Clinical care in the "Hot Zone"

M Byers,[1] M Russell,[2] D J Lockey[3]

[1] CBRN Advisor to Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine, Selly Oak Hospital, Birmingham, UK; [2] Department of Military Acute Medicine, Royal Centre for Defence Medicine, Selly Oak Hospital, Birmingham, UK; [3] Anaesthesia and Intensive Care Medicine, Frenchay Hospital, Bristol and Pre-hospital Care, Royal London Hospital, London, UK

Correspondence to: Dr D Lockey, Anaesthesia and Intensive Care Medicine, Frenchay Hospital, Bristol BS16 1LE, UK; david.lockey@nbt.nhs.uk

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ABSTRACT

The threat of chemical, biological, radiological and nuclear incidents is unlikely to decrease and preparations to deal with this type of incident are well established in most European emergency medical systems. In the UK medical care is not currently provided in the "Hot" or contaminated zone. This article discusses the background to the current threat and suggests that, where survivors are present in the "Hot Zone", medical care should be started there to minimise delay and maximise the chances of survival.

The events of 11 September 2001 and subsequent attacks in Europe[1–3] have focused the emergency services on the threat of conventional and unconventional terrorist attacks in the UK. The unconventional threat consists of chemical, biological, radiological and nuclear (CBRN) and hazardous materials (HAZMAT). Hazardous materials are those that have legitimate uses. It is clear that, with a high threat level, the fundamentals of CBRN medicine need to be an essential part of the training of emergency in-hospital and pre-hospital care providers. Unfortunately, gaps in the knowledge of relevant providers have been documented.[4] The concept that early definitive care of trauma victims may improve outcome is well established. Effective emergency medical systems are designed to deliver life-saving interventions at the scene and deliver patients rapidly to definitive care. This article will discuss why we believe a similar approach is required at CBRN incidents if the best results are to be achieved. This may require treatment to be administered in the "Hot Zone", an area which is potentially contaminated and requires rescuers to operate in high-level personal protective equipment. The concept of physicians and paramedics working in this area is well established in some emergency medical systems[5–7] but is not yet normal practice in the UK.[8] This paper discusses the interventions that are possible before decontamination and removal to definitive care in order to improve survival. A model of care is suggested that could be adopted in the UK to improve medical management of CBRN casualties prior to arrival in hospital.

BACKGROUND

The CBRN threat is not new but has sometimes been ignored. The Tatar hordes are often credited with being the first to use CBRN weapons. During the siege of Kaffa in 1345, bodies infected with plague were catapulted over the city walls. Since then, unconventional weapons have been used regularly. Chlorine was first used in 1915 by the Germans at Ypres and mustard gas, again at Ypres, in 1918. In 1984 members of the Rajneeshee Cult caused 751 casualties by releasing *Salmonella typhimurium* in Oregon, USA. In 1995 the Aum Shinrikyo cult successfully released the nerve agent Sarin in the Tokyo subway system after two previous but ineffective attacks using botulinum toxin in 1990 and anthrax in 1993.

The accidental release of toxic industrial hazards, chemicals and materials has also been regularly reported. In 1979 at Sverdlovsk in the USSR there was an unexplained outbreak of anthrax which led to speculation of an unintentional release from a research establishment. In 1984 there was an explosion in Bhopal, India that caused the release of methyl isocyanate from the Union Carbide factory killing around 2600 and injuring many more. At Chernobyl in the Ukraine in 1986 a nuclear reactor suffered a meltdown and a year later in Brazil a lost medical caesium source led to the radioactive contamination of 249 people. The numbers and characteristics of commercially available chemical substances are vast. The American Chemical Society (ACS) Chemical Abstracts Service (CAS) has over 21 million substances registered. The CAS Online Chemical Catalogues File (CHEMCATS) contains data on around 5 400 000 commercially available chemicals of which over 229 000 are regulated. Spillage of chlorine has been one source of concern for emergency planners. In 2004, 9 856 302 tonnes of chlorine were produced in Europe[9] and around 10% (approximately 1 million tons) was transported from producers by rail or road.

The post-exercise reports from the Bank Street CBRN exercise in London in September 2003 and Exercise Horizon in Birmingham in July 2004 both identified that casualty management (triage, assessment, decontamination and treatment) needs to be faster.[10 11] In the latter exercise it took 2.5 h to commence treatment of casualties and another 2 h to clear the scene.

Although chemical, biological and radiological hazards are often considered together, biological hazards do not usually present an immediate threat to either casualties or responders and radiological hazards pose an intermediate threat (related to dose and proximity). Chemical hazards pose an immediate threat and are potentially lethal in a very short time. It is for this reason that rapid and effective casualty assessment, triage, treatment and transfer followed by decontamination and onward movement to definitive care are essential.

CLASSIFICATION OF CHEMICAL INCIDENTS

Chemical incidents may involve deliberate (CBRN) or unintentional (HAZMAT) release of hazardous

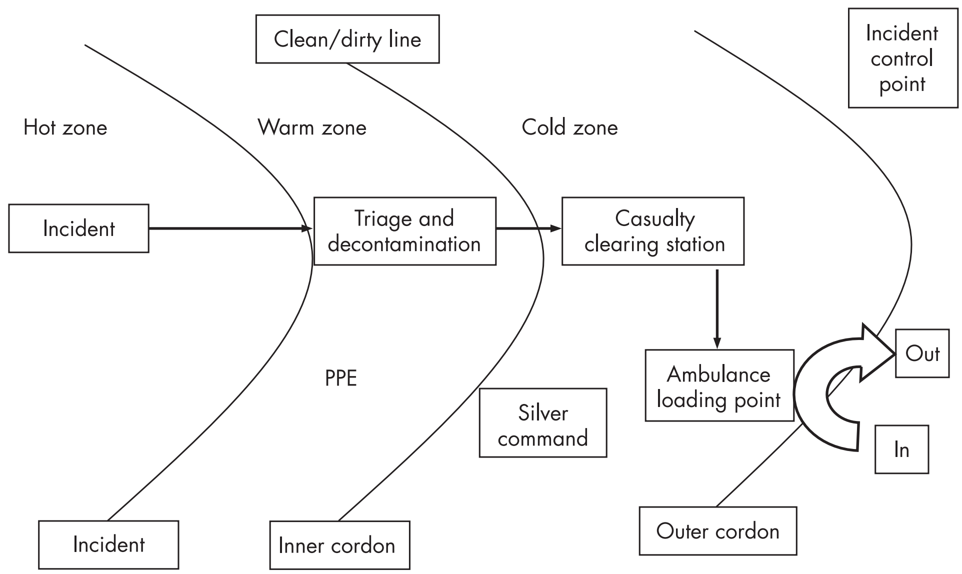


Figure 1 Medical HAZMAT site plan. PPE, personal protective equipment.

materials. Deliberate releases of a hazardous material can be further divided into those with warning prior to release and those where unexpected release has already occurred. In the second type of incident a considerable period of time can elapse before the casualties present with signs or symptoms.

Chemical hazards

Chemicals are usually introduced into the body by inhalation, absorption, ingestion or inoculation. They can be rapidly acting and have immediate and delayed effects. Only a few chemical agents have effective antidotes and the most important life-saving procedure available is to extract the casualty to a safe environment. This is analogous to the military concept of "care under fire" [12 13] in which only essential life-saving treatments take precedence over extraction. Chemical terrorism has received much attention. Some of the agents of specific concern are nerve agents, cyanide and lung-damaging agents. The mechanism of action and treatment of exposure to these agents is described elsewhere.[14 15] Immediate administration of specific antidotes can, for some agents, be life-saving (eg, atropine, oximes and anticonvulsants in the case of nerve agents). Care of casualties exposed to chemical hazards requires rapid transfer to a safe atmosphere, appropriate antidotes and attention to the ABCs of trauma care prior to and during decontamination.

Biological hazards

Biological agents (apart from some toxins) do not produce immediate effects. No specific emergency management measures are required prior to decontamination and transfer to definitive care. For those affected by rapidly acting agents such as *Staphylococcus enterotoxin B*, botulinum toxin and ricin, good airway management and general supportive measures are all that is available.[16]

Radiological and nuclear hazards

Casualties may be contaminated or irradiated. The harmful effects of radiation may be mitigated by "time, distance and shielding". Casualties should be exposed to a radiological source for as short a time as possible, be removed to a safe distance and shielded from further radiation. The adverse effects of radiation are related to the dose and time of exposure. Irradiated casualties pose no threat to healthcare workers and should be managed like any other casualty. Casualties who are contaminated pose some risk to rescuers until decontaminated but still require standard trauma care.

CLINICAL RESPONSE

Most emergency medical systems have a broadly similar approach to CBRN incidents.[17] Although terminology can vary slightly, the scene is divided into zones with the toxic hazard being initially confined to the Hot Zone (fig 1).

The ambulance/medical presence usually starts at the clean/dirty line. In current UK practice, only the Fire Service enters the Hot Zone to triage and extract casualties. It is in this area that the clinical first responder is likely to make the most impact. Decontamination currently occurs in the Warm Zone and casualties are then passed to the casualty clearing station in the Cold Zone. In the Cold Zone casualties are divided by medical priority and receive a primary survey and initial treatment before being moved to the ambulance loading point for onward transfer. This is also the site of Silver Command, the operational command level where the Police, Fire, Ambulance and Medical Commanders work in close proximity.

There are several deficiencies in this plan. There is no clinical oversight of the Hot Zone and diagnosis, assessment, triage and emergency treatment do not occur until casualties arrive at the decontamination area. Medical support to personnel operating in this environment may have a significant impact on appropriate deployment of clinical personnel and on patient outcome.

THE THREAT

The British military have always tried to push advanced medical care as close as possible to the point of wounding. However, in a CBRN incident, military responders are likely already to be in personal protective equipment[18] and well rehearsed in treatment and decontamination drills. They are also trained in self-decontamination and carry nerve agent antidotes for self and casualty administration. This is very different to a civilian incident.

Following a CBRN incident, casualties in a toxic lethal atmosphere will either self-extract, be incapacitated, trapped or succumb in a non-respirable atmosphere. Casualties who have received a sublethal exposure or are trapped but able to breathe are those who may benefit from the immediate attention of a medically trained first responder (suitably protected in personal and respiratory protective equipment). Casualties will fall into one of three groups: contaminated, conventional or mixed. Those who are contaminated with conventional injuries have the worst prognosis and this may need to be considered when triaging and treating these individuals.

Casualties are currently extracted by the fire service and decontaminated before being assessed and treated by deployed medical teams and transferred to hospital. As decontamination can take up to 12 min per patient, the fifth casualty could—in a worst case scenario—be left for an hour without treatment after extraction from the scene. If there are many casualties, the situation could be much worse. This is clearly suboptimal as there are some straightforward treatments that can be administered prior to decontamination that can influence survival.

CLINICAL ROLES

The potential roles for medical personnel in a CBRN incident are as follows:

- Medical reconnaissance
- Triage
- Trauma care
- Antidotes

Medical reconnaissance

During the initial triage of casualties, medically trained personnel can observe the casualty's signs and symptoms. This may allow early agent identification. In the Tokyo Sarin attack there was a significant delay before the agent was identified. Nerve agent exposure was finally diagnosed by a physician in a receiving hospital. The diagnosis of disease by pattern recognition is a key medical skill.

Triage

Although the simple triage of patients can be taught to non-medical staff, it is a well established principle that, if available, a senior clinician should perform this role.[19] Triage in this type of incident is more complex because evacuation may be delayed for decontamination, rescuer personal protective equipment may limit effective clinical assessment, and casualties with mixed CBRN and conventional injuries may be difficult to assess. The triage sieve[20] is ideally suited to this environment. Triage of trapped casualties using the criteria of airway patency and respiratory rate will triage for extraction, decontamination and treatment. In a mass casualty situation, expectant and dead categories should be used to improve outcomes for the survivors and protect limited resources. Medical training for major incidents often prepares the responder for a scenario of many casualties and minimal medical resources. In this situation, triage—but little more—may be appropriate. However, in many major incidents the number of seriously injured casualties is relatively small and, as the infrastructure of the incident develops, the amount of medical resource rapidly escalates and the options for treatment improve.

CBRN emergency trauma management

M–control of massive haemorrhage

A–airway and antidote

R–respiratory protection and oxygen

C–circulatory system management

H–head (CNS assessment AVPU and pupils)

Figure 2 Treatment of a chemical, biological, radiological and nuclear (CBRN) incident in the "Hot Zone". AVPU, awake, verbal, pain, unresponsive; CNS, central nervous system.

Trauma care

In a toxic environment the first priority is to remove patients to an uncontaminated atmosphere. For those casualties who remain within the Hot Zone and have not succumbed to the toxic assault, attention can be given to the ABCs. If casualty numbers allow airway management including advanced airway techniques, provision of oxygen and an initial dose of antidote (where indicated), control of life-threatening breathing problems (tension pneumothorax is not uncommon following blast injury)[21] and the control of catastrophic bleeding can all be carried out prior to and during the decontamination process. All of these interventions can be provided to casualties by trained rescuers in personal protective equipment (fig 2).

Antidotes

There are few antidotes available, but the following can be of value before and during decontamination.[20]

Nerve agents

These are rapidly fatal if inhaled and, if the skin is contaminated, can be quickly absorbed through the skin.[22] Within 15 min most skin contaminants will have been absorbed or evaporated. Depending on the dose, this will have an effect in minutes or hours.[14] The use of intravenous, interosseus or intramuscular atropine is life-saving. Auto-injectors are available that contain atropine and an initial dose of oxime. As nerve agents can cause fitting, benzodiazepines should be considered to protect the central nervous system.

Cyanides and hydrogen sulphide

Definitive treatment regimes are not practical before decontamination, but any patient who has been exposed and is still alive needs high-dose oxygen as soon as possible. Traditionally, amyl nitrite is used for cyanide poisoning, given by inhalation (which can be administered by bag-valve-mask techniques) and, although its effectiveness is questioned, anecdotal reports from the Iran-Iraq war suggest its early use might be valuable.[23]

Lung-damaging agents

These include phosgene and chlorine, common agents regularly transported on British roads. Although the mechanism of action is not fully understood, casualties exposed to these agents should be not be allowed to exert themselves and should be treated as stretcher cases and given oxygen. Usually no decontamination is required.

High-flow oxygen

All agents causing breathing difficulties and all patients suffering trauma may benefit from high-flow oxygen. Since casualties are unlikely to have respiratory protection, a high-flow reservoir mask will provide both a source of oxygen and a degree of respiratory protection from the environment since high gas flows limit entrainment of atmospheric gas.

DECONTAMINATION

Not all CBRN incidents require casualties to be decontaminated.[17 24 25] Decontamination is rarely required where casualties have been exposed to chemical vapours and the removal of clothing eliminates the majority of the hazard by preventing "off-gassing". Liquid chemical agents do require removal but, with the exception of some vesicants, if a casualty is still alive by the time they arrive at a decontamination facility it is likely that the agent is of low toxicity. Biological agents should also be removed, although re-aerosolisation is unlikely after initial exposure. As has previously been stated, irradiated casualties need no decontamination, and removal of clothing from a contaminated casualty will remove most of the threat to healthcare workers. Advanced radiological decontamination techniques require training and time and are most appropriately carried out in a designated healthcare facility. Prior to and following decontamination, patients should be re-triaged, monitored for contamination and continue to receive advanced life support.

EQUIPMENT AND TRAINING

Currently in the UK the Fire Service is the only national organisation capable and equipped to operate in an unidentified HAZMAT environment. If clinical personnel are to operate inside the Hot Zone, they too need appropriate levels of personal protective equipment.[26] Different types of personal protective equipment provide different levels of protection and different levels of restriction. The US system of designation is probably the most easily understood and defines levels of protection from A to D.[27]

1. Level A is the highest level of protection with a fully encapsulated chemically resistant suit with a full-face self-contained breathing apparatus. The suit must be capable of withstanding the chemical that is encountered.
2. Level B is similar to level A but there is less skin protection.
3. Level C has chemical resistant material and an air-purifying canister respirator.

Equipment	Appropriate PPE to include Suit, SCBA, helmet, gloves, boots, identification tabard, communication system. Torch. Decontamination solution/powder
Medical equipment (triage)	Triage labels Tourniquets Airways
Medical equipment (CBRN treatment)	Airways and oxygen (B-V-M with CBRN respirator canister) Advanced airway kit Needles and chest seals IV/IO access, fluids Dressings and splintage
Drugs	Atropine Diazepam (amyl nitrite) Analgesia

Figure 3 Chemical, biological, radiological and nuclear (CBRN) equipment. B-V-M, bag-valve-mask; IO, intraoral; IV, intravenous; PPE, personal protective equipment; SCBA, self-contained breathing apparatus.

4. Level D is the lowest level with no respiratory protection and coveralls only.

The highest level of personal protective equipment makes practical procedures difficult, only allows short periods of work in a hazardous environment, and relies on battery power. The military operate in level C personal protective equipment with negative pressure air-purifying respirators appropriate to their level of risk (operating in a chemical warfare environment). The current NHS standard has a higher specification suit and powered respirator offering greater protection to more hazardous materials, but the personal protective equipment is still only level C (with a powered air-purified respirator).

Provision of properly equipped and trained healthcare workers requires significant resources. A minimum level of fitness is also necessary for clinical personnel who are to operate in personal protective equipment in this type of hazardous environment.

The medical equipment needed for a HAZMAT environment is little different from that required for dealing with straightforward trauma but should be dedicated to CBRN use and be CBRN safe. A suggested packing list is shown in fig 3.

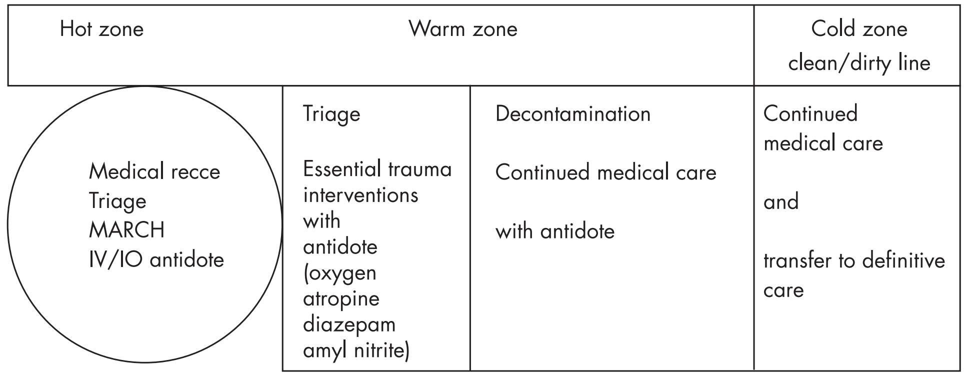
MEDICAL CARE IN THE "HOT ZONE"

We believe the model of care shown in fig 4 would improve the efficiency and effectiveness of on-scene medical care at CBRN incidents. Suitably trained multidisciplinary clinical teams should deploy to a CBRN incident at the earliest opportunity. The Fire Service (dressed in class A personal protective equipment) should enter the scene and perform a rapid assessment of the likely agents. They should also search for live casualties. If any live casualties are present, ambulance and medical responders should enter the scene in class C personal protective equipment as part of a multi-agency assessment and treatment team. Higher levels of personal protective equipment would not be required unless there was a significant liquid threat. The presence of live casualties suggests that an atmosphere is not immediately lethal. Under these circumstances, simple air-purifying respirators should be sufficient. Medical reconnaissance should provide information on the number and triage category of casualties and identification of the agent type (based on clinical pattern recognition). If the ratio of casualties to medical resources is reasonable, other medical responders should provide immediate medical care while extraction occurs. Interventions on live casualties might include control of significant external haemorrhage, positioning of casualties for airway protection and, if appropriate, the first dose of atropine by an intramuscular auto-jet device. The Fire Service should then rapidly extract triaged casualties. At the decontamination facility (casualty collection point), secondary triage will occur with further escalation of clinical care and advanced life support as required, prior to decontamination. This might include further antidote administration, advanced airway procedures, oxygen, immobilisation and splinting. Treatment should continue through decontamination to arrival at the casualty clearing station and hospital.

CONCLUSIONS

The UK medical response to a CBRN incident currently starts after the decontamination of casualties. This approach denies patients early access to simple life-saving interventions and the delivery of antidotes to some chemical agents. UK exercises have identified that there may be a significant delay in removing chemical casualties from the scene. Other emergency medical service systems have established medical care in the Hot Zone to

Figure 4 Proposed "Hot Zone" treatment plan. IO, intraoral; IV, intravenous. For definition of "MARCH", see fig 2.



maximise the prospects of survival. Casualties should ideally receive advanced life support from the point of injury until delivery to definitive care. This approach requires the rapid deployment of suitably equipped and trained medical staff into the Hot Zone in order to assess, triage, treat and transfer casualties from the point of injury to the decontamination facility and then on to hospital. This approach is not without cost. It could most easily be achieved by using current pre-hospital medical infrastructures where available. London hospital emergency medical service and several regional immediate care schemes have experience of major incident management and preparation for chemical incidents and could provide valuable clinical support for such complex and challenging incidents. It would seem prudent to have properly trained providers with professional contracts providing this type of service rather than relying on voluntary providers. There may be resistance to this type of change by ambulance services, but the role of trained doctors in major incident management is firmly established and CBRN incidents should be no exception. A Department of Health Working Party has been set up to consider the care of casualties in the Hot Zone and will hopefully address these issues.

A limitation of the recommendations in this paper is that they are based on one practical approach to a demonstrated need rather than an evidence-based review. However, there is no high quality published evidence on the practical management of CBRN incidents. Guidelines are usually based on experience from previous incidents and the consensus of available "experts". Despite this, we believe that these recommendations provide a basis for robust discussion and progress in a difficult area of patient care.

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REFERENCES

1. **Rodoplu U,** Arnold JL, Tokyay R, *et al*. Mass-casualty terrorist bombings in Istanbul, Turkey, November 2003: report of the events and the prehospital emergency response. *Prehosp Disaster Med* 2004;**19**:133–45.
2. **Gutierrez de Ceballos JP,** Turegano Fuentes F, Perez Diaz D, *et al*. Casualties treated at the closest hospital in the Madrid, March 11, terrorist bombings. *Crit Care Med* 2005;**33**(1 Suppl):S107–12.
3. **Lockey DJ,** Makenzie R, Redhead J, *et al*. London bombings July 2005: the immediate pre-hospital medical response. *Resuscitation* 2005;**66**:ix–xii.
4. **Wimbush S,** Davies G, Lockey D. The presentation and management of victims of chemical and biological agents: a survey of knowledge of UK clinicians. *Resuscitation* 2003;**58**:289–92.
5. **Laurent JF,** Richter F, Michel A. Management of victims of urban chemical attack: the French approach. *Resuscitation* 1999;**42**;141–9.
6. **Baker D.** Civilian exposure to toxic agents: emergency medical response. *Prehosp Disaster Med* 2004;**19**:174–8.
7. **Okumuru T,** Ninomiya N, Ohta M. The chemical distaster response system in Japan. *Prehosp Disaster Med* 2003;**18**:189–92.
8. **Han KH,** Walker R, Kuhri M. An integrated response to chemical incidents – the UK perspective. *Resuscitation* 1999;**42**;133–40.
9. **Chlorine Online Information Resource**. http://www.eurochlor.org/transportation (accessed 12 Nov 2007).
10. **Anon**. *Lessons learned. Bank Street exercise*. http://www.ukresilience.info/preparedness/exercises/londoncasestudies/osiris4.aspx.
11. **Braithwaite H**. *Exercise horizon: review of exercise to test the emergency response to a chemical, biological, radiological and nuclear incident.* Emergency Planning College Library. Reports 363.341.
12. **De Lorenzo RA,** Porter RS. *Tactical emergency care*. Brady Books,1999:8–28.
13. **Butler FK,** Hagmann J, Butler E. Tactical combat casualty care in special operations. *Milit Med* 1996;**161**(Suppl 3):3–16.
14. **United States Medical Research Institute of Chemical Defense (USAMRICD)**. *Medical management of chemical casualties handbook*. 3rd edn. International Medical Publishing, 2000.
15. **Department of Health**. *The Blain Report. Treatment of poisoning by selected chemical compounds*. London: Department of Health, 2003.
16. **Gosden C,** Gardiner D. ABC of conflict and disaster: weapons of mass destruction threats and responses. *BMJ* 2005;**13**:353–96.
17. **Home Office**. *Strategic National Guidance. The decontamination of people exposed to chemical, biological, radiological or nuclear (CBRN) substances and materials*. London: Home Office 2004. http://www.ukresilience.info/cbrn/peoplecbrn.pdf
18. **Baker D.** The pre-hospital management of injury following mass toxic release: a comparison of military and civilian approaches. *Resuscitation* 1999;**42**:155–9.
19. **Advanced Life Support Group**. *Major incident medical management and support*. 2nd edn. London: BMJ Books, 2002.
20. **Advanced Life Support Group**. Triage sieve. In: *Major incident medical management and support*. 2nd edn. London: BMJ Books, 2002;107–20.
21. **Health Protection Agency**. *Chemical incidents*. http://www.hpa.org.uk/emergency/pdfs/associated.pdf (accessed 12 Nov 2007).
22. **Anon**. Medical Management Guidelines (MMGs) for acute chemical exposures. http://www.atsdr.cdc.gov/MHMI/mmg.html.
23. **Helm UK**. *Triage of chemical casualties*. Library of the Defence CBRN Centre, Ministry of Defence, UK, 1991.
24. **Levitin HW,** Siegelson HJ, Dickinson S, *et al*. Decontamination of mass casualties: re-evaluating existing dogma. *Prehosp Disaster Med* 2003;**18**:200–7.
25. **United States Medical Research Institute of Chemical Defense (USAMRICD)**. Decontamination. In: *Medical management of chemical casualties – handbook*. 3rd edn. International Medical Publishing, 2000, chapter 15.
26. **Department of Health**. *Pre-hospital chemical and biological incident response*. 2001. http://www.dh.gov.uk/assetRoot/04/01/89/63/04018963.pdf (accessed 12 Nov 2007).
27. **Kleiner G.** *Occupational safety and health guidance manual for hazardous waste site activities*. Washington, DC: Department of Health and Human Services Diane Publishing Co., 1996.