fallback procedures as the default.

3.3 Implications for the EMT role

Taken together, these characteristics define a role for EMTs that is wider than treatment. Teams must recognize unusual patterns, protect themselves, establish and maintain control of contamination, deliver time-critical treatment, communicate under uncertainty, and hand over patients without contaminating receiving facilities. The WHO classification of EMTs formalizes several of these expectations through minimum standards for different team types, including requirements for self-sufficiency, coordination, and quality of care (WHO, 2021). A systematic approach to the CBRN dimension of those standards, however, remains less developed than for trauma or outbreak response, and the training evidence reviewed below explains part of the reason why.

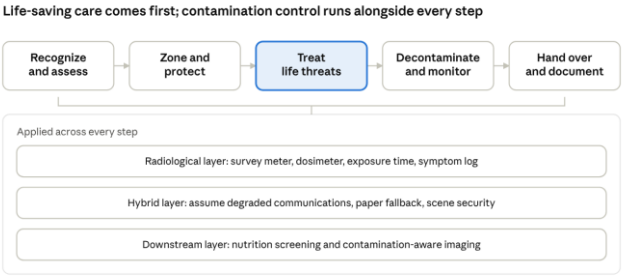


Figure 1. Integrated EMT response pathway for CBRN and hybrid incidents. Life-saving care takes precedence, while radiological, hybrid, and downstream clinical considerations apply throughout.

4. Training EMT Personnel for CBRN and Hybrid Incidents

4.1 What the evidence shows

An integrative review of education and training approaches for CBRN incidents among health professionals concluded that training is widely recommended but inconsistently delivered, that content and duration vary considerably across settings, and that evaluation is limited (Kako et al., 2018). Many programs rely on didactic sessions, tabletop exercises, and occasional field drills. Few report learner outcomes beyond satisfaction or short-term knowledge, and fewer still assess performance in conditions approximating real contamination. A complementary integrative review of disaster preparedness among health professionals and support staff reached a similar conclusion: knowledge and confidence tend to improve after training, but there is little evidence that training translates into sustained competence or better patient outcomes, and training that is repeated, practical, and multi-professional appears more promising than one-off lectures (Gowing et al., 2017).

This pattern has an important practical implication. If competence decays, as it does for most infrequently used skills, then a team trained once and certified for life is not a prepared team. The few CBRN skills that are both critical and perishable, such as donning and doffing protective equipment in the correct sequence, operating a survey meter or personal dosimeter, setting up a decontamination line, and administering antidotes under time pressure, require

deliberate practice at intervals. Simulation offers a means of providing that practice without exposing trainees to real hazards, and fluorescent or inert tracer materials can make otherwise invisible contamination visible during exercises, giving immediate feedback on technique.

4.2 Curriculum content for radiological preparedness

For radiological hazards, a competent EMT should be able to explain the difference between irradiation and contamination, recognize circumstances in which radiological involvement is plausible, use basic detection instruments, apply time, distance, and shielding principles, and prioritize life-saving care over decontamination when injuries are severe. Radiological emergency medicine literature has long stressed that urgent medical treatment takes precedence over radiological concerns, because contamination rarely poses an immediate threat to responders who use standard precautions (Coleman et al., 2019). Teams should also understand triage principles specific to radiation events, including the use of early signs and symptoms such as the time to onset of vomiting, and the importance of recording the time of exposure, because these data inform dose estimation and later treatment decisions (Dainiak, 2018).

Biodosimetry networks, such as the European network that coordinates cytogenetic and physical retrospective dosimetry, illustrate how clinical information collected by EMTs at the scene connects to laboratory capacity that may be hundreds of kilometers away (Kulka et al., 2018). EMTs do not perform those assays, but they must know that a documented exposure time, location, and symptom timeline, together with a properly labeled blood sample where protocols allow, can shorten the interval between exposure and an informed treatment decision. Training should therefore include documentation as a skill, not only as an administrative afterthought.

4.3 Training for hybrid and degraded conditions

Current curricula rarely address hybrid dimensions explicitly. Yet the characteristics of hybrid threats, such as ambiguous attribution, information manipulation, simultaneous attacks on multiple systems, and the targeting of responders, suggest several additional training priorities. These include decision-making under uncertainty, working with partial or contradictory information, operating when electronic systems fail, scene security awareness, and communication with a public exposed to deliberately misleading messages (Giannopoulos et al., 2021; Haar et al., 2021). Exercises that inject cyber failures or misinformation into otherwise conventional CBRN scenarios could test these capacities, though published evaluations of such exercises are scarce.

4.4 Gaps and recommendations

The training literature supports four conclusions. First, programs should shift from attendance-based to competency-based models, with explicit performance standards for critical tasks. Second, refresher intervals should be defined and audited. Third, training should be interprofessional, bringing together EMTs, fire and rescue services, hospital decontamination teams, radiation protection experts, and public-health authorities, because real incidents will require that coordination. Fourth, evaluation should extend beyond knowledge tests to include observed performance, contamination-spread metrics during exercises, and, where feasible, downstream indicators such as time to decontamination and rates of responder contamination. These recommendations are consistent with the integrative reviews cited above but remain largely untested in controlled studies, and the field would benefit from multicentre evaluations using common outcome measures (Gowing et al., 2017; Kako et al., 2018).

5. Protective Protocols for Responders and Patients

5.1 Principles of contamination control

Protective protocols for CBRN incidents share a common logic: identify the hazard, limit the number of people exposed, create physical zones that separate contaminated from clean areas, equip responders with protection proportionate to the hazard, remove contamination from patients as early as is compatible with life-saving care, and prevent the movement of contamination into receiving facilities. The operational expression of this logic is the familiar division of an incident site into hot, warm, and cold zones, with a controlled access point and a one-way flow of casualties from the hot zone through decontamination to clinical care. In practice, however, the protocols must be adapted to the hazard. Table 1 summarizes how the principal measures vary across chemical, biological, radiological, and nuclear incidents, based on the sources reviewed.

Table 1. Hazard-specific protective considerations for EMT responders

Hazard	Principal responder risk	Core protective measures	Decontamination emphasis	Illustrative sources
Chemical (e.g., nerve agents)	Skin and respiratory exposure to liquid or vapor; secondary exposure from patients' clothing	Chemical-protective ensemble with respiratory protection; early antidote administration; strict zoning	Rapid disrobing and structured decontamination, because the hazard is acute	Chai et al. (2018); Chilcott et al. (2019); Hulse et al. (2019)
Biological	Droplet, airborne, or contact transmission;	Transmission-based precautions; respiratory	Hand hygiene and equipment disinfection rather	Verbeek et al. (2020)

	self-contamination during doffing	protection; trained doffing with supervision	than mass decontamination	
Radiological (e.g., dispersal device)	Inhalation or ingestion of radioactive particles; contamination of skin and wounds	Standard precautions with double gloves, gown, and respirator; dosimetry and survey instruments; time, distance, and shielding	Removal of outer clothing, then washing of skin and wounds; waste segregation and monitoring	Coleman et al. (2019); IAEA (2018); ICRP (2020)
Nuclear (detonation or reactor accident)	External irradiation in the field; contamination by fallout; mass casualties with combined injuries	Limiting time in high-dose areas; sheltering; dosimetry; prioritization of resources	Fallout removal when feasible; triage based on injuries and dose indicators	Dainiak (2018); Gale & Armitage (2018); Chen (2024)

5.2 Chemical and biological considerations

In chemical incidents, the decisive variable is time. Research evaluating decontamination guidance for chemical casualties has supported early, structured procedures that begin with removal of clothing, because this single step eliminates a large proportion of surface contamination and can be performed before any equipment arrives (Chilcott et al., 2019). Where nerve agent poisoning is suspected, antidotes, airway management, and seizure control must be delivered in parallel with decontamination, which places a premium on rehearsed task allocation within the team (Hulse et al., 2019). Persistent agents such as those in the Novichok class intensify the need for secure containment of clothing and equipment (Chai et al., 2018).

In biological incidents, the evidence base is largely drawn from infectious-disease outbreaks. A Cochrane review of personal protective equipment for highly infectious diseases found low-certainty evidence on most comparisons, but suggested that covering more of the body, using more rigorous doffing procedures, and training with supervision may reduce contamination of healthcare workers (Verbeek et al., 2020). Although this evidence concerns infectious agents, the underlying lesson applies equally to radiological contamination: protection fails most often at the interface between the clean and the contaminated, and the removal sequence deserves as much rehearsal as the donning sequence.

5.3 Radiological and nuclear protocols

Radiological protection for responders rests on three classical principles: minimizing time near the source, maximizing distance, and using shielding where practical. For an EMT, whose members must come into close contact with patients, the dominant concern is usually contamination rather than penetrating external radiation, and the dose from a contaminated casualty to a carefully protected responder is generally low (Coleman et al., 2019). Standard precautions with additional measures, namely double gloves, a fluid-resistant gown, eye protection, shoe covers, and respiratory protection against particulates, together with the taping of cuffs and the use of personal dosimetry, are widely recommended to prevent contamination of skin and clothing and inhalation of particles (IAEA, 2018). Frequent monitoring with survey instruments during doffing helps verify that protection has worked.

The ICRP framework for emergency exposure situations adds a governance dimension. Rather than applying normal occupational limits, it uses reference levels to guide optimization of protection, recognizes that higher exposures may be accepted by informed volunteers for life-saving actions, and emphasizes justification, stakeholder engagement, and monitoring after large nuclear accidents (ICRP, 2020). For EMT leaders, this means that responder dose decisions are management decisions that should be made in advance with radiation-protection advisers, documented, and communicated, and not improvised in the field.

Patient-focused protocols follow the same logic. For externally contaminated patients without immediately life-threatening injuries, removal of outer clothing followed by washing of skin, hair, and wounds, with attention to preventing the spread of runoff, is the mainstay. For wounds, irrigation and covering precede surrounding skin decontamination. Cutaneous radiation injury, which may develop over days to weeks after high-dose skin exposure, calls for careful documentation and referral for specialist assessment, and the research literature on assessment and treatment of cutaneous radiation injury underlines how quickly such cases outstrip routine wound-care expertise (DiCarlo et al., 2020).

Where internal contamination is suspected, clinical guidance describes radionuclide-specific measures, including stable iodine to block thyroid uptake of radioiodine, Prussian blue for radiocesium, and chelating agents such as DTPA for certain actinides (IAEA, 2018; Dainiak, 2018). Stable iodine is most effective when administered shortly before or soon after exposure to radioiodine, offers no protection against other radionuclides, and requires age-appropriate dosing, which is why WHO guidance stresses prior planning for stockpiling and distribution (WHO, 2017). An EMT is unlikely to administer decorporation agents routinely in the field, but it should know which agents exist, how to record

suspected internal contamination, and how to convey that information to receiving clinicians. Reviews of pharmacological management of radiation injury further indicate that most agents are still being developed and that supportive care remains central in the early phase (Singh & Seed, 2020).

5.4 Protective protocols under hybrid conditions

Hybrid conditions complicate every element above. Responders may arrive before the hazard is identified, protective equipment may be in limited supply, and the scene may itself be a target. Protocols should therefore specify default levels of protection for unknown hazards, criteria for escalation or de-escalation as information arrives, and pre-agreed arrangements with security forces for scene control. Equally, EMT plans should assume that electronic dosimeter readings, pre-alert messages, and patient-tracking systems may be unavailable, which strengthens the case for simple paper-based tags and redundant communication channels (Jalali & Kaiser, 2018; Neprash et al., 2022).

6. Nutritional Support for Contaminated Patients

6.1 Why nutrition matters and why it is neglected

Nutrition is rarely mentioned in CBRN response doctrine, which concentrates on airway, breathing, circulation, antidotes, and decontamination. This omission is understandable in the first minutes of an incident but becomes harder to defend in the hours and days that follow, when many contaminated patients will be held in isolation, evacuated through extended chains of care, or treated in austere EMT facilities. Several features of radiological and chemical injury make nutritional care clinically relevant. The gastrointestinal syndrome of acute radiation injury produces nausea, vomiting, diarrhea, mucosal damage, and fluid and electrolyte losses at higher doses, with consequent malnutrition risk; patients with combined burn, blast, and radiation injury have raised metabolic demands; and prolonged isolation and psychological distress reduce intake (Dainiak, 2018). The literature search conducted for this review identified no controlled studies of nutritional interventions in contaminated casualties, so the discussion below relies on extrapolation from adjacent fields and is explicitly provisional.

6.2 Screening and assessment

Malnutrition criteria developed through a global consensus process combine phenotypic criteria, such as weight loss, low body mass index, and reduced muscle mass, with etiologic criteria, such as reduced intake or inflammation (Cederholm et al., 2019). In an acute CBRN incident, formal body-composition assessment is unrealistic, but the underlying idea of a brief risk screen at the first stable point of care is adaptable. A pragmatic screen would record the expected duration of impaired intake, the presence of vomiting or diarrhea, burns or major trauma, pre-existing frailty, and the need for isolation. Older adults deserve particular attention, since European guidance on clinical nutrition and hydration in geriatrics highlights their vulnerability to dehydration and rapid loss of muscle mass during acute illness (Volkert et al., 2019).

6.3 Timing, route, and composition

For patients who are critically ill, European and North American guidelines converge on several principles that are transferable. Early enteral nutrition, usually started within 48 hours once the patient is hemodynamically stable, is preferred to parenteral nutrition where the gut is functional; energy and protein targets are increased progressively to avoid overfeeding in the acute phase (Singer et al., 2019; Compher et al., 2022). Gastrointestinal dysfunction, which is common in critical illness and likely in severe radiation exposure, should be monitored using clinical indicators, and guidance on gastrointestinal function in intensive care recommends careful assessment of feeding tolerance and individualized adjustment (Reintam Blaser et al., 2017). Perioperative guidance supports early oral or enteral feeding and the avoidance of unnecessary fasting, which is relevant to casualties undergoing urgent surgery for blast or penetrating injury (Weimann et al., 2021).

Oncology guidance offers the nearest analogue for radiation-induced mucosal and intestinal toxicity. Guidelines for patients with cancer emphasize screening for nutritional risk, individualized dietary counseling, oral nutritional supplements when intake is inadequate, and enteral or parenteral support when oral intake fails (Arends et al., 2017; Muscaritoli et al., 2021). Evidence-based practice guidelines for oncology nutrition similarly support nutrition intervention during radiotherapy to maintain intake and weight (Thompson et al., 2017). These recommendations concern therapeutic fractionated radiotherapy, not accidental whole-body exposure, so their applicability is partial; nonetheless, they establish plausible principles, including small frequent meals, low-residue or lactose-restricted choices when diarrhea occurs, and early escalation when intake is insufficient.

6.4 Micronutrients, antioxidants, and the limits of evidence

Because radiation generates reactive oxygen species, antioxidant micronutrients attract interest as potential protectants. Current European guidance on micronutrients in clinical nutrition, however, supports provision of recommended amounts to prevent deficiency in at-risk patients and does not support high-dose antioxidant supplementation as a protective strategy in acute illness (Berger et al., 2022). Reviews of radiation countermeasures likewise point to a small number of licensed pharmacological agents and few nutrition-based interventions with convincing evidence (Singh & Seed, 2020). The honest summary for EMT planners is therefore that nutritional care is supportive, and that claims of nutritional radioprotection should not displace evidence-based

measures such as early decontamination, timely stable iodine where indicated, and supportive care.

6.5 Contamination-specific nutritional considerations

Three issues are specific to contaminated patients. First, intake must be safe. Ingestion is a pathway for internal contamination, so food, drink, and utensils must be kept out of contaminated zones, and patients should not eat or drink until external decontamination is complete. Second, treatment can alter nutritional management. For example, decorporation therapies and fluid-loading strategies for specific radionuclides require attention to hydration, electrolytes, and bowel function, and IAEA guidance on internally contaminated persons should be consulted for radionuclide-specific details (IAEA, 2018). Third, food and water supply in affected areas may itself be compromised. Humanitarian standards define minimum requirements for food security and nutrition in emergencies, including safe water and food distribution, and these provide a framework that EMTs working alongside humanitarian agencies can adopt, with radiological monitoring of local supplies added where contamination is suspected (Sphere Association, 2018).

6.6 A proposed pathway

Figure 2 proposes a stepwise nutritional pathway that integrates these considerations. It is a conceptual synthesis built from the guidelines above, not a validated protocol, and it should be tested through exercises and observational study before adoption.

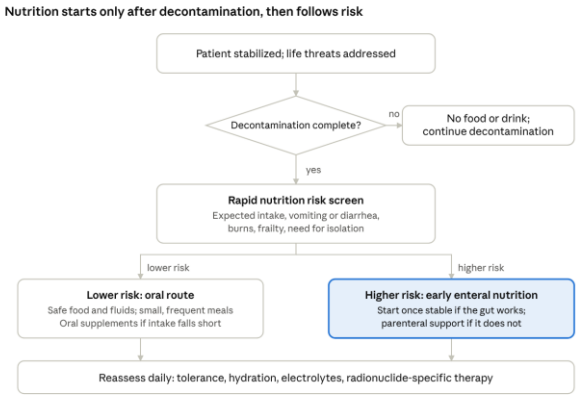


Figure 2. Conceptual pathway for nutritional support of contaminated patients.

7. Imaging Challenges in Contaminated Environments

Imaging is essential for trauma, blast, and inhalational injury, yet contaminated settings impose three constraints: equipment becomes a vector for spread, dose must be justified, and workflow slows. Radiology departments facing highly infectious patients developed practical lessons that transfer directly, including dedicated imaging pathways, disposable covers for equipment, defined cleaning intervals, and staff training in donning and doffing (Mossa-Basha et al., 2020). Table 2 compares the main modalities.

Table 2. Imaging modalities in contaminated environments

Modality	Principal advantage	Contamination and dose challenges	Mitigation	Illustrative sources
Portable radiography	Deployable at the point of care; fast	Detector and cassette contamination; staff proximity	Disposable covers; designated clean and contaminated detectors; survey after use	Mossa-Basha et al. (2020)
Point-of-care ultrasound	No ionizing radiation; portable; repeatable	Probe and gel contamination; cleaning demands	Probe covers; dedicated devices; validated cleaning protocols	Abramowicz & Basseal (2020)
Computed tomography	Comprehensive assessment of trauma and chest injury	Fixed scanner contamination; higher patient dose; slow turnover	Decontaminate before scanning where feasible; cover gantry and table; justify each examination	Mettler et al. (2020); Smith-Bindman et al. (2019); ICRP (2020)
Imaging selection and triage	Preserves capacity during surges	Competing demands for scanners and staff	Consensus-based indications; protocolized pathways	Rubin et al. (2020)

Portable radiography and point-of-care ultrasound are the most compatible with EMT operations. Ultrasound avoids ionizing radiation, which is attractive when a patient may already have received a significant dose, and international guidance on safe ultrasound examination emphasizes protective covers, dedicated equipment, and defined cleaning procedures, all of which map onto contamination control (Abramowicz & Basseal, 2020). Computed tomography is more problematic. Fixed scanners are difficult to decontaminate, a contaminated scanner may be withdrawn from service, and CT delivers considerably higher doses than plain radiography. Population studies of imaging in the United States describe both the large contribution of CT to medical radiation exposure and its rising use, which supports strict justification of each examination (Mettler et al., 2020; Smith-Bindman et al., 2019). For a possibly irradiated patient, ICRP principles of justification and optimization continue to apply, although a clinically

indicated, life-saving scan should never be withheld because of radiological concerns (ICRP, 2020).

Pandemic experience also shows that consensus-based indications help preserve capacity when demand exceeds supply. The Fleischner Society statement, for instance, set out which clinical circumstances warranted chest imaging and which did not (Rubin et al., 2020). A comparable consensus for contaminated casualties is lacking and would be a valuable research product. In the interim, EMTs should protect equipment before use, survey it afterward, segregate contaminated waste, and record which devices were exposed, so that returning them to service is a deliberate decision.

8. Integrating the Domains

Training, protection, nutrition, and imaging are usually planned separately, yet in an incident they interact. A team that has trained in protective doffing but not in imaging cover procedures will contaminate its detectors; a team that decontaminates well but ignores nutrition will deliver patients who are dehydrated and catabolic. Figure 1 therefore presents a single pathway in which radiological, hybrid, and downstream clinical layers apply throughout, and Figure 2 expands the nutritional layer. Practical implications include embedding nutrition screening and imaging-cover procedures within decontamination exercises, adding dosimetry and documentation to performance standards, and rehearsing the loss of electronic systems as a routine inject. Aligning these functions with the minimum standards already used for EMT classification would give them a governance home (WHO, 2021).

9. Limitations

This review has several limitations. It is narrative rather than systematic, so selection bias is possible, and no formal quality appraisal was applied. The 2017 to 2024 window excluded earlier foundational work. The most relevant evidence for nutrition and imaging in contaminated casualties does not yet exist, so these sections rely on extrapolation from critical care, oncology, and infection control, and conclusions about them should be treated as hypotheses. Finally, restricting the search to English-language sources may have omitted useful regional experience.

10. Conclusion and Research Priorities

EMT-led responses to CBRN and hybrid threats depend on competent, protected, well-supported teams working with imperfect information. The evidence reviewed indicates that training should become competency-based and recurrent, that protective protocols should be hazard-specific and rehearsed through doffing, that nutrition should enter CBRN doctrine as a supportive but real component of care, and that imaging should be planned with explicit contamination-control and justification rules. Priority research questions include whether competency-based training reduces responder contamination, how nutritional risk should be screened in radiation-exposed patients, and which imaging indications and equipment-cover protocols are safest for contaminated casualties. Until such evidence accumulates, integrated exercises that test the pathways in Figures 1 and 2 offer the most practical route to credible health security.

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