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A Practical Classification Approach for Chemical, Biological, Radiological and Nuclear (CBRN) Hazards Based on Toxicological and Situational Parameters

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Featured Application

The proposed CBRN hazard classification framework aims to integrate all CBRN silos' hazard information, simplify it, and make it understandable for civil society and, particularly, for the potentially engaged groups. Sharing scientific background with the classifications used by emergency services and occupational safety, it can be directly applied by emergency responders, security services, and public safety agencies to rapidly assess and communicate risks during chemical, biological, radiological, nuclear, and energetic incidents. Integrating toxicological endpoints, exposure routes, and observable situational indicators into a unified, field-adapted system enables effective decision-making even when the hazardous agent is unidentified. This approach is especially valuable in the first minutes of an incident, supporting triage, protective action, and public warning, while also serving as a training and planning tool to enhance local and national CBRN preparedness.

Abstract

CBRN incidents are characterized by high uncertainty in terms of agent identity, dissemination methods, and situational context. This unpredictability complicates effective and timely response, especially in the initial phase before specialist services arrive, and lays the burden of applying protection and response measures on members of civil society participating in the incident. This paper proposes a structured classification framework for CBRN hazards to address this gap, integrating key characteristics from existing systems such as the GHS (Globally Harmonized System), WHO (World Health Organization) biosafety levels, and radiological exposure guidelines. The system emphasizes properties relevant for first responders and non-specialists, including observable effects, exposure routes, and hazard endpoints such as toxicity, virulence, and radiation dose. The goal is to enable rapid hazard recognition, improve communication, and support situational decision-making in public security scenarios.

Keywords: CBRN threats; hazard classification; chemicals; toxicity assessment; safety and security

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1. Introduction

Chemical, biological, radiological, and nuclear threats represent a complex challenge for public safety and emergency response systems due to their inherent unpredictability regarding agent type, dissemination method, location, and impact. Unlike controlled exposures in occupational or industrial settings, CBRN events are often characterized by unknown variables, including the nature and quantity of the hazardous material, exposure routes, environmental conditions, and affected populations [1,2]. The increasing risk of intentional release of hazardous agents, such as in terrorism, sabotage, or hybrid warfare, further complicates preparedness efforts. In such scenarios, the ability to rapidly recognize, classify, and communicate the type and severity of the threat becomes critical, especially in the early stages of an incident when first responders and local site personnel must act before the arrival of specialized CBRN services [3].

Civil society is, albeit often neglected, a potential partner in building CBRN resilience [4]. This capacity has been noticed by the European Commission, which is currently initiating many DRS (Disaster Resilient Society) projects focused on CBRN threats. Those leading resilience-enhancing projects implemented within the ISF have noted that first responders from the police and fire departments, except for a limited number of specialized units, lack a deep understanding of CBRN threats and only have a general understanding of the consequences. Therefore, the results of several CBRN trainings within the DRS-related European Commission Internal Security Fund Police projects [5–8] dedicated to raising CBRN resilience among civil society, particularly among facility or infrastructure operators identified as potentially exposed, allow us to conclude that the general population, facility operators, and non-specialized state and local services will benefit from introducing a system that more deeply explains the nature of threats, systematizes knowledge, and improves threat communication. The gained experience indicates that these groups, mainly consisting of personnel in charge of entities or infrastructure that gather the general public, need to understand the hazards at a level superior to that of the general public but not as advanced as emergency response professionals. In building prevention, and from the time of an incident to the arrival of responders, actions undertaken by that group are vital for reducing the consequences. Knowledge-building and training methodology of such a group differ from those adopted for professionals, i.e., civil protection or military, as they are time-consuming, requiring additional capacities, and assuming accessibility of resources that are not routinely allocated. Helping that group to understand the threat by creating a classification of hazards, implying practical consequences, and being understandable for civil protection, is a vital resilience-building component of civil protection. In summary, this system serves to include in the prevention and response a community that has above-average levels of vulnerability, is capable of being a partner in emergency response, and has limited resources and technical means.

Existing classification systems—such as the GHS, WHO biosafety guidelines, and radiological hazard assessment tools developed by the ICRP (International Commission on Radiological Protection)—were primarily designed for risk management under controlled conditions [9,10]. The classifications from different CBRN compartments are rarely listed together or compared, which causes concentration on one hazard silo at the expense of the others. While well-established within their respective domains, these systems often lack situational flexibility and are not tailored to the operational realities of CBRN incidents. They also do not provide simplified tools for decision-making by non-specialists in high-pressure environments. Additionally, the legacy of military chemical warfare agent classification continues to dominate the discourse, despite the growing significance of hazards arising from diverted peaceful-use materials. These include industrial toxins,

medical radiological sources, or bioactive compounds used in agriculture and sanitation, which can all be adapted for malicious purposes [11].

In response to these limitations, this work proposes a practical approach to CBRN hazard classification that adapts existing systems to the operational needs of emergency response. The proposed classification emphasizes observable effects, critical exposure routes, and health endpoints relevant to situational assessment. It also introduces an expanded conceptual model—CBRNE (Chemical, Biological, Radiological, Nuclear, and Energetic)—that accounts for energetic hazards such as explosions and fires, which frequently accompany malicious CBRN events. This model seeks to support both preventive planning and real-time management of incidents, providing a simplified yet scientifically grounded framework that can enhance local CBRN resilience and communication capabilities.

2. Framework and Methodological Basis

CBRN hazard events differ significantly from standard industrial, occupational, or environmental exposure scenarios due to the multitude of unknowns and the high variability in their manifestation. The unpredictability of time, location, type, quantity, and method of hazardous agent release makes classical hazard communication systems insufficient in the context of public security incidents involving chemical, biological, radiological, or nuclear agents. While traditional systems rely on predefined scenarios, controlled environments, and deterministic planning, the nature of CBRN events demands a more flexible, rapidly deployable classification approach that supports situational awareness and decision-making under uncertainty.

A central methodological assumption of this classification framework is that in a typical CBRN event, the identity of the hazardous agent, its concentration, delivery method, and even the route of exposure may be initially unknown. Consequently, the system must allow for inference and estimation based on observable features, rather than rely solely on confirming agent-specific data. This stands in contrast to domains such as occupational safety or industrial risk assessment, where exposure parameters are well-defined, and classification is used primarily for planning and regulatory compliance.

Table 1 of this study presents a comparative overview of different exposure contexts—ranging from workplace incidents to terrorist attacks—highlighting the increasing degree of uncertainty that characterizes CBRN events. In such settings, where both the agent and its behavior are undefined, precise dose–response calculations become impractical or even misleading. Instead, the emphasis shifts toward qualitative descriptors that support recognition of patterns, symptoms, and situational indicators.

Table 1. Comparison of the role of hazard description in various release scenarios. [1] Description is made assuming that risk is based on the defined scenarios, so data such as numbers are assumed.

Exposure Circumstances	Known or Approximated [1]	Unknown or Poorly Approximated	Scientific and Technical Objectives
Occupational exposure/	Hazard identity Exposure route Concentration, Time, location, Exposed subjects		Provide safe workplace conditions and operational safety
Accidental exposure of professionals/	Hazard identity Exposure route Concentrations, amount Location Exposed subjects	Date, time, atmospheric conditions	Reduce the risk of operations

Table 1. *Cont.*

Exposure Circumstances	Known or Approximated [1]	Unknown or Poorly Approximated	Scientific and Technical Objectives
Accidental exposure of the general public/ Hazardous material	Hazard identity Exposure route Concentration, Amount, Location, Exposed population [1]	Date, time, atmospheric conditions	Reduce risk, facilitate response, reduce the number of casualties
Malevolent CBRN incident/ Agent-by-diversion	Exposed population [1] Place	Date, time Hazard identity, Exposure route Concentration, amount Atmospheric conditions	Build awareness Reduce risk Prevent and prepare Facilitate response Reduce number of casualties
Exposure due to wartime WMD attack/ Agent-by design	Type of agent	Time, delivery, atmospheric conditions, amount	Reduce casualties Continue operations, Protect forces

Another foundational element of the proposed classification is the inclusion of both "agents-by-design" (i.e., substances or organisms engineered for deliberate harm, such as nerve agents or weaponized pathogens) and "agents-by-diversion" (i.e., materials originally produced for peaceful use that can be repurposed for malicious acts). The latter category is often overlooked in conventional military or regulatory classification systems, despite representing a significant portion of real-world CBRN threats. Examples include industrial biocides, radiological medical sources, and agricultural toxins, all of which can be adapted for intentional dissemination.

The classification also distinguishes between the preventive and reactive (situational) functions of hazard assessment. In preventive contexts, scenarios may be constructed using assumed agent characteristics to model vulnerability and preparedness; however, in situational contexts—i.e., the first minutes or hours after an incident—hazard classification must enable immediate estimation of risk and guide early protective actions, often before any laboratory confirmation is available. Therefore, the framework presented here focuses on supporting this initial window of decision-making, where the participation of non-professional actors and the lack of precise data must be compensated for by, among others, robust, simplified, situation-inferred communicative tools.

In response to this need, the structure of the classification model integrates components from regulatory systems such as the GHS, WHO biosafety levels, and ICRP radiological classifications, while also introducing dynamic elements not typically featured in those systems. These include intermediate health effect descriptors (e.g., "more than mild," "irreversible but non-fatal"), environmental persistence, visibility of effects, and the symbolic severity of the incident—features particularly relevant in intentional acts meant to cause panic or disruption.

Ultimately, the classification framework is designed to serve three complementary purposes: (1) facilitate the rapid characterization of unknown agents based on observable indicators, (2) guide emergency decision-making in the absence of analytical confirmation (that comes at a later stage with the onset of response and forensic activities), and (3) support the training and operational readiness of actors involved in CBRN preparedness and response, particularly those outside of specialized scientific institutions.

3. Results and Discussion

3.1. Chemical Hazard Domain

Classifying chemical hazards in the CBRN context requires substantial modification of existing regulatory and military systems to meet the specificity of intentional, high-impact scenarios affecting civilian populations. Traditional classification systems—such as those in the GHS—are detailed and legally binding but are primarily designed for stable exposure scenarios in occupational or industrial environments [12,13]. Similarly, military taxonomies categorize CWA (chemical warfare agents) by strategic function (e.g., nerve, blister, choking agents), but remain disconnected from the requirements of civilian emergency response [11,14,15].

In contrast, based on the scientific data used to create occupational safety or military classification, the proposed framework focuses on practical criteria relevant during incident response: health endpoints, exposure routes, and physical-chemical properties that can be observed or inferred without immediate laboratory confirmation, and which are borrowed from the GHS system.

Table 2 summarizes the toxicodynamic mechanisms by which chemical agents affect biological systems. These include systemic actions (e.g., acetylcholinesterase inhibition by organophosphates), corrosive tissue damage, oxidative stress, DNA disruption, and immunological effects [16,17]. Each mechanism is mapped to GHS hazard codes, such as H300–H330 for acute toxicity, H314–H319 for skin and eye corrosion, and H370–H371 for organ-specific toxicity [12].

Table 2. Toxicodynamic mechanisms and health endpoints of chemical agents.

Interaction	Impact Type	Protection
Systemic reaction	Neural, e.g., nerve agents Mitochondrial, e.g., cyanides Chemical: alteration of tissue properties, e.g., Cl_2, Phosgene reaction in alveoli DNA modification, e.g., Mustard Gas Immune response, e.g., sensitizers	No natural protection
Non-specific surface reaction	Oxidizing	No natural protection
	Acid/base: H^+, OH^-	Skin offers some physical protection

Occupational safety systems rely on accurate dose–response values to guide classification [18]. The practical use of those values is oriented toward the engineering of the workplace to reduce exposure or, in general, to provide workplace safety. At the same time, CBRN security has to deal with undefined, unstable, and dependent on environmental conditions, which can change by order of magnitude within seconds. This attempt has to assume exposure to a hazard beyond acceptable safety limits, similar to the AEGL (Acute Exposure Guideline Levels) concept, using linguistic descriptors that are fuzzy and intuitive instead of numerical limits. This framework therefore uses route-specific proxies for estimating dose severity.

Table 3 introduces a semi-qualitative matrix approximating absorbed dose levels based on barrier resistance, surface area, control over exposure, and agent concentration. Inhalation is prioritized due to the respiratory system's large surface area and limited natural defenses, especially in open-air or aerosol-generating events. Dermal exposure is also important, particularly for agents that are both hydrophilic and lipophilic and can rapidly cross the skin barrier [19,20]. Agent behavior depends not only on chemical

structure, but also on physical form [14,15]. The framework, therefore, includes a cross-mapping of form, route, and clinical outcome.

Table 3. Approximate dose impact by route of exposure and agent characteristics.

Exposure Factors				
Exposure	**The Organism's Barrier Strength**	**Contact Surface**	**Physiological or Physical Exposure: Examples of Simplified Instant Controls**	**Density of the Agent**
Inhalation	Weak, easily crossed	Large	Non-controllable: in extreme situations, stop breathing, e.g., until leaving contained space or when crossing a suspicious cloud	Low
Skin	Strong barrier except for some chemical agents	Moderate	Controllable: cover skin if dermal symptoms are observed, remove any settled liquid	High
G-I tract from cross-contamination	Weak barrier, easily crossed	Large	Controllable: don't touch lips directly or indirectly (through eating, drinking, smoking, vaping)	High
G-I tract from food chain	Weak barrier Easily crossed	Large	Controllable if expected: stop eating if poisoning symptoms observed; if food only food swallowed, consider inducing vomiting	High
Parenteral (CBRNe—or RDD induced)	Weak barrier/no barrier	Undefined, small to moderate	Not controllable: only professional medical assistance	High

Precautionary measures may be adopted for each type of exposure. A list of such standardized measures was assembled and tabularized in the GHS system. However, mass exposure situations require a supplementary approach. A summary of the integrated approach, including situational and standardized response-oriented precautions, is presented in Table 4.

Table 4. List of precautionary and instantaneous measures in relation to a type of exposure. [1] Contamination-free zone established first. [2] For acute toxicity estimates (ATE) below 100 ppm (Class 1 or 2) or time-concentration calculated dose for toxicity Class 1 and 2. [3] For oral acute toxicity estimates (ATE) 50 mg/kg and below (Class 1 and 2). [4] Dermal exposure, contrary to inhalation and oral exposure, is specific to physical and chemical properties so that toxicity estimates cannot be applied to it [21]. [5] Descriptive, non-measurable.

Exposure	**Precautions Situational**	**Precautions Response [1]**	**Hazard Endpoint & Limit**
Inhalation	Slow breathing rate No rapid movements Mark or provisionally adsorb the spillage If systemic or respiratory symptoms—assign priority triage Report to the crisis center	Remove from contaminated zone	Hazard: Acute toxicity Endpoint: Death [2]
			Hazard: Acute toxicity Endpoint: Respiratory sensitization [5]
			Hazard: Skin allergic reaction Endpoint: Skin sensitization [5]

Table 4. *Cont.*

Exposure	Precautions Situational	Precautions Response [1]	Hazard Endpoint & Limit
Oral	Block access to food No mouth touching, no eating, no smoking If systemic symptoms: assign to priority triage	Rinse mouth if exposed to corrosive matter Do not induce vomiting (except in case of food poisoning, consult a physician)	Hazard: Acute toxicity Endpoint: death [3]
			Hazard: Skin allergic reaction Endpoint: skin sensitization [5]
Dermal	Wash affected skin with any nontoxic, noncorrosive fluid Watch for symptoms [4] to approximate actual exposure If systemic symptoms—assign to priority triage Report to the crisis center	Take off contaminated clothing Rinse affected skin with water	Hazard: Acute toxicity Endpoint: Death [4]
			Hazard: Acute toxicity Endpoint: Skin sensitization [5]
			Hazard: Skin corrosion Endpoint Skin necrosis [5]
Ocular	No eye touching Assign to priority triage	Remove from contaminated zone, Rinse with water	Endpoint: Eye damage [5]
Parenteral	Assign to Priority triage	Not standardized	Not standardized

Table 5 presents further linking of a physical form, exposure route, hazard, and dose limits.

Table 5. Mapping of agent forms (gas, liquid, aerosol, solid) to health effects and exposure pathways. [1] Toxicity range values are taken from the CLP Regulation. [2] Information on the parenteral exposures was concluded from general knowledge as is omitted from the occupational exposure sources.

Chemically Reacting with Living Organisms (Toxic) CBRN Agents in GHS Systematics			
Physical Form	**Exposure Route [1]**	**Hazard Statement for the Highest Category**	**Dose Value [1] or Description for the Endpoint Extreme Category**
Solids (toxins)	Ingestion	Fatal if swallowed	<5 mg/kg
Solid aerosol	Ingestion Endpoint: death	Fatal if inhaled	<0.05 mg/L
	Inhalation, Endpoint: resp. hypersensitivity	May cause allergy, asthma symptoms, or breathing difficulties if inhaled	Asthma, rhinitis/conjunctivitis, and alveolitis
	Dermal Endpoint: skin damage	Severe skin burns	Destruction of tissue/visible necrosis
	Ocular Endpoint: eye damage	Eye damage	Irreversible effect on iris/cornea/conjunctiva
	Parenteral [2]	n/a	Damage analogous to dermal or Internal contamination of the bloodstream or the lymphatics

Table 5. *Cont.*

Chemically Reacting with Living Organisms (Toxic) CBRN Agents in GHS Systematics			
Physical Form	**Exposure Route [1]**	**Hazard Statement for the Highest Category**	**Dose Value [1] or Description for the Endpoint Extreme Category**
Liquid aerosol	Inhalation, Endpoint: death	Fatal if inhaled	<0.05 mg/L
	Inhalation Endpoint: irreversible or other serious, long-lasting adverse health effects	AEGL-2	As a substance-specific time/concentration matrix
	Inhalation Endpoint: notable discomfort, irritation, or certain asymptomatic non-sensory effect	AEGL-1	As a substance-specific time/concentration matrix
	Endpoint: Resp. hypersensitivity	May cause allergy, asthma symptoms, or breathing difficulties if inhaled	Asthma, rhinitis/conjunctivitis and alveolitis
	Ingestion, Endpoint: death	Fatal if swallowed	<5 mg/kg
	Dermal, Endpoint: death	Fatal when in contact with skin	<50 mg/kg b.w.
	Dermal Endpoint: skin damage	Severe skin burns	Destruction of tissue/visible necrosis
	Ocular Endpoint: eye damage	Eye damage	Irreversible effect on iris/cornea/conjunctiva
	Parenteral	n/a	Damage analogous to dermal or Internal contamination of the bloodstream or the lymphatics
Liquid	Dermal, Endpoint: death	Fatal when in contact with skin	Dermal: <50 mg/kg b.w.
	Ingestion, Endpoint death	Fatal if swallowed	Oral: <5 mg/kg
	Dermal, Endpoint: skin damage	Severe skin burns	Destruction of tissue/visible necrosis
	Ocular, Endpoint: eye damage	Eye damage	Irreversible effect on iris/cornea/conjunctiva
	Parenteral	n/a	Damage analogous to dermal or Internal contamination of the bloodstream or the lymphatics
Vapor	Inhalation, Endpoint: death	Fatal if inhaled	<0.5 mg/L
	Inhalation Endpoint: respiratory hypersensitivity	May cause allergy or asthma symptoms or breathing difficulties if inhaled	Asthma, rhinitis/conjunctivitis and alveolitis
	Inhalation Endpoint: irreversible or other serious, long-lasting adverse health effects	AEGL-1	As substance-specific time/concentration matrix

Table 5. *Cont.*

Chemically Reacting with Living Organisms (Toxic) CBRN Agents in GHS Systematics			
Physical Form	**Exposure Route [1]**	**Hazard Statement for the Highest Category**	**Dose Value [1] or Description for the Endpoint Extreme Category**
Vapor	Inhalation Endpoint notable discomfort, irritation, or certain asymptomatic non-sensory effect	AEGL-1	As substance-specific time/concentration matrix
	Dermal, Endpoint: death	Fatal when in contact with skin	<5 mg/kg b.w.
	Dermal, Endpoint damage	Severe skin burns	Destruction of tissue/visible necrosis
	Ocular Endpoint damage	Eye damage	Irreversible effect on iris/cornea/conjunctiva
Gas	Inhalation, Endpoint death	Fatal if inhaled	<100 ppmV
	Inhalation Endpoint hypersensitivity	May cause allergy or asthma symptoms, or breathing difficulties if inhaled	Asthma, rhinitis/conjunctivitis and alveolitis
	Inhalation Endpoint: irreversible or other serious, long-lasting adverse health effects	AEGL-2	As substance-specific time/concentration matrix
	Inhalation Endpoint notable discomfort, irritation, or certain asymptomatic non-sensory effect	AEGL-1	As substance-specific time/concentration matrix
	Dermal, Endpoint: death	Fatal when in contact with skin	<5 mg/kg b.w.
Biological infectious materials			
Exposure route Source	**Reservoir**	**Examples**	**Endpoint/symptoms**
Ingestion	Food and water	Bacteria: *Bacillus anthracis*, *Bacillus cereus*, *Vibrio cholerae*, *Clostridium botulinum*. Viruses: Rotavirus, Astrovirus, Adenovirus, Norovirus. Parasite: *Entamoeba histolytica*, *Trichinella spiralis*, *Taenia* spp.	General symptoms (fever, weakness) specific G-I tract symptoms
Inhalation	Airborne aerosol human or mechanically dispersed	Bacteria: *Bacillus anthracis*, *Legionella pneumophila*, *Mycobacterium* species, *Brucella* spp. Viruses: Othopoxviruses, Hantaviruses, Influenza viruses, Sin Nombre virus, SARS-CoV-2, Fungus: *Aspergillus* spp., *Histoplasma capsulatum*, *Coccidioides immitis*, *Cryptococcus neoformans*	General symptoms

Table 5. *Cont.*

Biological infectious materials			
Exposure route Source	**Reservoir**	**Examples**	**Endpoint/symptoms**
Parenteral (bite)	Vector-borne	Bacteria: *Francisella tularensis*, *Borrelia burgdorferi*. Viruses: West Nile, Chikungunya. Parasite: *Plasmodium falciparum*, *Babesia microti*	General and disease-specific symptoms
Parenteral (wound)	CBRNe incident delivered	Bacteria: *Clostridium botulinum*, *Staphylococcus aureus*. Viruses: Hepatitis C virus (HCV), Orf virus. Fungus: *Cladosporium cladosporioides*, *Aspergillus niger*	Bloodstream or the lymphatic system infection
Direct	Skin-to- skin	Bacteria: *Bacillus anthracis*, *Staphylococcus aureus*. Viruses: Human papillomavirus (HPV), Herpes simplex virus—HSV. Fungus: Ringworm (Tinea infections), Trichophyton (Onychomycosis)	Local skin lesions
	bodily fluids, e.g., vomit	Bacteria: *Yersinia pestis*, *Francisella tularensis*. Viruses: Ebola, Marburg virus. Fungus: *Candida albicans*, *Candida auris*	Fever, multiple organs failure
	dirty hands-to- mucous membranes	Bacteria: *Shigella* spp., *E. coli* O157:H7, Viruses: SARS-CoV-2, Rotavirus. Fungus: *Candida albicans*, *Trichophyton rubrum*	Conjunctivitis
Materials emitting ionizing radiation			
Exposure route endpoint	**Point source (debris) Closed source (industrial, medical)**	**Gamma**	**Dose dependent on Source strength, time, distance, and attenuating barriers**
Inhalation Endpoint: Death	Aerosol	Alpha, beta, gamma	Internal body contamination, effect depends on the source strength and decay
Inhalation Endpoint: Cancer or organ damage	Aerosol		Cancer or organ damage
Dermal	Aerosol	Alpha, beta, gamma	Dose dependent on source strength
Parenteral	Solid particles	Alpha, beta, gamma	Internal body contamination, the effect depends on the source strength and decay

Table 5. *Cont.*

Physically damaging CBRNE			
Physical form	Type of reaction	Energy delivery form	Health effects
Gas, liquid, solid	Highly reactive with water	Flame, heat	Skin burns internal burns
Gas, vapor, solid	Self-reacting	Explosion, projection, fire	Mechanical fragmentation burns
Solid, liquid	Self-reaction, Reaction upon ignition or exposure to air	Explosion; fire	Mechanical fragmentation burns

Table 5 links each physical form to typical toxicological endpoints, based on AEGL categories and GHS statements. For instance, inhalation of certain vapors or aerosols may cause fatal outcomes at concentrations below 0.05 mg/L. The classification also includes intermediate categories such as "irreversible but non-fatal" or "moderate discomfort" to enhance early-stage decision-making when analytical confirmation is pending [12,13].

Importantly, the system incorporates energy-releasing chemical hazards (e.g., explosives, flammable vapors) under the extended "E" in the CBRNE model. These agents are frequently involved in real-world CBRN events, where the combined effects of toxic release and physical trauma (from fire, blast, or shockwave) demand integrated classification.

Table 6 places these hazards within the physical hazard classes of the GHS system (H200–H204 for explosives, H220–H252 for flammables), accompanied by visual symbols and brief descriptors to ensure immediate recognition and appropriate response [12,13].

Table 6. Integration of chemical and energetic hazards with communicative symbols and hazard descriptors. [1] For code definition, see Regulation 1272/2008 [22], [2] also, corrosion of any other tissue. [3] CBRN-related: lungs, skin, upper respiratory tract, heart, blood. Description of hazard statements [H]. Format: HXYZ. X (2) physical hazard; (3) health hazard, (4) environmental hazard. Y route of exposure [0]—ingestion; (1)—dermal, (3)—inhalation (7) internal organ damage. Z action/severity (0–2) toxicity (fatal, toxic), (3,5)—other (damage, sensitizing, irritation).

Hazard	**Effects Description**		**GHS Hazard Codes [1]**	**Pictograms**
GHS-based				
Health hazards				
Hazard	Description		Hazard statement	Pictogram
	Effect	Action		
Acute toxicity	Fatal	POISO-NING	H300, H310, H330	Skull and bones
	Toxic		H301, H311, H331	Skull and bones
	Harmful		H302, H312, H332	Exclamation mark
Corrosion [2] skin/eye damage	Severe Burns	TISSUE DAMAGE CHEMICAL BURNS	H314, H318	Dripping acid
Irritation skin/eye	Irritation		H315, H319	Exclamation mark
Respiratory/skin sensitization	May cause allergy, asthma, breathing difficulties	SENSITI-ZING	H334	Health hazard
			H317	Exclamation mark

Table 6. *Cont.*

Hazard	Effects Description		GHS Hazard Codes [1]	Pictograms
Selective target Organ Toxicity—Single exposure	Causes damage to (organ) [3]	TOXIC TO TARGET ORGAN	H370	Health hazard
	May cause… damage to organ…		H371 H335	Exclamation mark
Physical hazards				
Explosive	Unstable	PHYSICAL DAMAGE	H200 to H204	Exploding bomb
	Mass explosion			
	Severe projection			
	Fire, blast or explosion			
Flammable	Extremely flammable gas	HEAT BURNS	H220	Flame over the surface
	Pyrophoric		H250	
	Emitting flammable gases in contact with water		H251	
	Self-heating		H252	
Other reactive Self-reactive	Heating may cause explosion/fire May cause fire/explosion	PHYSICAL DAMAGE	H240–H242	Exploding bomb or flame over a surface
Pyrophoric Peroxides Oxidizers	May intensify fire	CHEMICAL BURNS	H271, H272	Flame over circle
Non-GHS based				
Weaponized CWA	Nerve agents Blister agents Choking agents Blood-poisoning agents Psychoactive agents Incapacitating agents		Corresponding to GHS H330, H310 H300 Also H350, H370	Three-pronged black or red shape in a trefoil on yellow
Biological hazards				
All	No standardized effect descriptions		No symbolic hazard levels	Black triple crescent in a trefoil on yellow

Table 6. *Cont.*

Hazard	Effects Description	GHS Hazard Codes [1]	Pictograms
Radiological/Nuclear hazard			
Ionizing radiation	General		Text: Warning; Radioactive material or ionizing radiation + Black trefoil in a yellow circle (ISO 361 standardized)
	High-level sealed-source ionizing radiation		Black trefoil with rays emitting on a skull and a running figure
	Any transported radiation-emitting material		Diamond with a text: "Radioactive"
	Transported fissile material		"diamond with a text "Fissile"

Additionally, the framework highlights the growing concern of diverted-use chemical threats, such as TIC (toxic industrial chemicals), biocides, and pharmaceuticals. While not formally categorized as CWAs, these agents can cause mass harm when released intentionally. Their properties (e.g., aerosol-forming capacity, environmental persistence, reactivity) are often underappreciated in conventional systems. Databases like European Chemical Agency ECHA CHEM and HSDB (Hazardous Substances Data Bank) provide relevant toxicological data but lack operational context, which this model addresses.

By combining toxicological profiles, physical characteristics, exposure dynamics, and visual communication, the proposed classification offers a structured, field-ready tool for hazard recognition, scenario analysis, and responder training (Figure 1). It connects data-rich systems with real-time operational needs—enabling effective action even in the absence of confirmed agent identification.

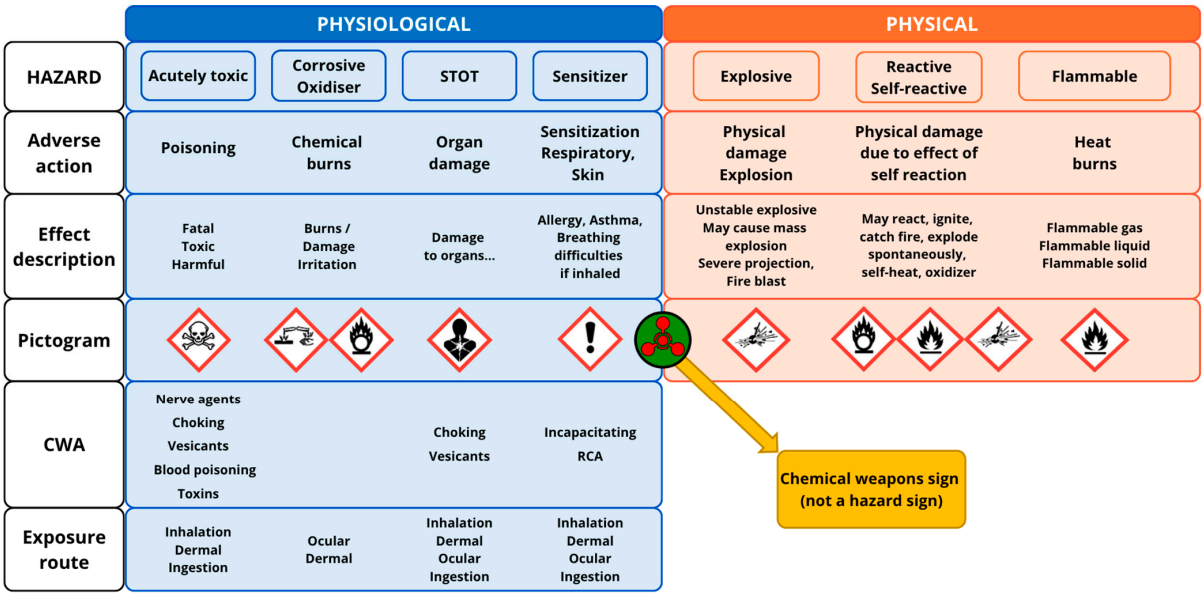


Figure 1. Description of the proposed CBRN-oriented chemical hazard classification system.

3.2. Biological Hazard Domain

Biological hazards in the CBRN context present a distinct classification challenge due to the variability of biological agents, their interaction with human hosts, and their potential

for uncontrolled secondary transmission. Unlike chemical or radiological agents, which act through predictable physicochemical mechanisms, biological agents have dynamic life cycles, can replicate and mutate, and often persist in the environment or spread through person-to-person contact [1,2,23]. This complexity requires a classification framework that supports decision-making in conditions of uncertainty and evolving outbreak scenarios.

Current international classification systems address biological hazards primarily from laboratory or regulatory perspectives. The WHO Biosafety Manual groups agents into four risk levels, based on pathogenicity, availability of treatment or prophylaxis, and whether risk applies primarily to individuals or communities [24,25]. The U.S. Centers for Disease Control and Prevention (CDC) uses a Select Agents and Toxins List, which emphasizes potential for bioterrorism and public health disruption. The European Federation of Biotechnology similarly classifies biological agents based on severity, dissemination potential, and environmental persistence [26]. While informative, these systems are not optimized for emergency use, where agent identification may be delayed, and decisions must be based on symptoms or initial epidemiological data.

In the proposed classification model, biological agents are assessed using operationally relevant parameters that facilitate situational judgment. These include the nature and severity of health endpoints, such as mortality, hospitalization, chronic illness, or the development of asymptomatic carrier states. Pathogenicity is defined as the likelihood of disease following exposure, whereas virulence relates to the severity of disease, including median lethal dose (LD_{50}), median infectious dose (ID_{50}), and threshold for herd immunity (R_0). Transmissibility encompasses both the route of transmission (inhalation, ingestion, contact) and its mechanism (e.g., airborne, droplet, fomite-mediated). Latency and time to onset are critical for estimating the detection window and the urgency of response (Figure 2).

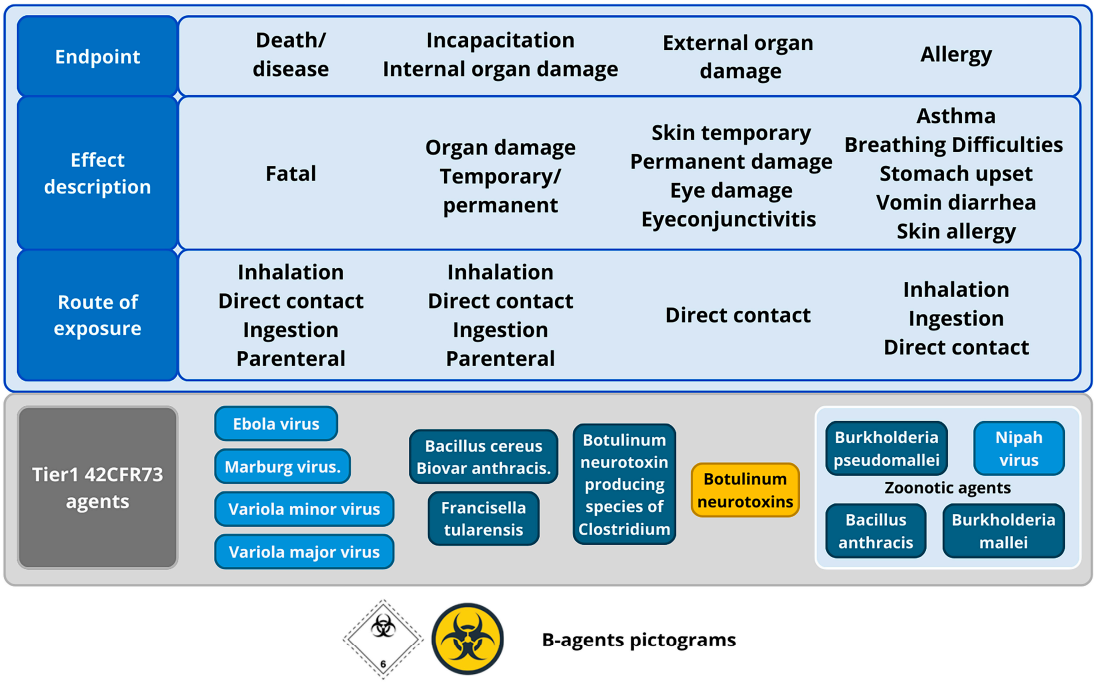


Figure 2. Description of the proposed CBRN-oriented biological hazard classification system.

The availability of treatment or prophylaxis further modifies the hazard level by defining the potential for effective intervention. A summary of these criteria is presented in Table 7.

Table 7. List of CBRN relevant properties and features for each of the CBRN domains.

Properties and Features Satisfying the CBRN Information Needs		
Subdomain	Existing classifications	Looked for in CBRN
Chemical	Endpoint: death, damage, asthma/allergy, selective target organ toxicity	Endpoint: death, damage, asthma/allergy, selective target organ toxicity
	Physical, chemical properties	Physical, chemical, and senses-determined (olfactory, visible)
	Route of exposure: inhalation, skin/ocular, ingestion	Inhalation, skin/ocular, ingestion, parenteral
	Symptoms	Manifestations, severity, onset
Biological	Endpoint: individual: death, hospitalization, population: epidemic, pandemic	Endpoint: death, hospitalization
	Virulence: LD_{50} median lethal dose, ID_{50} median infectious dose, R_0 threshold for herd immunity	Route of exposure: inhalation, ingestion, direct
	Pathogenicity Transmissibility	
	Treatment/remedies	Behavioral remedies
	Alert	Rapid, days, weeks
Radiological/Nuc-lear	Endpoint: Death, cancer, or organ damage	Endpoint: Death, cancer, or organ damage
	Energy: equivalent dose, effective dose	Energy: equivalent dose, effective dose
	Target organ Decay: in relation to absorbed corpuscular radioactive matter	Attenuation: attenuation factors
		Exposure routes: direct irradiation, inhalation, ingestion, parenteral

In contrast to chemical hazards, biological threats often lack well-defined exposure thresholds. Infectious dose values (ID_{50}) are highly variable and depend on multiple factors, including agent strain, host condition, and environmental context. Consequently, classification relies more heavily on observable clinical patterns and epidemiological indicators. Descriptive categorizations such as "high individual risk but low transmission potential" allow responders to act even in the absence of confirmed agent identification [27].

The classification system also allows for the inclusion of emerging and genetically engineered pathogens, which are not always present in official lists. These include synthetic biology constructs, recombinant organisms, and engineered toxins. In such cases, characteristics such as replication rate, immune evasion, resistance to treatment, and environmental survivability serve as proxies for hazard classification [28]. This approach ensures preparedness for novel or hybrid threats.

Exposure routes play a key role in biological hazard behavior. Due to their efficiency and involuntary nature, inhalation and ingestion are the most relevant routes in public-space scenarios. Parenteral exposure is less common but may occur in the context of device-based delivery [29]. A matrix of typical symptom presentations and routes of exposure for selected pathogen classes is shown in Table 5.

Communication of biological hazards poses unique challenges. Technical vocabulary, taxonomic ambiguity, and evolving case definitions can confuse responders and delay action. To address this, the proposed classification integrates simplified hazard communication tools, including internationally recognized symbols and operational descriptors. Table 6 presents visual and verbal cues adapted to field conditions—such as the biohazard trefoil, along with interpretive descriptors like "invisible agent", "delayed onset"

or "requires airborne PPE". These tools facilitate rapid risk recognition across diverse user groups.

Overall, the proposed biological hazard classification aligns scientific parameters with emergency management requirements. It emphasizes early symptom recognition, agent behavior inference, and actionability—particularly in contexts where information is incomplete and time is limited.

3.3. Radiological and Nuclear Hazard Domain

Radiological and nuclear hazards in the civilian CBRN context present distinct classification challenges due to their invisibility, long-term consequences, and the persistent fear they generate. While public perception often conflates radiological incidents with nuclear warfare, the practical risk landscape includes a broader range of events—from medical isotope releases and orphan sources to intentional dispersion of radioactive materials in so-called "dirty bombs" [30–33].

Unlike chemical or biological agents, ionizing radiation does not rely on chemical reactivity or biological replication. Its effects are mediated through energy transfer to biological tissues, leading to DNA damage, oxidative stress, and organ dysfunction. These effects vary widely depending on radiation type (alpha, beta, gamma, neutron), dose, dose rate, and duration of exposure [33–35]. The classification of radiological hazards must therefore consider not only the intrinsic properties of the source, but also the exposure scenario and route.

International standards, such as those from the ICRP, the U.S. EPA (Environmental Protection Agency), and the IAEA (International Atomic Energy Agency), offer dose-based risk models that distinguish between deterministic and stochastic effects. However, these models assume known exposure parameters and may not be readily applicable during emergency response [36–38]. In contrast, the framework proposed in this study emphasizes early hazard recognition based on observable symptoms, situational indicators, and agent properties that can be inferred or approximated during a radiological event (Figure 3).

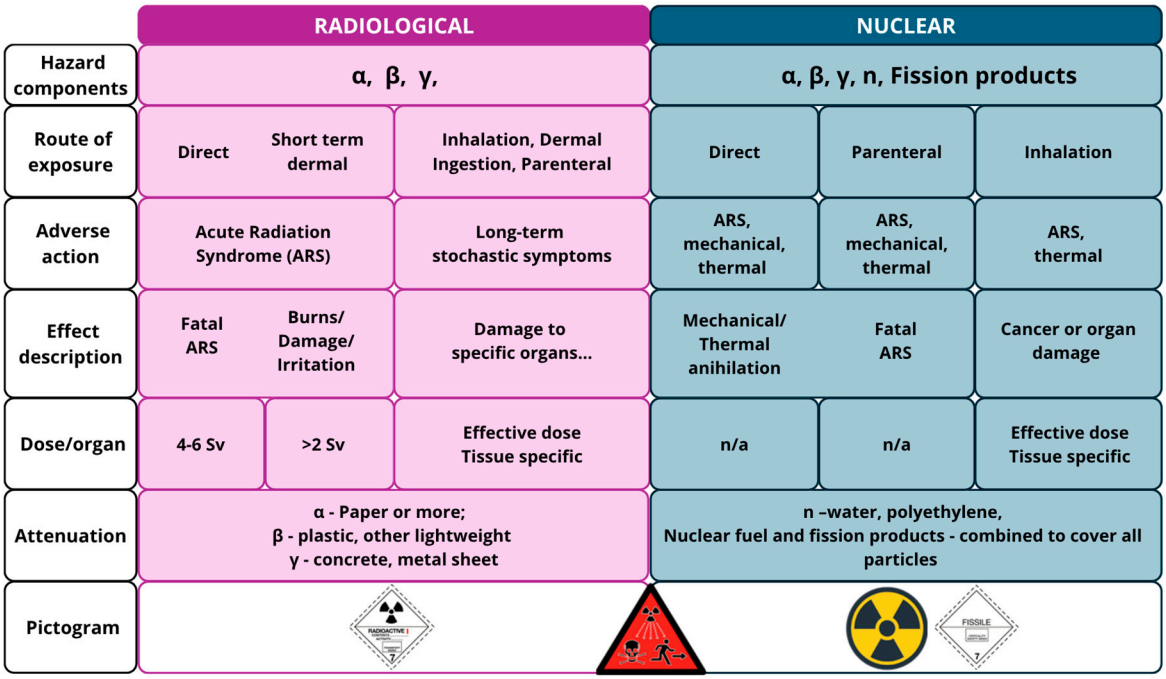


Figure 3. Description of the proposed CBRN-oriented radiological and nuclear hazard classification system. The route of exposure is central to hazard assessment. Inhalation and ingestion are particularly

concerning in cases of fine radioactive aerosols or contaminated food [39] and water supplies. External exposure becomes significant when high-energy photons or neutrons are involved, such as in close-range exposure to unshielded sources. The framework distinguishes between internalized radiation (with prolonged biological impact) and transient external exposure and integrates this into its classification logic [40,41].

As shown in Table 5, symptom onset and clinical presentation vary by exposure type and dose. Acute Radiation Syndrome (ARS) typically emerges after whole-body exposure above 1 Gy, with prodromal symptoms such as nausea, vomiting, and fatigue. In subacute cases, localized effects such as erythema or hair loss may indicate partial or prolonged exposure [42–44]. Because radiological symptoms can overlap with other medical conditions, classification also considers timing, clustering, and environmental indicators (e.g., radiation detector alarms, unusual contamination patterns).

Unlike biological and many chemical agents, radioactive materials may remain hazardous for extended periods due to physical half-life and environmental persistence. This necessitates, in the case of isotopes and persistent chemicals [39,40], the inclusion of variables such as isotope stability, volatility, and propensity for re-aerosolization during decontamination or cleanup. The classification system accounts for this by tagging isotopes with operational descriptors (e.g., "volatile alpha emitter—high internal hazard" or "persistent ground contaminant—low immediate effect, high long-term risk").

Another distinguishing factor is the availability and complexity of protective measures. While shielding, distance, and time are standard protective principles, implementation in urban or public spaces can be limited [36,45]. Moreover, effective decontamination, especially of internal exposures, is often unavailable or delayed. Therefore, the classification integrates not only hazard potential but also feasibility of mitigation and monitoring.

Although nuclear detonation scenarios are beyond the scope of most civilian planning, certain features—such as mixed radiological, thermal, and blast effects—are relevant in dual-threat or hybrid incidents [46]. The framework allows for inclusion of such composite hazards within its extended model, supporting comprehensive planning and triage.

Overall, radiological hazard classification in this framework prioritizes route, source type, and symptom progression, while retaining compatibility with international guidelines. It supports responder decision-making by aligning physical science with operational risk and by enabling early differentiation between high-impact and lower-priority events in real time.

3.4. Role of Exposure Routes and Physical Properties

The route of exposure is one of the most critical variables in determining both the clinical outcome of hazardous agent contact and the appropriate protective measures to be taken. In CBRN incidents, exposure routes are rarely uniform or predictable; agents may enter the body through inhalation, dermal absorption, ingestion, or less commonly, via ocular or parenteral pathways. Each route involves distinct physiological barriers, surface areas, and absorption kinetics, which collectively influence toxic effects' severity, latency, and reversibility [1,32,47].

Inhalation is the most significant route in open-space and aerosol-generating events. The respiratory tract presents a large, vulnerable surface with minimal protective layers, allowing for rapid systemic absorption of gases, vapors, and fine particulates [48,49]. Moreover, inhalation exposure is difficult to avoid in public or urban settings, especially when the agent is odorless or colorless. Consequently, agents that are volatile or form stable aerosols pose a disproportionately high operational risk and are prioritized in this classification model [50].

Dermal exposure becomes highly relevant in the case of agents with dual solubility properties—i.e., those capable of penetrating both lipophilic and hydrophilic skin layers [51]. Many chemical agents, such as vesicants and nerve agents, can penetrate intact skin and accumulate systemically. Environmental persistence, ambient temperature, and occlusion (e.g., clothing or personal protective equipment) can further modify the absorption profile [52]. While ingestion is less likely to be the primary route in CBRN events, it may occur secondary to contamination of food, water, or hands [1,53], and is particularly relevant in post-incident environments with inadequate decontamination.

Table 3 provides a route-specific framework for approximating absorbed dose based on four key modifiers: the strength of the biological barrier (e.g., skin vs. alveoli), the surface area available for contact, the degree of exposure control (e.g., availability of PPE or confinement), and the agent's concentration or form. This approach allows for semi-quantitative risk assessment even in the absence of exact dose measurements, supporting real-time triage and response.

The physical form of the agent—gas, vapor, liquid, solid, aerosol—further interacts with the exposure route to define the resulting hazard. Gaseous and vaporous agents are more likely to cause respiratory toxicity, while liquids may result in dermal or ocular injury depending on volatility and solubility. Aerosols are particularly hazardous due to their dual potential for inhalation and deposition on mucous membranes or open wounds. Solids, while generally less bioavailable, can be dangerous if fragmented or re-aerosolized under certain conditions, such as explosions or mechanical disruption [50,54–56].

Table 5 integrates agent form and exposure route to map expected toxicological outcomes. For instance, fine-particle aerosols may result in deep lung deposition and irreversible pulmonary damage, whereas contact with corrosive liquids may lead to localized skin necrosis with systemic sequelae depending on absorption rate and dose [57–60].

Another critical consideration is the onset time of symptoms, which often varies by exposure route. Inhalation exposure to high-potency nerve agents may result in symptoms within seconds, whereas ingestion of biological toxins may take hours to manifest [61–63]. This latency influences both recognition and intervention: fast-onset symptoms allow for rapid clinical suspicion, while delayed symptoms may result in widespread exposure before containment measures are enacted [63].

The classification also accounts for environmental and behavioral factors that modify exposure probability and outcome. For example, confined spaces amplify inhalation risk, while heat and moisture increase dermal absorption [64]. These situational variables are not constant across events but must be integrated into hazard interpretation when deciding on protective measures or public health recommendations.

The framework provides a more realistic and actionable understanding of hazard behavior by systematically incorporating exposure route dynamics and physical properties into the classification model. It moves beyond simple agent identity or toxicity values to support triage, planning, and responder protection in real-world, time-sensitive contexts.

3.5. Integration into a Communicative System

Effective communication of hazard information is fundamental to CBRN preparedness and response. In high-pressure incidents where analytical confirmation is unavailable or delayed, responders and decision-makers must rely on simplified, intuitive signals to identify threats, assess severity, and initiate protective measures [65]. The challenge lies in translating highly technical, domain-specific knowledge into accessible, rapidly interpretable forms—particularly for mixed-audience environments involving first responders, medical personnel, public officials, and affected populations.

Traditional hazard communication systems, such as the GHS or transport labeling schemes (e.g., ADR, DOT), provide standardized visual and textual warnings based on chemical identity and classification. However, these systems often assume that the identity of the substance is known and that users are trained in chemical hazard interpretation [65–68]. Such assumptions cannot be made in real-world CBRN events—especially those involving intentional release or novel agents. Communication tools must therefore bridge the gap between scientific rigor and operational usability.

The framework developed in this study introduces a multi-level communicative model, designed to integrate seamlessly with the proposed classification structure. This model includes symbolic icons, color-coded risk indicators, textual descriptors, and scenario-based modifiers that together enable hazard recognition even under conditions of uncertainty. Rather than focusing solely on agent names or UN numbers, the communicative layer conveys what responders need to know: how the agent behaves, what kind of harm it can cause, how fast symptoms may appear, and what protection is necessary.

Table 6 presents a visual and semantic hazard matrix, where classified agents—whether chemical, biological, radiological, or energetic—are annotated with pictograms, effect profiles, and recommended response cues. For example, an inhalation-priority chemical agent may be marked with a gas mask symbol, the label "rapid onset," and a red bar indicating "high severity." A persistent biological agent with unknown identity may receive the biohazard symbol, the tag "invisible vector," and a yellow bar indicating "delayed effects, quarantine advised." Energetic hazards are tagged with explosion or flame icons, as well as physical impact descriptors to alert responders to blast-related trauma risk in addition to toxicity.

These communicative cues are not intended to replace technical data but to supplement and translate it for fast decision-making. The model maintains internal consistency by linking each communicative unit back to the core classification criteria—such as health endpoints, exposure route relevance, and physical-chemical properties. This ensures that visual indicators are meaningful, not arbitrary, and that they support scenario modeling, tabletop training, and real-time coordination.

Furthermore, the system accounts for compound threats and evolving incidents. It allows for combination symbols, layered risk cues, and updateable status tags (e.g., "unconfirmed agent", "PPE escalation", "secondary contamination suspected"). In this way, the classification is not only a static reference but a dynamic communication tool.

The framework supports interdisciplinary interoperability and rapid threat recognition by integrating classification logic with symbolic and textual representation. It facilitates everyday situational awareness across organizational and technical boundaries, empowering even non-specialist actors to contribute meaningfully to emergency response. Ultimately, this communicative model bridges the final gap between technical analysis and actionable knowledge—a crucial element in any effective CBRN system.

The framework presented above will be significantly empowered if combined with detection capacity, strengthening the relation between observation and the surety of response. Detection, which is considered an important preventive measure, is also a powerful response tool. It must be remembered that it delivers only partial information covering either a limited number of agents or describes a selection of chemically, biologically, or radiologically similar agents, with the range of identification spectrum inverse to accuracy. That applies equally to CBRN chemical, biological, and radiological subdomains. Bringing together detection information with the observed form, exposure route, observed effects, classification typical for those effects, and possibly knowledge of some adverse effects, may help narrow the agent search and conclude undertaking measures, supporting the

decision, e.g., whether to begin with evacuation or removal of the agent. Some examples are provided below.

4. Practical Applications

The proposed hazard identification and communication methodology can serve as a framework in decision-making during a potential CBRNE incident. The practical applications discussed in this paper, in addition to rapid hazard assessment and exposure reduction measures, include those taken by response services on the scene after their arrival. These actions aim to achieve exact hazard identification/confirmation, which is done by sampling and analysis, and further steps: triage, decision about decontamination, and extent of medical intervention. Sampling also supports investigation, an activity outside health concerns but essential, specifically in cases of deterministic CBRN releases. The role of sampling is envisaged in the charts presented in Figures 4–6, following sampling and analysis results.

The full decision chart using components of the proposed classification framework is presented in Figure 4.

Based on the hazard identification and systematization described in this paper, the decision chart presented in Figure 4 allows better hazard understanding, improves identification and decision-making, contributes to communication, and unifies situation reports from the incident zone.

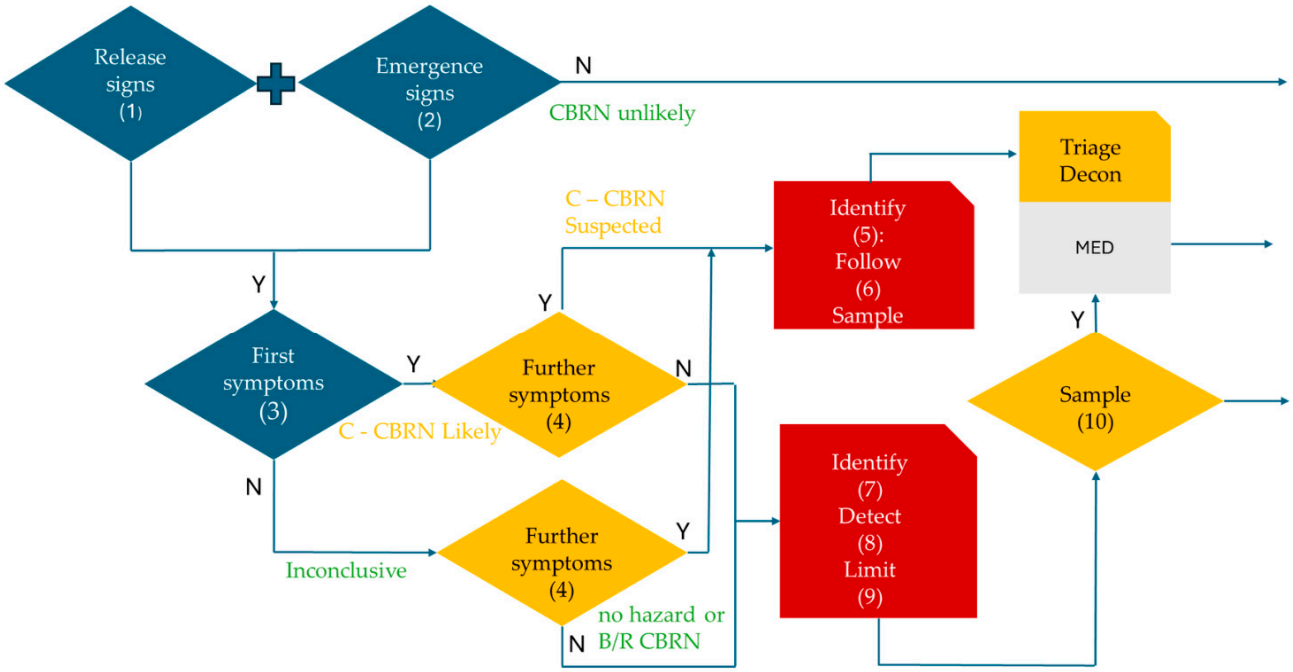


Figure 4. The decision flowchart employing the proposed classification. Release signs: (1) Blast, hiss, cloud. Emergence signs: (2) condensate, light refraction, odor. First symptoms: (3) Eye redness, rash, breathing difficulties (children, allergies). Further symptoms: (4) Conjunctivitis, laryngitis, asthma, rash, blisters. Identify hazard: (5) exposure route and symptoms: cross-check with Hazard class. Follow precautions: (6) P-statements [CLP]. Assigned to the identified hazard classes. Identify: (7) Possible B and R exposure routes. Detect: (8) When available to support inference. Limit exposure: (9) based on observations and hazard characteristics. Sample: (10) to support epidemiological or sanitary steps.

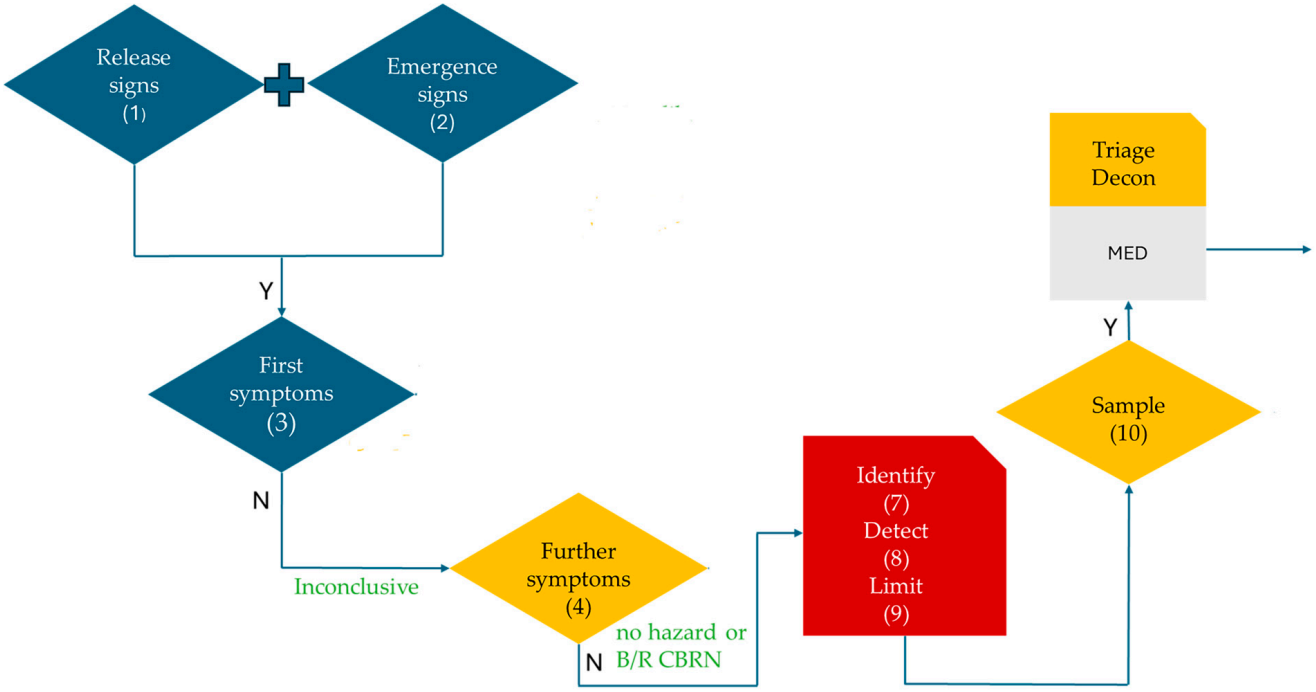


Figure 5. Decision chart for the exercised scenario. Release signs: (1) No. Emergence signs: (2) spotted powder. First symptoms: (3) None. Further symptoms: (4) Conjunctivitis, laryngitis, asthma, rash, blisters. Identify: (7) Possible B and R exposure routes: inhalation. Detect: (8) When available to support inference; detected Anthrax bacteria spores. Limit (9) apply any available provisional respiratory protection. Sample: (10) to confirm the agent and support epidemiological or sanitary steps. Triage: Exposed individuals who qualify for advanced treatment.

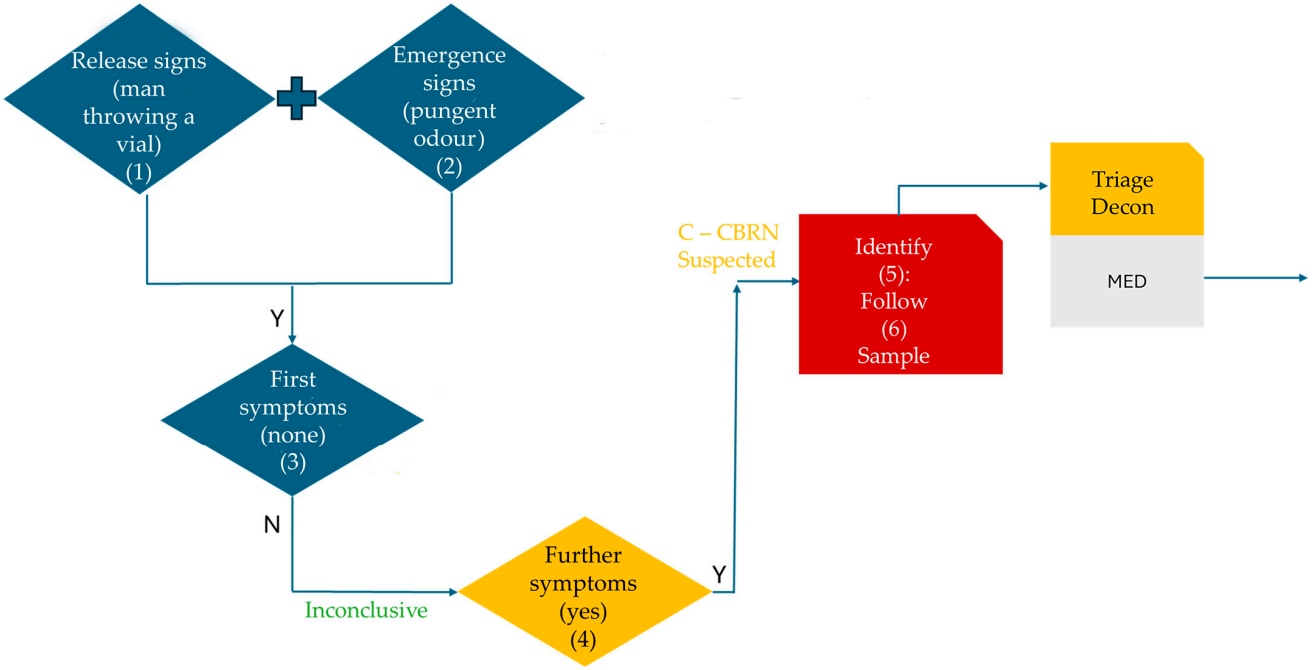


Figure 6. Decision chart for large-scale CBRN incident. Release signs: (1) Observed perpetrator. Emergence signs: (2) Odor. First symptoms: (3) None. Further symptoms: (4) Headaches, weakness, burning in the eyes and throat, coughs, nausea. Identify hazard: (5) Exposure via inhalation only; symptoms: non-specific, Hazard low or delayed, eventually H312. Follow precautions: (6) P-statements: For H312 hazard class P304 + P340 + P312 [22]. Detect: (8) No detection. Limit exposure: (9) Removal from the area. Sample: (10) Samples taken but announced only later.

This algorithm for responding to the CBRN type of incident employs specific procedures listed below.

- 1, 2, 3+: reaction depending on how many victims are identified on scene; if three or more, CBRN accident is likely to have happened.
- 5S: Sights, Signs, Smells, Sounds, Symptoms; identification of phenomena accompanying the suspected incident.
- Remove x3: (Remove yourself, remove clothes, remove residues of agents (means depend on the situation) by washing them out.
- CBRN Evacuation: more complicated than in case of fire.
- Initial decontamination: based on symptoms, contamination routes, and available resources.

These procedures have been developed and tested by globally recognized organizations such as DSTL (Defense Science and Technology Laboratory), CDC, NPSA (National Protective Security Authority), Protect UK, UK Health Security Agency, PHE (Public Health England), National Fire Chiefs Council, and others, mainly from the UK and the USA. At their origin, they all have one thing in common—they do not depend on or rely on the previously cited systems for categorizing CBRN or HAZMAT substances. At the same time, that knowledge would be helpful, particularly when supported by detection capacity, a functionality requiring understanding and systematization brought by the proposed framework. The latter is particularly relevant in the case of cross-border, regional, and any incidents at large public gatherings, being the subject of the CBRN security-related projects mentioned in the Introduction chapter. It appears that the services already use methods of determining risk based on sensory observation (smell, sight of clouds, oily spots on the surface of water, effects of poisoning on plants, absence or presence of typical insects, etc.), but do not relate them further to the scientifically based classifications and hazard communications systems.

4.1. Examples

The proposed framework and the procedures were tested in the exercises conducted as part of the previously mentioned projects. The application presented below comes from the NEST Project [8].

Scenario: In the middle of the congress day, the facility manager receives information from security staff who find yellow and white powders in a mobile air condition unit

The response is shown in Figure 5. It includes the existing detection device based on the tested antibody-based electrochemical biosensor used in the project. It is assumed that the antibody for the pathogen involved in the attack is among those available in the bio-detecting device.

4.2. Application to the Historical CBRNE Situations

Fortunately, CBRN mass incidents happen rarely. To demonstrate how the decision chart based on the proposed framework would work, an event from 1981 was selected [69,70]. On 27 October 1981, around noon, in the square in front of the main gate of the Sosnowiec Coal Mine, unidentified perpetrators threw three vials of gas from a passenger car. Two of them remained undamaged, while one began to emit an invisible but highly pungent gas. Within a few hours, over sixty people were hospitalized with symptoms of poisoning—mostly mine workers, as well as residents of nearby apartment buildings, including several children. The specialized chemical services arrived at the scene only late in the evening, several hours after the miners had secured the area themselves. The application of the chart would look as presented in Figure 6.

Short explanatory notice: The incident was provoked by secret services (SB) to support civil unrest related to the trial scheduled for the same day in the local District Court against Wojciech Figel and seven other "Solidarność" activists from the Sosnowiec Coal Mine.

5. Conclusions

The classification of CBRN hazards remains a critical but underdeveloped element of civilian emergency preparedness. While scientifically rigorous within their respective domains, existing systems are often unsuited to the operational demands of CBRN incidents—particularly those marked by uncertainty, intentionality, and time pressure. The framework proposed in this study addresses this gap by integrating toxicological, microbiological, radiological, and physical hazard characteristics into a unified, situationally adaptive classification model.

The model reinterprets these standards in light of emergency response needs by drawing upon internationally recognized systems such as GHS, WHO biosafety levels, ICRP radiological guidelines, and AEGL thresholds. It emphasizes key operational parameters, including health endpoints, exposure routes, onset latency, environmental persistence, and symbolic severity. Furthermore, it incorporates dual-use hazards and energetic threats, reflecting the increasingly hybrid nature of modern CBRN events.

A core innovation of the framework lies in its communicative structure, which enables effective information transfer across expert, responder, and public interfaces. By combining visual symbols, intuitive descriptors, and route-specific hazard profiling, the system supports rapid recognition, triage, and protective decision-making even in the absence of agent identification or analytical confirmation. This enhances its usability not only in acute response scenarios but also in training, planning, and cross-agency coordination.

The framework also recognizes the evolving threat landscape, including the proliferation of toxic industrial chemicals, biological toxins, and radioactive materials accessible outside military contexts. By including both "agents-by-design" and "agents-by-diversion," the classification offers a more realistic and comprehensive perspective on civilian CBRN risks.

Overall, the proposed classification system serves as a bridge between scientific knowledge and field-level action. It offers a flexible yet structured approach to hazard identification and communication, designed to support pre-incident preparedness and in-incident response. Future research should explore its validation through simulation exercises, integration into digital decision-support tools, and potential role in harmonizing international CBRN communication standards.

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Abbreviations

The following abbreviations are used in this manuscript:

5S	Sights, Signs, Smells, Sounds, Symptoms
ADR	Accord relatif au transport international des marchandises Dangereuses par Route
AEGL	Acute Response Guideline Level
ARS	Acute Radiation Syndrome
CBRN	Chemical, Biological, Radiological, and Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear, and Energetic
CDC	Centers for Disease Control and Prevention
DOT	USDOT Department of Transportation (US)
DSTL	Defense Science and Technology Laboratory
ECHA	European Chemical Agency
EPA	USEPA Environmental Protection Agency
CWAs	Chemical Warfare Agents
GHS	Globally Harmonized System (of Classification and Labelling of Chemicals)
G-I	Gastrointestinal (route of exposure)
HAZMAT	Hazardous materials
HSDB	Hazardous Substances Data Bank
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ID_{50}	Median Infectious Dose
ISO	International Organization for Standardization
LD_{50}	Median Lethal Dose
METHANE/ ETHANE	Major incident, Exact location, Type of incident, Hazards, Access, Number of casualties, required Emergency services
NPSA	National Protective Security Authority
PHE	Public Health England
PPE	Personal Protective Equipment
RAR	Recognize, Assess, React
RDD	Radiological Dispersal Device
STOT	Selective Target Organ Toxicity
TICs	Toxic Industrial Chemicals
WHO	World Health Organization
WMD	Weapons of Mass Destruction
W_R	Radiation weighting factor
W_T	Tissue sensitivity factor

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