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Chemical, biological, radiological and nuclear considerations in a major incident

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Abstract
Chemical, biological, radiological and nuclear (CBRN) incidents have a disproportionate effect on all aspects of efficient management of casualties. The immediate risks to rescue and healthcare staff, along with damage and threats to existing infrastructure, make CBRN incidents an important consideration to plan and train for, even if the likelihood of encountering them is remote. In addition to the generic ‘all hazards’ approach shared with all major incident planning, CBRN incident management has a number of specific treatments and interventions which require early identification of the agent involved, and thus a high degree of specialist knowledge among responders.

Keywords Biological; CBRN; chemical; contamination; Hazmat; major incident; nuclear; pre-hospital; radiological; triage

The term CBRN stands for ‘chemical, biological, radiological and nuclear’, and relates to specific hazards that may be encountered during an incident. The term CBRN is generally reserved for the deliberate release of a hazardous material such as in a terrorist attack, whereas the term Hazmat is used for accidental release or exposure to toxic industrial material. Examples of some incidents that have taken place over the past 20 years are listed in Table 1. This article will use the term CBRN to relate to both deliberate and accidental exposure to hazardous materials.

The presence or even potential presence of a CBRN hazard in a major incident will make the management of the incident even more challenging for the following reasons.

- Increased risk to responder from on-scene hazards, as well as contaminated or contagious casualties. Unrecognized hazards may cause responders to become casualties themselves. For example: chemical suicide cases where the responder may become exposed to the chemical used, such as hydrogen sulphide.
- Increased risk or anxiety to the wider population. Industrial incidents may release plumes travelling beyond the conventional cordons and response zones. For example: Buncefield oil refinery smoke cloud crossed international borders.
- Increased number of psychological casualties. Bystanders and other members of the population may fear that they have been affected due to poor understanding of these agents. For example: radiation and the West African Ebola outbreak.

Consequently it is essential that all agencies and personnel that may be involved in a major incident response are aware of the additional problems that a CBRN threat can add.

Principles of CBRN medical incident management
The principles of CBRN incident management (SC3AT3ER) are:
- safety
- command
- communications
- assessment (scene/casualties)
-triage
- treatment
- transport
- exploitation (forensics)
- recovery.

Pre-hospital responsibilities
In the UK, the fire and rescue service, police and ambulance services have robust plans in place to deal with major incidents including CBRN and Hazmat incidents. Regular training and exercises are conducted at regional and at national levels.

The fire and rescue service are responsible for tackling fires, dealing with released chemicals and hazard assessment, including detection, identification and monitoring (DIM), at an incident. They are also able to deliver a mass decontamination facility on scene should it be required. They will generally have the lead role at a Hazmat incident.

The police are responsible for coordinating the emergency services at an incident, to provide an effective outer cordon and to maintain public order. They will be the lead agency at a CBRN incident and will conduct appropriate investigations at any incident especially if there is loss of life.

The ambulance service have a dedicated hazardous area response team (HART) who can go forward into the inner cordon of a CBRN incident and perform triage and life-saving interventions. The ambulance service supported by a medical advisor will be the lead service with regard to medical matters at any incident.
As with other major incidents it may be necessary for more advanced clinical care to be deployed to the scene. For example, a medical emergency response incident team (MERIT) may be required to assist with casualty assessment, casualty extrication and emergency medical treatment in a potential hazardous environment. In a CBRN or Hazmat incident it is likely that enhanced PPE will be required to be worn by all personnel within this area. Personnel likely to be called to such incidents need to be familiar with this equipment before attending the scene.

In-hospital responsibilities

It is a pre-hospital requirement for all casualties to be decontaminated before they arrive at the hospital. However in some circumstances, casualties in triage category 1 (T1/IMMEDIATE) may be conveyed before decontamination has taken place either due to a delay in recognizing the type of incident, or delay in decontamination due to the severity of the case. If there is a delay in the recognition of the incident or the deployment of pre-hospital decontamination units, there is a significant risk of contaminated walking casualties and well survivors self-referring to the hospitals.

As with any major incident the initial focus is on resourcing the emergency department (ED) with additional staff to cope with the large numbers of casualties that will arrive in quick succession. Clinical staff will be drafted from all areas of the hospital to work in and potentially lead resuscitation teams. All hospital staff that may be called to augment the ED response should be familiar with their local plans, have trained in the relevant PPE and be familiar with the processes of decontamination, as required. Although senior and specialist advice will be readily available for clinical decisions it is essential that all clinicians are able to identify certain signs and symptoms of chemical intoxication (toxidromes) (Table 2) but also be knowledgeable in the basic principles of managing casualties exposed to CBRN agents, including the use of antidotes.

The hazards

Initial assessment of the risk to individuals and the department should be based upon the toxicity of the substance involved; in general this can be broken into lethal, damaging, incapacitating and iatrogenic effects due to antidotes.

Chemical hazards

Chemical hazards are encountered daily both at home and in industry. The hazards they present cover a wide range of effects from lethality to mild symptoms. These substances include household chemicals, toxic industrial chemicals and chemical weapons. There is some overlap and the approach to any chemical hazard depends on its characteristics, as follows.

### Example of CBRN, Hazmat and explosive incidents over the past 20 years

| Chemical    | Biological | Radiation/nuclear | Other          |
|-------------|------------|-------------------|----------------|
| Deliberate  | Deliberate | Deliberate        | Deliberate     |
| Sarin (Tokyo 1995) | Anthrax letters (USA, 2001) | Polonium-210 (London, 2006) | 9/11 (USA, 2001) |
| Chlorine (Iraq 2007) | Ricin letters (USA, 2013) |                     | London bombings (2005) |
| Nerve agent (Syria 2013) |                     |                     |                |
| Chemical suicides (various) |                     |                     |                |
| Accidental  | Natural    | Accidental        | Accidental     |
| Swimming pool over-chlorination | SARS (2003) | Fukushima (2011) | Buncefield oil refinery (2005) |
| Carbon monoxide incidents | Ebola (West Africa 2014) |                     |                |

CBRN, chemical, biological, radiological and nuclear; SARS, severe acute respiratory syndrome.

### CBRN toxidromes and antidotes

| Nerve agent | Methaem | Cyanide | Pulmonary agents | Vesicant/acid/alkali | Atropine | Botulinum | Opiate |
|-------------|---------|---------|------------------|----------------------|----------|-----------|--------|
| Fitting/↓   | Agitated| Fitting/↓| Normal          | Normal               | Confused | Normal    | ↓      |
| ↑↑          | ↑↑↓     | ↑↑↓     | ↑↑1/2            | ↑↑↑↓                 | Dilated  | Dilated   | Pinpoint↓|
| Pinpoint    | Normal  | N/Dilated| N/Dilated/Painful| N/Red/Painful        | Dilated  | Dilated   | Normal  |
| ↑↑          | ↑↑↓     | ↑↑↓     | ↑↑1/2            | ↑↑↑↓                 | Dilated  | Dilated   | Normal  |
| Cyanosed    | Normal  | N/Dilated| N/Dilated/Painful| N/Red/Painful        | Dilated  | Dilated   | Normal  |
| Pink/Cyanosed| Normal | Normal | N/Dilated/Painful| N/Red/Painful        | Dilated  | Dilated   | Normal  |
| Very rapid onset | Lactic acidosis | Mustard (delayed 6–12 hours) | Red/Blisters | Descending paralysis |
| Lactic acidosis | N/Cyanosed | Red/Blisters | Mustard (delayed 6–12 hours) | Descending paralysis |
| Nitrites | pink sputum | pink sputum | pink sputum | pink sputum |
| Methylene blue | Sodium thiosulphate | Sodium thiosulphate | Sodium thiosulphate | Sodium thiosulphate |
| Atropine | Oxime | Benzodiazepine | ? inhaled steroids | Lewisite — | Botulinum anti-toxin | Naloxone |

Table 2
Priorities in the management of these cases are based on:

- Toxicity (lethality) — the amount of a chemical (depending on route of exposure) that may cause a clinical effect (intoxication).
- Latency — the period of time between exposure and becoming unwell.
- Persistence — the physical properties of the chemical that determine the risk of secondary contamination to emergency responders. For example: a person exposed to a gas such as carbon monoxide does not present a hazard to the ED staff while a patient covered in asbestos (particulate hazard) or a VX nerve agent (liquid) would be a hazard to staff.

Priorities in the management of these cases are based on:

- triage category of casualty and the requirement for life-saving interventions
- contamination risk to responders.

Biological hazards

Biological hazards can be differentiated into live agents (microorganisms) and toxins. This is important as the risks and medical management differ for each type of hazard.

Live biological agents include bacterial, viral and fungal organisms. Effects due to infection may range from incapacitation (Salmonella) through to death (viral haemorrhagic fevers/inhalational anthrax). Infected casualties may also be contagious. In some cases, there may be biological contamination with material including sewage, spores, blood and faeces. A similar safe approach should be used and the risk assessment should include containment, decontamination and/or isolation.

The characteristics of live agents is based on:

- Pathogenicity — risk of causing a disease (e.g. variability of disease with strains of Escherichia coli)
- Virulence — severity of the disease (avian flu compared to swine flu)
- Lethality — risk of death (case fatality rate) (e.g. 100% for untreated inhalational anthrax and the planning assumption of 3–4% for pandemic influenza)
- Infectivity — risk of an infection becoming established following exposure (e.g. the comparison of risk following needle-stick injury with hepatitis B compared to HIV)
- Transmissibility — risk of person-to-person spread (contagious). This can be quantified by the R0 meaning the average number of other people a contagious casualty may infect.

Biological toxins are essentially chemical agents of biological origin (bacterial, plant, animal or fungal). These may potentially be weaponized as toxin only (botulinum or ricin) or be encountered following a toxin-forming infection (bacterial toxins), ingestion (plant toxins) or envenomation (animal toxin following a bite or sting). Toxins are non-transmissible but present a potential contamination hazard. The risk assessment for toxins is based on that for chemicals: toxicity, latency and persistency. Wounds may be contaminated with either live agents (including blood-borne agents) or toxins.

Radiological/nuclear hazards

Radiological and nuclear hazards are managed similarly. Radiological incidents may include any event involving ionizing radiation. Incidents may include industrial sites, transportation and medical facilities. Deliberate release may include the use of an explosive radiological dispersion device (‘dirty bomb’) and are likely to include blast (combined) injuries. Casualties will have a spectrum of injuries that may include trauma, irradiation and contamination. Although there is a contamination hazard, the level of radiation is likely to be low and, therefore, the risk of acute radiation syndrome is also low. High levels of radiation may be associated with pieces of radioactive shrapnel.

In general, a nuclear incident is also a radiological incident but may be associated with very high doses of radiation due to nuclear fission. Nuclear fission incidents are generally isolated to nuclear detonation and reactor accidents.

Radiological sources such as those used in industry and medicine may also be associated with localized high radiation doses.

Ionizing radiation (alpha, beta, gamma and X-ray, neutrons) has different effects depending on the severity of the dose (irradiation). At low doses effects are due to cell damage and characteristically have a slow onset (years). The effects may result in cancer and mutations. Higher doses above a threshold level of 0.5–2 Gy will result in cell death and lead to acute radiation syndrome (ARS). This syndrome is a result of the death of cells with a rapid turnover. After prodromal symptoms (nausea, vomiting and lethargy) and a latency period, ARS results in bone marrow suppression and failure of the gastrointestinal mucosa. Death is primarily due to infection or bleeding. Early surgery may be indicated in these patients if there is concurrent trauma.

Casualty types from radiation incidents are likely to be:

- external exposure (irradiation)
- external contamination
- internal contamination
- combination of above with/without trauma.

The principles of radiation protection and personal safety are based on:

- amount and type of radiation, including dose rate (μSv/hour)
- time exposed to radiation
- distance from radiation source
- shielding between radiation source and personnel (protection factor).

This means that to keep exposure to radiation as low as reasonably practicable (ALARP), the following techniques should be followed:

- remove all contaminated materials (AMOUNT, DISTANCE)
- work carefully but quickly (TIME)
- alternate personnel if possible (TIME)
- keep away from the patient if not involved in medical procedures (DISTANCE)
- use long-handled instruments to remove contaminated items (DISTANCE)
- use appropriate protective clothing to prevent transferring contamination to medical staff (AMOUNT)
- use appropriate shielded and marked containers, as directed by medical physics (SHIELDING).

Combined injuries

As well as the effects of CBRN agents: intoxication (C), infection (B) and irradiation (RN), many incidents may also generate
conventional casualties due to trauma (injuries). Casualties with combined injuries will have a significantly worse prognosis, due to potential marrow suppression, increased risk of infections and interactions with anaesthetic agents.

Catastrophic haemorrhage and airway obstruction may compromise casualties in less time than most CBRN agents. Figure 1 highlights the typical onset of effects. In a CBRN incident, advanced trauma life support principles still apply, and lack or delay of life-saving measures may have more of a deleterious effect than the CBRN exposure.

**General considerations (T C I)**

The variation in the type of incidents and the number of potential agents means that there is no specific management plan. However, a generic approach can be used with similar considerations for all CBRN incidents. The assessments are listed below and can be remembered by the letters T C I, remembered as “To Come In”. These letters stand for:

- **Triage**
- Contamination and/or Contagious?
- Intoxication (Chem, Bio – toxin)/Infection (Bio – live)/Irradiation (Rad, Nuc)/Injuries?

The first and second assessments remain the same for all four incident types, while the third is dependent upon the incident type (C, B and RN). This generic approach can also be inserted into recognized incident management systems.

**Triage**

Triage is the first clinical assessment to be made, as clinical priority is also a priority for decontamination. Triage can also be carried out along the casualty evacuation chain including arrival and departure from decontamination facilities. Decontamination reduces further absorption of certain hazards (chemicals/toxins) and allows better access for primary survey and life-saving interventions. It also allows definitive care to be provided within a clean area. Each category is preceded with the letter T to denote triage category. CBRN prioritization uses the same triage...
categories as conventional triage — immediate/severe (T1), urgent/moderate (T2), delayed/minor (T3) and expectant (T4).

The triage sieve is non-invasive, reproducible, rapid and identifies significant airway, breathing or circulation problems and prioritizes accordingly. In austere environments, ‘triage and treat’ is recommended due to finite medical resources on scene. CBRN incidents also have other indications for prioritization (Table 3) and can be incorporated into a modified triage sieve (Figure 2).

Contamination and/or contagious

Safety is paramount and one of the key areas covered by all contingency plans. The risk of secondary contamination or contagion needs to be assessed. Depending on the type of incident this is likely to be contaminated, possible contamination or not contaminated. The same applies to the risk that a casualty is contagious; this can also be applied to the response to an epidemic. Contamination can be external, internal and wound. The requirement for decontamination, decontamination (removal of internal radioactive contamination, such as using Prussian blue to promote the removal of caesium-137 through the process of chelation) and isolation should be determined. This decision process is called casualty hazard management.

The priority for decontamination for any incident is gross decontamination. This is the removal of clothing (disrobing) and any gross contaminant. This should be followed by either dry or wet decontamination, or a combination of the two. Emergency decontamination of non-caustic agents can be achieved rapidly by the use of absorbent material such as clinical tissue. Wet decontamination can be used as a rinse using a temperature of 35°C for 90 seconds or until all gross particulate material has been removed or in the case of radiological contamination is no longer than twice background radiation.

Personal protective equipment

For chemical incidents and unknown hazards, a chemical resistant suit is to be used. This suit has a number of disadvantages:
- increased effort of work
- reduced communication
- reduced manual dexterity
- less interaction with casualty.

For any biological agent, a minimum of standard precautions should be worn. Protection against airborne or aerosolized biological agents should include a European standard EN149:2001 FFP3 filter mask. Where there is an aerosol risk from an infected casualty; the patient should also wear a mask (unvalved) if transferred.

Radiological hazards are generally particulate or liquid, and pose less of a secondary contamination risk compared to chemical vapours. Standard precautions similar to biological agents would be appropriate.

Containment of contagious casualties

In some scenarios some casualties, even after decontamination, may still present a hazard. Internally contaminated or contagious casualties will need to be isolated. Casualties should not be taken into any areas of high patient turnover. Any movement within hospital should be limited, but patients should be given respiratory protection to reduce any aerosol spread.

Intoxication/Infection/Irradiation/Injuries

This third assessment looks for signs of exposure and is the only parameter to depend on the incident type. As well as the effects of the exposure to CBRN agents (Intoxication/Infection/Irradiation) the assessment also includes the effects of trauma (Injury). Examples of the assessment of exposure include a trauma and chemical primary survey, and the syndrome approach to the assessment of biological agents. The requirement for supportive and definitive management can be assigned as a result of this assessment. Casualties that do not exhibit signs of exposure may either be observed or released, depending on the agent type and latency period.

Principles of CBRN casualty management

The principles of casualty management are:
- recognition
- safety, including selection of PPE and hazard avoidance
- first aid
- triage
- clinical assessment (primary survey and toxidrome recognition)
- life-saving interventions (LSIs)
- casualty hazard management (decontamination/isolation)
- supportive management
- definitive management including antidotes and surgery
- rehabilitation.

Priorities of CBRN casualty treatment

The priorities for casualty treatment are <C>AaBC-D-Evac. These are:
- catastrophic haemorrhage control
- airway (basic) management
- antidote administration
- breathing (or oxygen delivery)
- circulation (once out of the hot zone)
- decontamination (and disability)
- evacuation to a safer zone or area.

Specific management considerations

Chemical

The standard treatment approach should be followed when managing all CBRN casualties. Treating catastrophic haemorrhage, airway complications and breathing problems remain the

| Chemical                  | Biological            | Radiological/nuclear                     |
|---------------------------|-----------------------|------------------------------------------|
| Cyanosis                  | Purpuric rash         | Dose >2 Gy (where dose is known or estimated, this threshold can be increased depending on casualty numbers) |
| Excessive secretions      | Septic shock          |                                          |
| Unresponsive burns        | Pyrexia (>38.3°C)     |                                          |
| Gross contamination       | History of vomiting and/or diarrhoea |                                          |
| Erythema                  |                        |                                          |

Table 3
priority but with the addition of antidote administration. A rapid CRESS assessment (Consciousness, Respirations, Eyes, Secretions and Skin) of the casualty can be easily incorporated into the airway and breathing assessment, which will allow identification of the common toxidromes (Table 1) that may be encountered. Administration of specific antidotes can therefore be commenced at this early stage.

Decontamination will need to be conducted prior to treatment of T2 and T3 casualties but should be conducted concurrently with initial life-saving interventions for T1 casualties, provided that the care providers are wearing appropriate PPE.

Contaminated wounds may be difficult to decontaminate thoroughly and should be irrigated as best as possible then covered with an appropriate dressing (e.g., cling film). Formal surgical debridement and irrigation may be required. Consequently all theatre staff must be made aware that the wound is contaminated and work in a well-ventilated area or wear appropriate PPE. Additionally certain chemical agents can interfere with the mechanism of anaesthetic drugs for example organophosphates may prolong the action of suxamethonium. Appropriate clinical waste management and disposal of the hazardous material (including contaminated tissues), irrigation fluid and equipment also need to be ensured.

**Biological**

Casualties involved in a biological incident are unlikely to present immediately with complications relating to the biological agent. However biological toxin exposure may result in early disease manifestations and should be managed similarly to chemical casualties. Live biological agents are more likely to present as a slowly evolving incident with the actual incident going unnoticed for some time.

Initial casualty management will follow the standard treatment pathways for sepsis such as early antibiotic therapy, high-flow oxygen, fluid resuscitation, appropriate investigations (chest radiograph, blood and urine cultures), measuring serum lactate and haemoglobin with appropriate fluid balance monitoring and early goal-directed therapy in severe sepsis.

More specific treatments for biological casualties may include the use of specific immunoglobulins, anti-toxins. Active and passive immunization as well as antibiotics may also be required for potential persons exposed and contacts, if contagious.

Casualties affected may require isolation and those that have been exposed but well may require quarantine. Some hospitals may be challenged to cope with a surge of inpatients, and consequently additional resources may be required for a longer period. This may result in a prolonged major incident scenario over weeks or months with an impact on conventional service provision.

**Radiation**

The initial management of the prodromal phase is mainly supportive with careful fluid balance for those with diarrhoea and vomiting in addition to anti-emetic medications. Diarrhoea and

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**Figure 2**

Modified CBRN triage sieve

![Modified CBRN triage sieve](https://example.com/modified_cbrn_triage_sieve.png)

GCS, Glasgow Coma Scale.
prompt onset vomiting within the prodromal phase are indicators of high levels of radiation exposure. Time to onset of vomiting can be used as a triage tool as well as a predictor of illness progression. Blood samples should be taken at 6-hourly intervals to monitor white cell counts with differentials, platelets, amylase and C-reactive protein. These can all be used together to estimate the dose of radiation received and predict the clinical course of the radiation exposure.

Any emergency medical treatment or damage control surgery should be undertaken as necessary, however definite surgical treatments should be performed in the latency period as surgical interventions conducted during the manifest illness stage would likely have poor outcomes due to increased risk of infection and reduced healing mechanisms (due to immunosuppression, anaemia, coagulopathies and malabsorption). Prophylactic antibiotics, reverse barrier nursing, blood product replacement and early use of colony stimulation factors (CSF) should be considered in all patients who have received significant doses.

Thermal burns should be managed according to normal principles; however radiation skin injuries (which may take days to weeks to manifest) are likely to require extensive debridement and radical resection due to the DNA damage and cell death within effected tissues that may initially appear healthy.

Exposure to radiation will increase a person’s lifetime risk of developing cancer (1Sv = 5% increase to lifetime risk), however there is very little that can be done to counter this. Consequently long term follow-up and surveillance is standard practice.

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FURTHER READING
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