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Making the UK safer: detecting and decontaminating chemical and biological agents

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Summary

Recent global events have given greater prominence to the threat of chemical and biological agents being used malevolently against civil targets such as key landmarks, transport hubs and postal sorting offices. Science, engineering and technology are central to reducing this threat and so making the United Kingdom safer.

The Royal Society established an independent, expert working group to examine the science, engineering and technology relevant to detecting when chemical or biological agents have been used and to decontaminating people and buildings subjected to attack using such agents. We took evidence extensively from key Government Departments, emergency service staff (or 'first responders'), emergency planners, the academic community and industry. The evidence received forms the basis of this report.

Rapid and effective detection and decontamination of an incident are necessary to minimise negative health impacts and reduce disruption to civil society. The UK has considerable scientific expertise in this area. This should be harnessed to strengthen the UK's existing resilience. Appropriate organisation of relevant science, engineering and technology is crucial and forms the focus of our main recommendation.

There are many similarities in dealing with the consequences of a malevolent and an accidental release of a chemical or biological agent. Therefore, many countermeasures will be equally applicable to either type of incident. So there is much to be gained from close communication between staff now focused on preparedness against malevolent attack and those dealing with accidental releases.

During our deliberations we became very aware that there is much knowledge and expertise available in the UK, some of which has been acquired in a military context. However, no single Government Department appears to have full responsibility for determining how this expertise can best be utilised. While the establishment of the CBRN (Chemical Biological Radiological Nuclear) Team in the Home Office has improved coordination and awareness, considerably more organisation of the resources is required.

Consequently, our major recommendation is that the UK Government should establish a new centre to improve the UK's resilience and to minimise the impact of any civilian chemical or biological incident. The centre's main functions would be to:

- Determine, commission and direct the work required on planning, preparedness, research and development related to detection and decontamination.

- Assess and disseminate protocols and procedures for detection, sampling and decontamination.

- Evaluate detection and decontamination equipment and establish agreed industrial standards.

- Ensure information is shared effectively between different Government Departments and agencies, the academic community, industry and other interested parties, including the public.

- Establish the maximum levels of agents below which it is appropriate to permit a return to normal use following an incident.

- Work with the academic community, industry and the research councils where appropriate and seek to make full use of developments and potential funding in the US, Europe and elsewhere.

- Provide a clearly identified source of expert advice regarding chemical or biological incidents for Government Department and agencies, first responders, NHS Trusts and national and local emergency planners.

The centre would work with existing expertise in the Defence Science & Technology Laboratory, Health Protection Agency, Home Office, Department for the Environment Food and Rural Affairs, Environment Agency, Cabinet Office, Department of Health, Office of the Deputy Prime Minister, Department for Transport, Research Councils, Office of Science and Technology, Department of Trade and Industry, National Health Service, first responders, the academic community and industry. It would be under independent management and require a physical location to undertake the required evaluation work. To increase information sharing and minimise costs, expertise and specialised equipment could be shared with existing facilities in Government, academia and industry where appropriate. The budget required by the centre will depend on the timescale envisaged for the work to be done and on the sophistication of the appropriate equipment and materials. Based on information received from a number of sources, we estimate that a reasonable figure would be of the order of £20 million per year for an initial five year period. After this initial period the funding should continue but the level would need to be reassessed.

All detection systems need to be designed to take into account how the information they generate will be used, the level of training of those who will use them, and the environment in which they will be used. A range of detection system requirements covering monitoring, identification and quantification of potential agents will be needed. Some potential technologies for novel detection systems will come from academic research.

We recommend that future work on detection systems should be concentrated on four objectives:

- Exploitation of new and existing science, engineering and technology for robust detection of chemical and biological agents.

- Development of point detectors for use by first responders at the scene of a suspected incident.

- Establishment of what information on background interferences and natural variability of agent levels might increase the reliability and sensitivity of different detection systems and decision making. Where appropriate the relevant data should be collected.

- Analysis of medical intelligence to enhance resilience and the effectiveness of responses.

In the event of the release of a chemical or biological agent, a rapid and effective medical response will be crucial. To help achieve this we recommend increasing the general awareness of all healthcare staff by training, particularly in the detection and management of chemical or biological incidents. We also recommend improved coordination of local and national electronic health surveillance systems to detect clusters of illness or symptoms.

With respect to decontamination studies, we recommend the following four priorities:

- Assessment of the efficacy of decontamination procedures and technologies.

- Detailed review of the various options for the decontamination of people, buildings, vehicles and the wider environment.

- Assessment of contact hazards from contaminated surfaces.

- Development and implementation of techniques for avoiding secondary contamination in hospitals and ambulances.

We recommend that realistic exercises be undertaken regularly involving first responders, emergency planners and some civilians in order to test and develop further the procedures for dealing with an incident. In addition to providing a considerable measure of reassurance to the public, such exercises would be an integral part of staff training and preparedness.

We also recommend greater dialogue between scientists, psychologists, politicians and the public to improve the communication and public understanding of hazard and risk issues in relation to terrorist incidents, and to inform planning for response to chemical and biological incidents.

Reducing the threat from chemical and biological agents requires political, economic, organisational and technological actions. Without political will and cost-effective implementation, organisational and technological innovation cannot deliver their full potential to make the UK safer.

1 Introduction

1.1 Background to project

The Royal Society has a long standing commitment to reducing the threat of biological weapons, and has produced two previous reports on this subject (Royal Society 1994 & 2000). This report concerns the malicious use of chemical and biological agents against civilian targets such as key landmarks, transport hubs, postal sorting offices, Government offices, water and power plants, or large gatherings of people. It examines how such attacks can be detected and the agent(s) identified and quantified, and how targeted people and infrastructure can be decontaminated after attack. It concentrates on the implications for humans and their environment.

We do not address all potential terrorist threats here. In particular, we do not deal with radiological threats (or 'dirty bombs'), nor infectious animal or plant diseases (Royal Society 2002). These are important issues and merit separate study.

For the purposes of this report, 'detection' will be used to cover systems and methods for early warning alarms, for monitoring and for identification and quantification.

There are many similarities in dealing with the consequences of a malevolent and an accidental release of a chemical or biological agent. Consequently, many countermeasures will be equally applicable in preparing the country against either type of incident.

The report is aimed principally at three groups: national and local Government policy-makers involved in long-term planning to increase preparedness against a possible incident; emergency service staff (or 'first responders') who would be directly involved in dealing with the consequences of an incident; and scientists and engineers working in areas that could be applied to extending existing detection and decontamination capabilities, particularly those who are currently unaware of the potential of their work.

Reducing the threat from chemical and biological agents requires political, economic, organisational and technological actions. A number of these issues were addressed by the House of Commons Science & Technology Select Committee in their recent report on the scientific response to terrorism (House of Commons 2003). A recent review article looked at the current US situation regarding technology challenges (Fitch, Raber & Imbro 2003). Our report concentrates on where science, engineering and technology can help in diminishing the consequences of incidents by reducing vulnerabilities, improving the response of society by consequence management, modelling and the early warning of potential threats. Detection and decontamination are central to all of these issues.

Our report Measures for controlling the threat from biological weapons (Royal Society 2000) concluded that the scale of effectiveness of biological weapons against human populations in war and by terrorist attack had mercifully not been proven in practice and that, while it would be irresponsible to be complacent about the possible effects, it would also seem prudent not to overestimate them. That report also concluded that the main negative effect of a biological weapons incident might be panic and disruption of civilian services. While the political and security scenario has changed since the 2000 report was produced, its conclusions remain valid.

Detection is an increasingly demanding and rapidly developing field, with considerable effort being devoted to new technical developments by both industry and the academic community. Detectors of various types are used throughout science and many could be adapted or developed for the specific or generic detection of chemical or biological agents. Chapter two addresses the priorities, concepts of use and implementation of detection systems. Issues relating to sampling are discussed in chapter three and the current capabilities and future needs of detection systems are investigated in chapter four.

Decontamination can be divided into the decontamination of people and the decontamination of structures including buildings, furniture, vehicles and equipment. The processes required for effective decontamination following an incident are not fully understood. This was clearly illustrated by the clean-up of the Senate buildings following the US anthrax letters in Autumn 2001 and the difficulties experienced in restoring them to use. How science, engineering and technology can assist in decontamination is discussed in chapter five.

The consequences of either a chemical or biological incident can be greatly reduced if the agent can be rapidly detected, allowing appropriate countermeasures to be put in place as soon as possible. Chapter six assesses how science, engineering and technology can determine when the environment is safe enough to justify a return to normal use following an incident.

How best to coordinate and organise research, development and planning relating to countermeasures against chemical and biological agents is discussed in chapter seven. Conclusions and recommendations for emergency planners, policy-makers and researchers are presented in chapter eight, bringing together the separate recommendations from the preceding chapters.

The use of mathematical modelling of chemical and biological dispersions is discussed in annex 3. Scientific uncertainty, scientific advice and decision support for risk management are covered in annex 4.

Many scientific disciplines must be brought to bear upon detection and decontamination if effective detectors and procedures for the decontamination are to be achieved. Key disciplines include microbiology, surface science, physics, chemistry, medicine and engineering. Novel science, engineering and technology have a vital role to play in meeting detection and decontamination challenges. Such developments could well occur in research disciplines that have not traditionally been focused on military or security related concerns, so it is vital to alert academics that their research might be relevant, even if there is no obvious link. Consequently, the coordination, commissioning and direction of relevant research are extremely important and are discussed throughout the report.

1.2 Conduct of project

A working group chaired by Professor Herbert Huppert FRS prepared this report; the full membership is given in annex 1. The Council of the Royal Society has endorsed the report.

We asked key Government Departments and end-users of existing detection and decontamination technologies for their views on where science, engineering and technology could improve their existing systems. Based on the detailed information received, we issued a public call for evidence in May 2003. This was principally directed at scientists and engineers in the academic community, industry and Government, and was aimed at determining where the cutting edge science, engineering and technology in the most appropriate areas exists and how it might be practically applied in the future. We also met a number of experts to discuss issues in greater depth. This extensive information forms the basis of the report. We are very grateful to everyone who supplied information. Details of the organisations and individuals who gave evidence are given in annex 2.

1.3 Types and properties of possible agents

The approaches required to detect and decontaminate different agents will vary according to the properties of the agent in question. Potential chemical and biological agents have a range of physical properties and levels of toxicity. The physical form and properties of the individual agent will determine the most likely route of exposure to a material. Examples illustrating the range of chemical and biological agents are given in table 1 and their different physical forms are outlined in table 2.

Table 1 Range and examples of chemical and biological agents

Biological agents	***Naturally occurring toxins***	***Synthetic chemicals***
• Bacteria eg *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague) • Viruses eg smallpox • Rickettsiae – *Coxiella burnetii* (Q fever) • Fungi – *Histoplasma capsulatum* • Modified bacteria and viruses	• Bacterial toxins including botulinum toxin • Naturally occurring bio-regulators • Ricin and related protein toxins • Mycotoxins (T2), aflatoxin • Palytoxin, batrachotoxin, tetraodotoxin, saxitoxin • Animal, plant, marine, snake, frog, toad, spider and scorpion toxins • Immuno-modulators, mood modifiers, analgesics, psychopeptides	• Chemical warfare agents, including nerve gases (mustard, sarin and VX), blister, blood and choking agents • Toxic industrial chemicals such as chlorine and phosgene • Highly potent pharmaceuticals and agrochemicals

Table 2 Physical form of examples of chemical and biological agents

Physical form at room temperature	***Example agent***	***Comments***
Gas	Ammonia Chlorine	
Volatile liquid	Sarin Tabun	Liquids can be thickened with polymers to increase their persistence
Persistent liquid	Mustard gas VX Soman (when thickened)	
Liquid droplets	Viruses eg Variola (smallpox)	
Solid	Ricin Anthrax (spores)	Possibly in the form of spores, a dust or an aerosol

The level of toxicity will influence the requirements for detection and decontamination. For example, the level of decontamination required for a highly toxic agent is much greater than that for a less toxic agent. Also, it becomes more important to be able to detect small quantities of highly toxic materials because a minute quantity could have a serious impact on human health. For the most toxic materials, uptake of sub-milligram quantities per person could be lethal, but for the majority of chemicals higher doses are required. A particular toxic material will affect different species to varying degrees. It might thus be misleading to extrapolate lethal doses established in the laboratory to determine the number of people a small quantity of a toxin will kill. Also, there are fortunately considerable difficulties that would need to be overcome to successfully disseminate chemical and biological agents.

Materials can be inhaled, absorbed through the skin or ingested along with contaminated food or drink. Their toxicity will be altered according to the different routes of exposure. Although materials can be almost as toxic when inhaled as when injected, absorption through the skin usually leads to a reduction in potency. For example, anthrax is considerable more toxic when inhaled than when it is in contact with the skin.

The fate of agents following an incident will also alter the potential danger they pose. How long airborne agents stay suspended in the air and how air currents distribute them will determine their impact on humans. What happens to an agent when it lands on a surface, whether it becomes adsorbed or degrades over time, will also alter its potential effect on people. Physical form also affects detection, sampling and decontamination procedures. For example, detecting a highly toxic particulate will require sampling large volumes of air or large areas of a surface.

Detection, identification, monitoring and sampling procedures will depend on the physical form of the agent. For gases, liquids with a high vapour pressure or those in aerosols will involve air sampling. In contrast, solid agents on surfaces will need to be removed from surfaces by swabs or wipes. The impact of these differences on detection systems is discussed further in chapters 2 and 4, and on sampling strategies in chapter 3.

1.4 Types of possible incident

There are many possible incidents that could occur, ranging in size from small to large. These could target air, food, water, people, livestock, horticulture, aquaculture, crop plants, strategic facilities or symbolic targets. The agents involved could be used in combination with radiological, nuclear or conventional explosives. The combination of these different factors will influence how the incident will best be dealt with.

2 Priorities, concepts of use and implementation of detection systems

Summary

A fully integrated and coherent approach to detection, identification, monitoring and decontamination is needed. This must seamlessly span pre-event planning, organisation, continuous monitoring, the actual event and post-event stages of a chemical or biological incident. This is currently not always the case. Science, engineering and technology can be used to improve the detection of chemical and biological agents for static, continuous and automated monitoring of specific installations, and the resulting equipment must be usable by operators after minimal training. The most urgent need is for mobile or hand-held instruments capable of point detection at the scene of an incident for use by first responders. Portable test systems based on laboratory-based techniques need to be developed, because such systems would reduce the analysis time for unusual chemical and biological agents in the field. The proposed UK Government centre, as discussed in chapters 7 and 8, should develop standardised evaluation procedures to allow objective comparison of alternative techniques and to increase confidence in the reliability of newly introduced detection systems.

2.1 Detection, identification and monitoring

Establishing whether a chemical or biological agent is present is termed **detection**. The determination of the precise chemical or biological nature of the agent by use of appropriate analytical tools is termed **identification**. The analysis of the supposed agent to reveal the nature, magnitude and extent of the contamination is termed **monitoring**. This is often done in the context of background levels of the same agent, or potential interferences, and interpreted through a model of the environment. Whilst monitoring is straightforward in an aerial environment, it is harder where contamination is on surfaces, in soil or in food or water chains. Monitoring also gives an indication of the fate of the agent and provides essential information for any proposed decontamination procedures.

Detection, identification and monitoring systems need either to sample in (or near) real-time or to take discrete samples as a function of time. The current capabilities and future needs of detection are discussed in chapter 4.

2.2 Activities and decision-making at different stages of an incident

The UK Government (Cabinet Office 2003) has a three-tiered approach to dealing with all types of major emergencies, regardless of whether they are accidental or deliberate: operational, tactical and strategic. The Government's approach is based on the concept of resilience. This is defined as the ability at every relevant level to detect, prevent and, if necessary, to handle and recover from disruptive challenges. The Cabinet Office document also describes which organisations would take responsibility for different aspects of handling incidents, including interpreting the information generated by the detection systems. The following sections (chapter 2.2.1 to 2.2.3) highlight the importance of the output data from detection systems being interpreted objectively and used to organise the most appropriate response. The Cabinet Office is currently updating its *Dealing with disaster* document (Cabinet Office 2003), which is planned to give more attention to chemical and biological incidents.

In the event of an incident, decision-makers will need to make timely and informed choices about how, or whether, to respond. These decisions will need to be based on a number of scientific, social and economic aspects of the particular event. The scientific information that will inform these decisions can be divided into detection, decontamination, sampling, psychological and medical issues. It is crucial that all of these are used to inform decision-making at the various stages of an incident, and to improve strategies and planning for dealing with future incidents. Key decisions will depend on the outcomes of the deployed detection/identification equipment and the interpretation of the measurements. Table 3 outlines the main requirements from these areas before, during and after an event and how this information will inform the decision-making process. It also indicates which chapters of the report discuss these issues further.

A fully integrated approach to detection, identification, monitoring and decontamination, which covers the different stages of an incident, is essential.

Table 3 Outlining key requirements at the different stages of an incident

	Pre-event	***Event***	**Post-event**
Decision (Chapters 2, 6)	Determine detection and decontamination strategies.	Control movement of people at incident site.	Decide when safe to return to use. Determine impact of potential litigation.
Detection (Chapters 2, 4)	Define concept of use of detection system. Set up real-time monitoring / sampling systems. Establish background interference and agent levels. Intelligence gathering. Train operators to use detection systems.	Determine affected area. Preliminary identification of agent.	Confirm identity of agent. Collect evidence. Confirm effective decontamination.
Sampling (Chapter 3)	Decide on type and method of sampling for different agents. Identify and train personnel. Validate sampling procedures.	Adapt sampling strategy to locate source and distribution of agent.	Assess whether 'safe' level has been reached after decontamination.
Decontamination (Chapter 5)	Train first responders. Evaluate decontamination technologies and procedures.	Decontaminate people. Clean mobile infrastructure.	Decontaminate buildings and environment.
Psychological issues (Chapter 6)	Inform public what to expect. Prepare information to be circulated in the event of an incident.	Reduce impact of event using media, economic & civil tools.	Justify return to incident site.
Medical issues (Chapters 2, 3, 4, 5)	Establish a medical intelligence resource. Increase training of clinicians in CBRN-related subjects.	Decontaminate people on site. Transfer to designated receiving hospitals with separated treatment area. Avoid secondary contamination.	Implement medical countermeasures (eg vaccination). Long-term clinical follow-up of exposed populations.

Key decisions need to be taken depending on the nature of the event and the extent of the affected zone. These include what steps need to be taken to control people entering or leaving the affected zone, what needs to be done to decontaminate personnel and mobile infrastructure (such as ambulances), and by whom. Also, the central authorities need to use all available psychological, media, economic and civil tools at their disposal to minimise the negative impact of the incident. Post-event key decisions on decontamination of buildings and the environment, the determination of when something is sufficiently clean and the impact of potential litigation will have to be resolved.

2.2.1 Pre-event activities

Strategies and procedures for dealing with an event need to be established in advance of any potential incident. Sensitive installations should introduce continuous monitoring systems. It is essential to establish precisely what scientific information is required for the current operational strategies. Collating all existing information on thresholds and baseline levels for different agents can be used to assess their relative hazards.

A management communication and coordination structure needs to be in place before the event occurs. This requires the existence of a competent organisation with well trained staff to handle the entire process. Realistic exercises should be undertaken as an integral part of staff training. These should involving first responders, emergency planners and some civilians to test and develop the procedures for dealing with an incident.

Where practicable, the presence (or absence) of background interferences and the natural variation in the agent should be determined. This will involve establishing pre-event reference levels of agents and organisms and determining the geographical and statistical variability of doses or concentrations in order to give target levels for remediation. For example, in the case of chemical agents such as mustard gases there will be no background level of the agent itself. However, there might be background interferences for the detection system due to other chemicals present in the environment and consequently it would be important to understand the background levels of these ‘interfering’ chemicals rather than the agent itself.

Pre-event surveillance covers intelligence, real-time monitoring and sampling systems located at sensitive installations. This information should be reported to a central command post, which is run by a clearly identified leader. There is a need for static and continuous monitoring of specific installations, such as postal sorting offices, city water supply systems, Parliament, or networked systems of monitors on the London Underground and other cities with similar underground transport systems, and systems for post-incident detection or monitoring to confirm effectiveness of decontamination procedures. Currently deployed military systems for continuous air sampling and monitoring of biological agents could be adapted for monitoring sensitive civilian installations. More widespread general pre-event continuous monitoring is not presently considered to be feasible or effective. Some key locations currently have detection systems in place, which have been successfully deployed and have yet to detect any significant incidents.

2.2.2 Event activities

When an event takes place, first responders will ideally deploy hand-held or vehicle located detectors for sampling, determining the affected area and preliminary identification of the nature of the event.

All available data about the agent must be collected with proper scientific rigour, taking into account the uncertainty on all parameters and measurements. This should be followed by quantitative monitoring of the reduction of the contamination level through naturally occurring processes, such as wind dispersal and rain wash-out.

The first detection of a deliberate release may be by a General Practitioner (GP) or Accident and Emergency doctor seeing a cluster of an illness or an unusual clinical presentation. There is a short window of opportunity after detection of a biological event in which the administration of antibiotics can minimise the impact. This window corresponds to the incubation period, which ranges from 48 hours for respiratory anthrax to 21 days for Q-fever. In those who have received a lower exposure dose, the incubation period will be greater. Evidence based diagnostic techniques and appropriate training for healthcare professionals are important for detecting chemical or biological exposure, as well as validated treatments for the effective consequence management of adverse effects on health.

2.2.3 Post-event activities

Post-event activities include confirming the nature of the agents employed with more elaborate laboratory tests and collecting material from the site for evidence.

There will need to be an assessment of the effectiveness of decontamination to establish whether conditions exist for a justified return to use or occupancy. Before a building is re-occupied, or infrastructure is put back into use, the effectiveness of decontamination needs to be verified by reference to objectives agreed, preferably set at the outset, or just as the work of decontamination begins. Confirmation that decontamination has been effective will require advice from specialist agencies, such as the proposed new centre, Health Protection Agency (HPA) or Defence Science and Technology Laboratory (dstl) Porton Down, as well as the body responsible for health and safety enforcement on the premises concerned. Similar considerations are likely to apply to determining the effectiveness of items decontaminated off-site. In all cases, if the initial decontamination is not completely effective the process will need to be repeated, or another more effective decontamination method applied, until it is successful. How science, engineering and technology can assist in decontamination and in determining when to justify a return to normal use following an incident is discussed further in chapters 5 and 6 respectively.

Once the identity of the agent is known and its release location defined the following steps will need to be implemented:

- Issue correct personal protection equipment
- Activate first-aid and therapy regimes
- Implement decontamination procedures
- Monitor the extent and fate of the contamination
- Establish a safe-to-return decision protocol.
- Update procedures for future similar incidents as appropriate.

There are few data on the long-term risks to health in populations exposed to chemical agents. Agents such as mustard gas are suspected carcinogens, but the long-term effects of organophosphates are still unclear. Consequently, it will be important that exposed populations are identified and subjected to close long-term clinical follow-up. With both chemical and biological agents, an understanding of the toxic and pathogenic mechanisms involved will contribute to the diagnosis and management of suspected long-term adverse health effects.

2.3 User requirements and concepts of use

It is vital that those using detection and monitoring systems develop the concept of use of the particular systems. This defines the properties of the equipment and how the data it generates will be interpreted and used to inform decision-making. The following issues should be considered when specifying the concept of use:

- Selectivity
- Sensitivity
- Response times
- False-alarm rates
- Target analytes and agents
- Down-time and redundancies
- Area or volume monitored
- Infrastructure requirements
- Maintenance regimes and logistical support
- Operator and support staffing requirement
- Training needs
- Output data interpretation models
- Calibration and checking protocols
- Numbers, locations and cost
- Equipment lifetime and replacement
- Background levels of agent
- Specific environment systems will be used in.

The concept of use needs to take into account a realistic assessment of the detector's performance. The level of training of the user is vitally important. For example, equipment to be used by first responders at the scene of an incident needs to give as unambiguous a result as possible. In contrast, equipment utilised by highly trained operators can be used to determine the complex influences of background interferences and natural variation of agents. Other factors include the communication network, the interpretation model and overall response capability. Ensuring that concepts of use for detection systems are clear, so that equipment and procedures can be designed accordingly, would best be coordinated and directed by the proposed new centre.

In addition to the requirements outlined for generic detection systems, the additional key requirements for the rapid detection of a range of chemical and biological species are:

- Inexpensive instruments and disposables
- Simplicity of use, especially for emergency situations
- Portability, robustness and a lack of moving parts, which might be enhanced by miniaturisation and mass production
- Long shelf-life of detectors and any reagents
- Low power consumption
- Known reliability
- Sensitivity appropriate for the agent
- Near-zero false alarm rate

A response time of the detector of the order of one minute or less is desirable. Good specificity is required where the agent must be immediately identified. Rapid generic detectors for toxicity or the presence of biological materials, backed up by subsequent identification and quantification, would provide a useful aid to immediate decision-making. The ability to analyse all of the data generated and distribute the most relevant information across command and control systems is desirable but not currently feasible. The creation of a coordinated network of first responders who share best practice will be crucial to the efficient application and use of detection technologies in a civil context.

2.4 Current detection and monitoring technologies

Currently, there are few detection and monitoring technologies that fulfil the requirements in chapter 2.3. Hand-held immuno-chromatography strips and 'pocket' polymerase chain reaction (PCR) tests are unreliable in the field and a report to the White House has dismissed their utility (CDC 2001). There is a particularly urgent need for rapidly deployable hand-held or vehicle-carried detectors for detection of chemical and biological agents at incidents that will respond in a few minutes and permit first responders to gauge the nature and severity of the event as quickly as possible in order to minimise disruption. Such field-based systems will be operated by trained first responders acutely aware of the response times, inherent limitations and false positive/negative rates of the devices. The current capabilities and future needs of detection are discussed in further detail in chapter 4.

The speed of action of many chemical agents means that no current detector will alarm in time to prevent exposure of some individuals. So it may not be possible to use available technology for detection, but rather apply it for incident monitoring and agent identification. In most situations it is more likely that initially the identity of the agent will not be known and that the sudden occurrence of casualties will be the first indication of a deliberate release. Clinical features should be a good indicator of the probable chemical or biological agent involved and appropriate clinical skills should be available at the site of an incident to aid the identification and management of casualties.

Highlighting the similarities between preparing for accidental and deliberate releases, the methods of virus detection used in human and veterinary medicine have been reviewed in relation to infectious diseases in livestock (Royal Society 2002). The key aims of detection of the foot and mouth disease virus were identified as sensitivity, specificity and speed.

2.5 Issues needing to be addressed

The data from the devices needs to create sufficient confidence in the operators to allow positive decisions to be made that promote a state of 'peace-of-mind' in distressed public observers. Additionally, all chemical or biological detectors and monitors that are used pre-event, event or post-event, and whether real-time, discrete, generic, array or specific, must be part of an overall integrated response system that collects and collates data from all available sources.

False alarms occur whenever sensors or monitors show a response to an agent that is not present or is present below some threshold level (false positive) or fail to respond when an agent is present (false negative). Ideally, these false-alarm rates should be zero but in practice, this is rarely so. It is important to determine the likely incidence of false responses caused by operator error, instrument and software quirks and chemical interferences.

Significant numbers of false negatives cannot be tolerated in civil environments, as these could result in unprotected individuals being exposed to the contamination. The occurrence of false positives also has serious implications, as they could lead to extreme disruption, and possibly panic, which might have more harmful consequences than a chemical or biological release itself. Repeated false positives might lead to future real alarms being ignored. Using two or more independent measurement techniques will reduce the occurrence of false positives to near zero. Additionally, all systems should be fully validated prior to use in service by the new Government centre.

Monitoring methods are required that can be placed in the environment to monitor the quality of food, water, soil and air. Improved sampling, pre-processing and interference elimination techniques are required. The development of system automation for use by operators with minimal training and concepts-of-use should be addressed. The transfer of laboratory-based techniques to portable test systems will also be important in reducing development times for the analysis of novel chemical and biological agents in the field.

2.6 Key detection system requirements

The most urgent need is for mobile or hand-held instruments for point detection at the scene of an incident for use by first responders. Ideally, these should be remote (or 'stand-off') instruments to avoid contamination of emergency staff. Rapid, inexpensive and broad-based tests with a zero or near-zero false-alarm rate must be developed for detection and identification of toxic materials and organisms. These analytical tests should preferably provide high quality data at the point of use of the same standard as tests conducted in a laboratory. At their current state of development, present day detectors are of limited use in the civilian context, particularly those that are agent-specific. Detectors under development for military use are not fully suitable for civilian application, as they often require specialist operators and might not be available in sufficient numbers to cover all scenarios and response teams. Similar systems would be used for verification of use and collection of forensic evidence for any subsequent litigation.

Detectors suitable for use by first responders would also prove useful for monitoring the spread of contamination and the efficacy of decontamination. These operators will need to be highly trained and practised, and work to the same standard operating protocols. They must have personal protective equipment so that they can be deployed immediately after an incident. Training should involve real chemical and biological agents.

2.7 Validation and implementation

Standards must be developed for validation and comparison of newly developed technologies. All hand-held, vehicle-borne and laboratory equipment used as the basis for decisions need to be procured, stored, maintained, tested and systematically replaced. Chosen equipment would be tested in realistic scenarios based on the concept-of-use by competent organisations, such as the new centre or dstl Porton Down and, when proven, accepted into service. Arrangements would be made with local laboratories to have access to their laboratory facilities post-event and to provide second-line analysis capability. Local laboratories should also routinely run standard samples to ensure that their equipment and skills are still at an appropriate level. Scientific advisors would have established methodologies and maintained essential stocks of kit and consumables to permit rapid modification of laboratory assets to the analysis of samples.

2.8 Impacts on detection

Many other factors might impact on the detection and/or monitoring of chemical or biological agents, particularly where deliberate attempts are made to conceal the target agent. For example, the use of interfering or inhibitory materials and genetic engineering could all thwart current detection technologies. Also, modern genetic engineering, genomics and proteomics could be exploited to create new agents, aid their production, impede their detection and subsequent decontamination, and reduce the effectiveness of medical countermeasures. Unlike other potential agents, the ability to create biological agents is not limited to the sophisticated nations. A state-of-the-art biological laboratory could be built at low cost, housed in a small room and staffed with any one of many people who have the appropriate basic biological know-how. The technology is well within the grasp of determined small terrorist groups. Developers of novel detection systems will need to be aware of these capabilities and the capacity of potential aggressors to evade existing detection and decontamination approaches.

2.9 Conclusions and recommendations

The continuous protection of the entire civilian population against unannounced chemical or biological attack is impractical. Realistically, only a limited number of target locations can be monitored. National and regional planners, ideally advised by the proposed centre, will need to establish detection systems to protect key target. To meet these needs the concepts of use and user requirements should be followed throughout the development of detectors and monitors. Candidate detection systems must be tested before being put in place, including how the information they generate will be used.

The most urgent need is for mobile or hand-held instruments capable of point detection at the scene of an incident for use by first-responders. Ideally these should be remote (or 'stand-off') instruments to avoid contamination of emergency staff. Rapid, inexpensive and broad-based tests with zero or near-zero false-alarm rate must be developed for detection and identification of toxic materials and organisms.

We recommend that the next edition of the Cabinet Office document *Dealing with disaster*, which is expected to pay more attention to dealing with chemical and biological incidents, clearly spells out the concepts of use for detection systems, so equipment and procedures can be designed and implemented accordingly. In particular, this updated document should cover the scope for better coordination of pre-event action plans, scientific responses at the time of an incident, and timely implementation of scientific advances.

Realistic exercises should be undertaken involving first responders, emergency planners and some civilians in order to test and develop the procedures for dealing with an incident. In addition to providing a considerable measure of reassurance to the public, such exercises would be an integral part of staff training and preparedness.

Evidence based diagnostic techniques and appropriate training of medical personnel are important for detecting chemical or biological exposure. It is also vital to validate treatments for the effective consequence management of adverse effects on health. The identification and treatment of unusual casualties will require special training for initial medical responders in the community, hospitals and health protection teams. Increased training should be extended to undergraduate and postgraduate medical training so that all doctors are aware of relevant toxicological and infectious diseases. The General Medical Council and the Royal Colleges should take the lead on this issue.

There are few data on the long-term risks to health in populations exposed to chemical agents. Consequently, it will be important that exposed populations are identified and subjected to close long term clinical follow up. The HPA should take the lead in undertaking this.

3 Issues relating to sampling

Summary

At present, there is little readily available guidance on either sampling protocols or sample preparation specifically for chemical and biological agents. This should be a priority. Procedures are needed to ensure rapid and reliable collection of samples to support subsequent analysis. In the event of a chemical or biological incident, the standard of subsequent analysis will depend on the quality of the sampling carried out. Different sampling schemes will be required to reflect the detection technology being used.

3.1 Introduction

In this chapter most of the discussion concentrates on taking samples likely to contain solid or liquid agents for analysis. Air sampling is briefly discussed in chapter 3.5.

The primary objectives for sampling are that the strategy provides representative samples, that an appropriate number of samples are taken and that the sampling regime is tailored to the physical properties of the likely agent as well as the environment being sampled, eg water, air, soil and/or clothing. The resulting samples should support accurate identification and quantification of the analyte at appropriate concentrations (related to known harmful doses) that would reflect both acute and chronic exposure dosages.

Any sampling methodology should be robust and repeatable. In addition to analytical considerations, details of the nature and location of individual samples should be logged, and samples should be stored and transported to the point of analysis in a secure manner so that their whereabouts can be accounted for at all times (chain-of-custody). Consideration should also be given to the need for police evidence gathering. When detection is not carried out on site, national or regional analytical laboratories need to be identified in advance and reporting procedures agreed.

A chemical or biological agent might be deliberately released through the air, with water systems being the next most likely target. Food and bottled beverages could also be contaminated deliberately and there have been criminal incidents of this kind. An example of this was the contamination with salmonella of salad bars in ten restaurants in 1984 in Oregon by the Rajneeshee cult, which resulted in 751 cases of food poisoning (Tucker 1999). The quality control systems currently in place for food and drink mean far fewer people might be affected than an incident involving deliberate releases in air or water systems. The existing quality control systems for food and drink might help identify which sampling techniques should be used and where work is needed to improve detection.

When an incident occurs the primary objective of the sampling strategy is to determine the distribution and nature of the agent concerned. Minimising the time taken to do this is important and consideration should be given to how samples should be taken, stored and transported to aid subsequent analysis. Immediately following an event, and for some time afterwards, both the air and surfaces might need to be tested.

The objective of post-event sampling will be to provide information on the persistence of an agent, and any dispersal from the point of the initial incident, and also to inform decisions on decontamination procedures and when it is safe to return to the area. Once decontamination has started, sampling could be complicated by the presence of decontamination agents, such as foams that might disperse the agent.

3.2 Sampling strategies

When determining the most appropriate sampling strategy, it is crucial to take into account different issues that apply to chemical and biological agents. However, a number of generic issues that should be considered in all strategy planning to achieve a representative sample that are discussed below.

- Sampling techniques must be compatible with the detection and identification technologies used. For example, if microbes are to be detected by culturing the extraction technique must not contain harsh chemicals that will reduce viability. Polymerase chain reaction (PCR) amplification of nucleic acid requires careful sampling, storage and transportation to avoid contamination and degradation of the sample.

- The frequency of sampling should be determined, taking the resources available into account. Maximum coverage needs to be achieved from the minimum number of samples.

- Sampling strategies need to be designed to locate the sources of the agent and the scope of its effect (vulnerable sites, likely chain of infection). Visual evidence should be taken into account (eg white powder, agent plumes) in addition to prevailing conditions, such as the weather, that may affect the scope of the agent's effect. Strategies must also ensure that a range of concentrations can be detected (eg high concentration at the focus of the event and lower concentration as the agent disperses.) If infective dose is very low then rapid concentration of samples will be required.

- Sampling strategies need to be validated to identify any likely sources of contamination.

- The type of sample (eg air/water/surface/soil) and the method of sampling (eg swab, scrape, suck) need to be decided for different agents. Swab or wipe samples are probably the most suitable for collecting material from solid surfaces, but clear guidance is needed on the area to be sampled and on any solvents that are used to impregnate the wipe. Several wipes might need to be used in one location with one dry, another water impregnated and a third with solvent. Chemicals vary in their solubility in water and organic solvents and this will need to be taken account of in the interpretation of results. Wipe samples might only indicate where more detailed sampling is required.

- The method of sampling will be affected by the porosity of surfaces. Tape lift samples and swab samples can be considered and the nature of the moistening agent for swab samples can be chosen to enhance collection of samples from non-porous surfaces (eg containing mild detergent solution, solvents.) Porous samples will tend to absorb the agent and will be harder to sample accurately, and any samples obtained are likely to underestimate the amount of agent present. On the other hand, the material that is available to sample from these surfaces may fairly reflect the immediate concentration of agent that would present a hazard.

- Samples may need to be treated to liberate the agent for analysis. Some chemicals, for example, may bind to organic matter in the soil and require treatment with acid or solvent to release them for analysis. Also, surfactants may be considered to promote detachment of biological materials from surfaces.

- To extract agents from soil pores, a variety of techniques including suction to draw materials out of soil pores, centrifugation to collect soil pore water and ion-exchange techniques to enhance recovery of chemical and biological agents from soil matrices can be used. Recovery of biological agents from soil depends on the physical and chemical characteristics of the soil. Between 10% and 25% of a bacterial sample from soil would be extracted at best.

- It might be necessary or appropriate to collect samples from individuals, and the forthcoming Health and Safety Executive (HSE) sampling guidelines should be followed. There are ethical issues associated with sampling individuals, with a need to obtain informed consent if at all possible. Any data resulting from the sampling should be kept confidential in terms of patient identity but be available for informing clinicians involved in the medical management of the patient.

- Lessons can be learned from existing protocols for environmental sampling and biological monitoring, procedures necessary for regulatory compliance and forensic applications. Recommendations for biological sampling are to be published in the near future by the UK HSE.

- Guidance on both the collection and preparation of a range of environmental samples is available from other sources. Defence and Science Technology Laboratory (dstl) Porton Down and the Health Protection Agency (HPA) both have extensive experience in sampling for biological agents and this information needs to be shared so that it can be applied in a civilian context.

3.3 Sampling issues needing to be addressed

The personnel who can and will carry out sampling need to be identified and trained. Suitable respiratory and personal protective equipment needs to be made available for their use and decontamination facilities should be ordered and tested. Strategies for undertaking sampling need to be devised and can be based on available guidance for sampling the environment and the more specific suggestions for sampling for known chemical warfare agents and biological agents (Carlson, MacQueen & Krauter 2001).

Because of the large variability in the amount of agent recovered from different surfaces it is important to know the effectiveness of sampling procedures for a variety of agents when used on a range of surfaces. Knowing whether agent recovery is high or low is essential to be able to provide good advice. All procedures for soil sampling should be validated. This should include recording soil pH, the physical make-up of the soil described (matrix) and moisture content, as this will affect retrieval of agent from the sample.

The feasibility of remote sampling, particularly for volatile materials, should be assessed to limit exposure of personnel. The outside of collection vials should be suitably packaged or treated prior to sending for analysis to protect laboratory personnel from secondary contamination.

Sampling strategies might require taking very large numbers of samples to be effective. The work involved in preparing and undertaking the analysis of these samples using current technology is likely to be considerable and very time consuming. Consideration needs to be given to reducing this amount of work through pre-event training, simplifying procedures and developing new technologies.

3.4 Distribution of agent

An important issue for both chemical and biological agent sampling is the likely lack of uniformity in the distribution of the agent released. In some instances sampling could miss an agent entirely. Dispersion models have been developed for chemical and biological agents to track the plume of the released agent and its movement downwind. The models can be used to map the likely dispersion of a released chemical using the appropriate meteorological data. These maps can then be used to help devise where sampling might take place initially and to estimate the variations in the agent concentration from the point of release.

A chemical released in the open as a gas, vapour or aerosol will disperse, with most blowing downwind. Concentrations of the agent will decrease with increasing distance from the point of release. Movement of chemicals in restricted environments (buildings, underground tunnels etc) will be governed by air circulation and ventilation procedures. For most gases or vapours the likelihood of any surface contamination will be minimal. If there were concerns about a continuing plume of agent in circumstances where the agent was being continuously produced then air sampling for a gas or vapour would be appropriate.

Increasingly sophisticated and reliable computational fluid dynamics (CFD) models have been developed to track the dispersal of agents in air and water. Movement of substances in the air has been modelled for both rural and built-up environments and this approach provides guidance on the likely concentrations of either gases or aerosols. Mathematical modelling of chemical and biological dispersions is discussed further in annex 3. In addition to identifying surfaces to sample, consideration should be given to whether control samples collected nearby will help to validate predictions about dispersal of the agent.

Timing of the event will have a major influence on the approach adopted. If there is a likelihood of an airborne hazard then estimates of average air concentrations might be sufficient over a period of time. Potential hot spots will require a different approach and the shape of the contaminated area will dictate where to sample. Probability models using a grid in the form of a square, rectangle or triangle are available and will provide guidance on the likelihood of the hot spot being located (Carlsen et al 2001).

The most likely routes for contamination for each potential agent should be evaluated and used to inform the sampling strategy. For example, samples taken from water supplies might contain very low, but harmful, concentrations of biological agent and so would need to be concentrated as part of the sampling procedure. The nature of pathogens (relatively large particle size and density) means that they would be unlikely to be readily sampled in air samplers or to be found on vertical surfaces, as after any release the highest concentrations would be found on surfaces as they settle quickly. They will be more prevalent on horizontal surfaces near the floor of buildings and where ambient conditions favour their growth. By contrast, chemicals, if released as an aerosol of liquid or solid, will deposit on a wide range of both horizontal and vertical surfaces.

3.5 Air sampling

Air sampling has a number of associated issues. Microbial aerosol samplers must take into account mode of capture, flow rate, flow characteristics and collection efficiency. These parameters will be a function of particle size and shape. Microbes are very difficult to sample in air as they will not be uniformly distributed, and sampling devices can have significant shear forces that might generate samples unsuitable for certain detection techniques. The flow rate of sampler should be the same as ambient flow rate or only small particles might be captured.

A variety of traditional air sampling devices can be used to sample continuously over an extended period of hours or even days. For example, Hirst traps are often employed to allow sampling of pollen grains, fungal spores and other biological particles. Traditional air sampling devices such as the Anderson sampler depend upon trapping spores and other viable airborne particles that are subsequently detected using culture-based methods. Where the local conditions are thought to be hazardous, remote sampling vehicles (eg radio-controlled aircraft) can be used in conjunction with agar plate sampling devices to trap and establish the amount of viable biological material. In addition, new technology is being developed and may be particularly attractive for single-use applications (Environmental Microbiology Laboratories 2004). A wide variety of portable air sampling devices are designed to detect volatile organic compounds (VOCs) that can be sealed and sent to a laboratory for analysis. There are many examples where air quality is measured routinely using on-line monitoring systems to detect total suspended particulate material, VOCs and a variety of metals. There are no absolute data on sensitivity and to an extent it depends upon the sensitivity of subsequent detection technologies. There are logistical problems with carrying out experiments to determine the efficiency of air samplers in 'real life' situations.

3.6 Biological agent release

Because biological agents are active in small quantities, in contrast to chemical agents that invariably require larger concentrations to have a comparable impact (in terms of numbers affected), the sampling strategy should be related to the so-called 'infective dose' of the agent concerned.

Sampling air or water to obtain an early indicator of an incident might allow the use of countermeasures, such as administering antibiotics. However, there will be a limited opportunity to do this because of the likely delay between the event and the first indication of the incident. This is most likely to be the reporting of symptoms to NHS Direct, GPs or hospital accident and emergency departments. If the cost of sampling is very high, particularly for pre-event sampling, then there is likely to be very little support for it.

The release of a biological agent does not produce a sudden or immediately visible health outcome. The generic issues are the slow evolution of the incident and how soon it will be detected. The speed an incident is detected depends on improvements in the systems used for health surveillance, such as NHS net. One issue is whether there is a case to be made for the provision of rapid response vehicles that can sample, analyse and identify the agent at the scene. A specialist group using a dedicated response vehicle capable of sampling and identifying microbes would aid diagnosis and treatment and define the contamination. These rapid response teams would be highly trained scientists skilled in sampling and analysis, able to utilise mobile analytical and detection equipment. In downtime this group could be used to build up knowledge of the relevant background levels for biological agents. This would enable greater awareness and detection of deviations from the norm in unusual incidents when there was no indication of the cause. They would work for organisations such as HPA, dstl, the Home Office and the Environment Agency.

For some bacterial pathogens the mode of collection and subsequent transport are crucial because they will be subject to stress in environmental conditions (since many are used to warm, humid conditions). Once released into the environment, some biological agents (eg *Vibrio cholerae*) might enter a viable but non-culturable (VBNC) phase where they will be hard to resuscitate for detection using traditional microbiological culturing methods. Therefore it would be advisable to employ both PCR-based detection technologies and traditional culture-based methodologies to ensure that organisms in the VNBC state are not missed.

3.7 Chemical agent release

In the absence of a warning, the first indications of a deliberate release of chemicals are likely to be increasing numbers of people in obvious distress either with difficulty breathing or complaining of irritation to the eyes, nose, throat or skin. Animals, and particularly birds, are likely to be affected too. The clinical effects from exposure will be informative and appropriate monitoring and sampling, using broad-spectrum detectors, should provide guidance as to the nature of the agent(s). Monitoring will also help define the topography of the hot and warm zones of contamination.

There is a critical need for a rapid assessment at the scene including some indication of the nature, if not the identity, of the agent. A rapid response team, similar to that outlined for a biological agent in chapter 3.6, that can sample, analyse and identify the agent at the scene would aid the diagnosis and treatment of casualties and suggest methods of decontamination.

Post-event, the major concern for chemical agents will be to limit skin contact with the agent. However, it might also be necessary to consider whether there is a remaining airborne hazard. Identification of the agent will enable decisions to be taken about where to collect samples.

3.8 Conclusions and recommendations

Sampling for chemical and biological agents must provide a representative picture of the total area contaminated, and strategies are needed to ensure this is achieved. These strategies should be informed by the nature of the agent to be detected and the infective or harmful dose.

Sampling methodologies must be consistent with detection methods and take into account the need for evidence gathering. The logging and storage of samples must be appropriate for the nature of agent to be detected. This will require liaison with the testing laboratories.

We recommend the following priorities for future work on sampling issues:

- Standard sampling protocols and guidelines should be developed and provided to all those who will require them.

- Relevant personnel should be identified and trained in sampling.

- Expert advice should be provided for personnel responsible for sampling to help identify the most appropriate laboratory to undertake analysis.

- Existing dispersal models should be evaluated to ensure they provide the information required to establish good sampling strategies.

- Efficiency of different sampling methods should be quantified.

The proposed new centre should take the lead on this work. If such a centre is not established, then we recommend that a relevant Government Department such as the Home Office CBRN Team take the lead.

4 Current capabilities and future needs of detection

Summary

The existing techniques and devices for chemical and biological agent detection fall short of requirements for the civil environment in terms of specification, ease-of-use, reliability and/or user confidence. Much scientific and technological research that may contribute to meeting the demand is being carried out in diverse fields, in particular in cell- and tissue-based recognition elements and lab-on-a-chip technologies, and this effort should receive continued support. The key detection requirement is for a safe, efficient and rapid means for first responders to confirm the presence of chemical or biological agents at an incident and to identify and quantify them. The establishment of a civilian medical intelligence unit that could collect surveillance data from multiple sources would assist with the early detection of an evolving incident. Both basic and applied research into more reliable and sensitive low-cost, in-the-field and point-of-use detectors, non-contact (standoff) techniques, and continuous monitors for specific sites should be focused on chemical and biological agent applications, and military systems should be adapted for civil use.

This chapter provides an overview of research that could be applied to extending existing detection and decontamination capabilities or developing new ones and the challenges associated with this research.

4.1 Technologies for detecting chemical agents

Point detectors. Potential chemical agents are presently detected by first responders at the scene using either spot papers for detection and a limited degree of identification or, in a few cases, more sensitive systems for chemical vapours using ion mobility spectrometry (IMS) or combining IMS and surface acoustic wave (SAW) devices for detection, limited identification and monitoring. These provide a useful first warning that is subsequently confirmed, typically after 6 to 48 hours depending on the agent, by more sensitive laboratory techniques such as gas chromatography-mass spectrometry (GC-MS). Reduction of false positives is being achieved both by combining the two techniques and by 'profiling' for background signals at specific installations in repeated in-situ tests. However, there is little consensus on the reliability of such systems and broadening the range of analytes, reduction in false positives, and lowering of detection limits would be welcome.

Chromatography. GC-MS and high performance liquid chromatography (HPLC) are widely accepted as the standard method for identification and quantification of chemical agents. Mobile (but far from hand-held) systems have been successfully deployed and there is a substantial body of work on further miniaturisation of mass spectrometry systems, including matrix-assisted laser desorption ionisation time-of-flight mass spectrometry (MALDI-TOF-MS). Current limitations of miniaturised or microfabricated MS instruments relate to poor mass-resolution. The parent systems are the existing standard for identification and may become more widely applicable for detection with further advances in miniaturisation and integration.

Laser standoff systems. These are not yet available for practical use but are being developed for both liquid and solid chemical contamination. Those reported in the literature are either visible or UV Raman systems with upwards of ten meters range. High-intensity, low-cost and miniaturised laser sources are being developed rapidly and should benefit the creation of portable laser standoff systems. If these approaches can reach appropriate specifications for sensitivity, selectivity and response time, they will be ideal for detection and monitoring applications. These are discussed further in relation to the detection of biological agents in chapter 4.2.

4.2 Technologies for detecting biological agents

Protein detection kits. These kits, presently used by first responders, detect whether there is biological material in a sample but do not identify the material. While it is useful to know that biological material is present in, for instance, a 'white powder' incident, these kits do not positively identify that the material is a biological agent rather than an innocuous substance, and are likely to result in false alarms. Currently, samples identified as biological are sent for identification to a central laboratory, and the result may not be known for several hours, or even days, by which time severe disruption may have been caused.

Immunoassays. Field immunoassay kits, enzyme-linked immunosorbent assays (ELISA), and immunochromatography strips are becoming available to first responders, and provide simple, rapid tests for specific agents such as Bacillus anthracis. While detection limits might not be below the lethal dose, in situ 'white powder' identification would be extremely useful for deployment by appropriately protected first responders. There is some danger of false positives due to cross-reactivities of antibodies used in immunoassays. These technologies are appropriate for detection and, in principle, identification. However, there is presently no defined decision-making process following use of existing field assays, and the sample is sent for laboratory analysis, whether the result is positive or negative, due to lack of user confidence.

DNA-based assays. This approach uses short DNA fragments to identify micro-organisms, often in an array format with fluorescence read-out. The polymerase chain reaction (PCR) might be used to amplify the DNA before detection, and a hand-held system has been developed, but PCR is considered to be slow and prone to contamination and thus false positives. These assays are available, but not yet in a format appropriate for practical use in the field, and so are presently more appropriate for identification rather than detection. However, developments in the field are rendering this technology much faster, which may make it suitable for some first-responder situations, and false positive rates are reported to be lower than for antibody-based technologies. Single primer isothermal amplification (SPIA) shows promise for faster throughput. Miniaturisation using disposable microfluidic systems and integration of detection is rendering these approaches portable, faster and simpler to use. Lab-on-a-chip or micro-electro-mechanical (MEMS) approaches (see chapter 4.4 below) are attracting much attention for this and other applications. Portable microfluidic devices for the identification of biological agents have been reported and commercialised. Devices extract and concentrate DNA from biological materials such as cells and spores, amplify the extracted DNA using PCR and identify the amplified sequence in a rapid manner.

Biosensors. Biosensors are being developed to combine immunoassays or DNA-based assays with signal transduction on a chip to provide more quantitative direct electronic readout of data, but are not presently available for practical application. Biosensors exploit electrochemical, acoustic or optical transduction, for example, usually with chemically-selective coatings, and will lend themselves to mass production and to realisation of arrays of sensors to detect several different analytes from one sample simultaneously. Optical transducers are being most aggressively pursued worldwide at present, with fluorescence or electroluminescence-based immunoassay systems and surface plasmon resonance or resonant mirror-based systems being prevalent.

However, optical devices are generally more expensive to produce and use than electrochemical and surface acoustic wave systems. Gold and semiconductor nanospheres are being used as alternative tags to fluorophores, with simple colorimetric readout and high luminescence yields. Sensor arrays for multianalyte detection are being developed in most of these technologies. Whole cell biosensors integrate living cells with physical transducers to measure the effect of toxic agents on cell activity, through changes in the level of bioluminescence, for example. While these do not provide identification of specific agents, they provide a direct measure of toxicity. Molecularly imprinted polymers are being developed that mimic biological molecules involved in immunobinding and may prove useful as the recognition unit in robust and stable biosensors.

These techniques require the sample to be brought into contact with the detection system and sample preparation to be performed prior to analysis, as discussed in chapter 3. This is not ideal, as it implies that some material has already been identified as potentially hazardous and will require clearing the area and donning protective clothing before proceeding to conduct the test. An extremely rapid non-contact (stand-off) system to determine whether there is a hazard present before clearing the area and conducting further tests to identify and quantify substances is required.

Laser-based techniques. UV-laser based aerosol detection systems using wavelengths in the region 250nm to 400nm detect fluorescence from biological materials in aerosols. These are not specific to hazardous biological materials but provide a non-contact method of determining whether biological material is present. Because these systems do not distinguish between toxic and non-toxic biological materials, they can only be used to provide partial evidence in a decision-making process, and not directly as an alarm system. In principle, the laser-based standoff techniques lend themselves well to monitoring and detection systems.

An agent-specific laser standoff technique has been developed for TNT where particles coated with specific fluorescent-tagged coatings are deposited (from a distance) on contaminated ground, and the presence of TNT strongly influences fluorescence from the spheres, excited by laser irradiation and detected at a distance. This approach could potentially be adapted to biological materials.

4.3 Detecting agents by recognising and diagnosing unusual incidents

As discussed in chapter 2.4, the speed of action of many chemical agents means that no current detector will alarm in time to prevent exposure of some individuals. Consequently, a major method of detecting chemical and biological agents is by recognising and diagnosing the effects of an unusual incident. The Health Protection Agency (HPA) is responsible for the surveillance of outbreaks of infectious diseases and incidents involving exposure to hazardous chemicals, and is delivering a CBRN training strategy. The NHS monitors hospital admissions and many GPs are able to provide real-time morbidity data about their patients. However, there is no proactive assessment of intelligence in a medical context or collation of multiple-source surveillance data for the early detection of an evolving incident. This is medical intelligence, and currently the only source of medical intelligence analysis is focused on military operational needs, run by the Ministry of Defence (MoD).

This comprehensive military medical intelligence service provides an all-source threat assessment for military medical and wider strategic and operational planning where the basic requirement is to provide timely and accurate intelligence based on defined requirements. A comparable civilian medical intelligence unit would provide timely advice to the UK Government and work in close collaboration with the MoD, but be specifically focused on:

- Issuing indicators and warnings of imminent health threats in the UK.
- Monitoring emerging diseases of chemical or biological causation, from a global perspective.
- Analysing intelligence source material from a medical perspective.
- Collating and analysing open source material.
- Producing regular medical intelligence briefings to Government.
- Monitoring occurrence of the unusual disease by liaison with the HPA.

A civilian medical intelligence output would include real-time mapping of incidents and outbreaks in the UK, development and validation of indicators and warnings for pre-event threat assessments, and interpretation of intelligence in a health context. We welcome the announcement that the HPA is planning to establish a medical intelligence unit (Home Office 2004).

In addition to enhancing the ability to deal with the deliberate use of chemical and biological agents, many of the points discussed here will improve capabilities to handle accidental releases of chemical or biological agents, as well as natural outbreaks of infectious diseases. One example is that improvements to health surveillance networks will enhance the ability of GPs and the NHS quickly to identify outbreaks of infectious diseases such as SARS or tuberculosis.

4.4 Requirements for research into detection systems

It is crucial to harness existing strands of research from a broad range of science, engineering and technology for application to the detection of chemical and biological agents. This requires, first, that scientists and engineers become aware that their work might make a useful contribution to these applications and, second, that novel science, engineering and technology have a route to develop devices and instruments that may be used with confidence in the field. The establishment of a centre to focus research into civilian applications of devices and systems for agent detection is therefore desirable (see chapter 7). Two priority research directions are highlighted and discussed below: (i) cell-based systems that show great promise as recognition elements for detectors, and (ii) nanoparticle and lab-on-a-chip technologies that will allow miniaturised, integrated automation of sample preparation, ruggedness and portability, thereby allowing practical use of a wider range of approaches in the field.

Cell-based biosensor systems. Cell- and tissue-based sensors offer unique potential for agent detection. Benefits include the ability to detect and classify unanticipated threats or novel pathogens, to relate sensor data to human physiology, toxicity and pathology, and to integrate numerous input stimuli into nonlinear cellular responses. This approach also offers the potential for creation of self-replicating biodegradable sensors with adaptive dynamic range, and can leverage emergent techniques in cell biology. However, key challenges include:

- Integration of viable cells and tissues with synthetic materials
- Strategies to improve genotypic and phenotypic stability of cells and longevity
- Preservation and enhancement of physiological input/output responses
- Localisation and confinement of cells in micro-patterned arrangement
- Monitoring of indirect measures of cell behaviour
- Metabolism or compounds released from actively metabolising cells
- Cell sourcing
- Uniform or synchronous cultures
- Generation of stem cells from both adult and embryonic sources
- Immortalised cell lines
- Knock-out cells as control populations
- Incorporation of fluorescent or luminescent technologies into genomes
- Improved storage
- Automation
- Modularity and portability
- Data mining
- Informatics and knowledge engineering
- Maintenance of aseptic environments and development of strains that can exist anaerobically

Lab-on-a-chip technologies. The key to low-cost hand-held analytical systems combining ease-of-use with reliability is in the further development of lab-on-a-chip, microfluidic and MEMS systems. Further miniaturisation that might allow the parallel or simultaneous detection of a number of agents with the same device offers the potential of extremely rapid and reliable systems for first-responders, incorporating a variety of processing and recognition systems, and needing little user intervention.

Lab-on-a-chip systems bring these generic benefits to detection systems for both chemical and biological agents, but are in a very early stage of development. Lab-on-a-chip technologies are broadly defined as microscale analytical instruments that employ semiconductor and MEMS technologies to assembly features such as channels, electrodes, reactors, filters and electronic circuits on the same small surface (usually a silicon chip). Such devices are able to manipulate fluid samples with high precision and efficiency and have been used in a wide variety of applications including nucleic acid separations, protein analysis, process control, small-molecule organic synthesis, DNA amplification, immunoassays, DNA sequencing, and cell manipulations.

Chip-based analytical systems have been shown to have many fundamental advantages over their conventional (larger) analogues. These include improved efficiency with regard to sample size, response times, cost, analytical performance, process control, integration, throughput and automation. A key benefit of these chip-based systems is the ability to integrate many functions on a single mass-produced device, thus affording highly miniaturised, portable instruments ideal for performing in-the-field analysis with high efficiency and low unit cost.

In addition to microfluidic separation systems, sensors, and miniature pumps and reactors, there is a requirement for low-cost light sources, sensitive detector arrays and integrated electronic systems. Research into lab-on-a-chip devices has been reported for chemical and biological agent detection and should ultimately provide handheld test devices for a wide range of agents for in-the-field applications. Such chip devices also offer the opportunity to integrate specific detection technologies, for example using DNA sequences or antibody fragments, with whole cell microbial biosensors that can now be sustained on chip surfaces. This will offer the potential of combining gross measurements on biological toxicity (potential scale of the event) with signals from other integrated devices indicating the nature of the agent being deployed.

Examples of additional research directions that show promise in providing solutions to detection of chemical and biological agents are given below.

- Novel chemical and biological recognition systems – antibodies, fragments, single chain antibody variable region fragments, aptamers (single stranded DNA and RNA molecules), peptides, molecular imprinted polymers, whole organism systems (IR, magnetic and optical), cell and tissue based sensors, nanoreactors.

- Microfabricated transducers – electrochemical/ electroluminescence sensors, thin film optical devices, magnetic systems, optical sensors based on surface plasmon resonance, quantum dots, photonic crystals, reflectivity and holography, fibre optic bundles, surface enhanced Raman spectroscopy (SERS) and surface enhanced resonance Raman spectroscopy (SERRS), optical, electrical and acoustic arrays, imaging techniques, instrumentation and software, acoustic sensors (rupture event scanning, Love wave, magnetic-acoustic resonance). Sample presentation, miniaturisation, ruggedisation, reagent-free techniques. Integration with force-based techniques (magnetic bead, optical tweezers).

- Highly integrated lab-on-a-chip devices for in-the-field measurements (eg micro PCR and capillary electrophoresis) with the capacity to assay multiple agents simultaneously or sequentially in a rapid manner. Key to the realisation of such devices will be the development of integrated optical detectors and light sources at low unit cost. Developments in MEMS and microfluidics and more sensitive Complimentary Metal Oxide Semiconductor (CMOS) chips, light sources, and photodetector arrays are required.

- Miniaturised MS and integrated hyphenated MS techniques (EI, MALDI, AP-MALDI, IR-MALDITOF), miniature pulsed lasers for MALDI. Developments in these areas will provide for chemical and biological fingerprinting in the field.

- Standoff techniques – laser sources, mid-IR and terahertz spectroscopies.

- Particle systems – upconverting phosphors, quantum dots, gold, magnetic, nanostructured silicon ‘smart dust’, core-shell particles to facilitate high-sensitivity optical detection. Improved fluorophores with high fluorescence quantum efficiencies and low photodegradation characteristics.

- Nanoparticle arrays. Interaction of nanoparticles with specific chemical species can be engineered to induce aggregation or disaggregation and thus a change in the optical characteristics of the nanoparticles.

- Integrated ‘plug-and-play’ systems that allow replacement of the sensor head for detection of different analytes.

- Networked systems, software, data mining and knowledge engineering, to generate useful knowledge from the raw data provided by sensors.

4.5 Conclusions and recommendations

Much scientific and technological research that may contribute to meeting the demand for novel detection systems is being carried out in diverse fields, in particular in cell- and tissue-based recognition elements and lab-on-a-chip technologies, and this effort should receive continued support. At present much relevant research and development is driven by military, medical or environmental applications and there is little coordinated effort in the UK to harness this research for applications to chemical and biological agent detection in the civil environment.

Considerable research is presently being undertaken on fledgling technologies of potential relevance to detection, identification and monitoring of chemical and biological agents, by parts of the academic community that have little or no experience of working on military or security-related projects. It is essential that this research be allowed to develop so that the potential technologies can be assessed. To achieve this we recommend that the UK Government support a cross-disciplinary programme, ideally coordinated by the proposed new centre, to raise awareness of the issues among the scientific community and to encourage the exploitation of new science, engineering and technology for detection of chemical and biological agents, including networking and data fusion activities and instrument development activities focused on solving problems in a real environment.

A key requirement to be addressed by this programme is for point detectors to be developed for use by first responders at the scene of a potential incident involving a chemical or biological agent. For these systems to be useful, it is also essential that research be carried out into background levels of chemical and biological agents and substances that interfere with detections systems, where appropriate in representative environments so that the significance of a detection event may be determined in comparison with normal levels.

Appropriate funding from the UK Government must be earmarked for research and development into systems for detection, identification and monitoring of chemical and biological agents, if the UK is to be well prepared. Funding is required both for short-term development to advance preparedness immediately and for longer-term scientific and technological research.

There should be improved coordination of national and local electronic health surveillance systems to detect clusters of illness/symptoms and unusual diseases. Surveillance data should be real time, and the HPA will have a key role in this development. The HPA and the NHS should utilise medical intelligence as it has the potential to make significant contributions to resilience and the effectiveness of responses. We welcome the announcement that the HPA is planning to establish a medical intelligence unit.

5 How science, engineering and technology can assist in decontamination

Summary

We have identified four areas of decontamination where different approaches would be needed: personal, vehicle, and the interior and exterior of buildings. These mostly fall outside the remit of military research (except for vehicle contamination). In the UK there is currently a considerable body of knowledge on decontamination of all kinds that would be relevant to the civil environment, but it is widely dispersed. It could form the basis for the implementation of effective practices for all four areas of decontamination, but it would need to be coordinated and supported. More quantitative data is needed on the persistence, transfer and contact hazards of toxic materials.

A major difficulty following an incident is the production of convincing criteria for the reoccupation of buildings or sites. Following decontamination of, for example, the external surface of a building, a substantial amount of toxic agent could remain embedded in the structure but be perfectly safe. Quantitative assessments of such contamination are feasible but do not seem to be currently available. Information on the effectiveness of decontaminants needs to be obtained and collated.

5.1 Introduction

The measures required for decontaminating buildings, equipment, furniture, paintings and the environment in general will very much depend on the type and level of contamination. The big difference between personal decontamination and decontamination of buildings is that whereas the former must be carried out as soon as possible (and probably before the agent has been identified), in the latter cases there should be time to identify the toxic materials and to select the most effective decontaminating procedure.

There has been little Government sponsored research to determine the most effective procedures for decontamination in a civilian environment. Military research has of necessity been focused on rapid decontamination methods under conditions where the availability of water might be limited. In a civil context there are fewer logistical limitations and consequently it is worth finding the best means of decontaminating buildings using procedures specific to each agent. The considerable amount of military research concerned with battlefield decontamination against agents such as mustard gas and nerve agents might not be totally relevant and neither might the procedures currently used to sterilise laboratories that are specifically designed to carry out work on dangerous pathogens. What has been learnt that is relevant is that the most obvious approaches of using oxidising, chlorinating or hydrolytic procedures to destroy chemical and biological agents all work well provided good contact between the agent and decontaminant can be achieved. In practice, most research into new procedures for decontamination is directed at topics such as gels, foams and microemulsions, very much with the purpose of enhancing the contact time between the decontaminant and agent. For civil use the main challenges are to find decontaminants that do not cause significant problems for people or material and that are compatible with sampling and measurement methods that could give confidence that effective clean up has been achieved.

The following sections discuss personal decontamination from the practical viewpoint of providing immediate help to casualties. Issues connected with decontaminating buildings are summarised, emphasising the large knowledge gaps and much experimental work required if optimum decontamination strategies are to be developed. Secondary contamination of vehicles is briefly considered. This is important in preventing secondary contamination in ambulances, which is an area where military research might be relevant. Finally, current technologies and strategies are reviewed.

5.2 Personal decontamination

The current practice is that those contaminated should first remove their clothes and then wash or be washed with luke warm water plus detergent ('rinse-wipe' – Home Office 2003). The washings might be held locally for subsequent treatment or discharged to a foul sewer. The need for rapid action, potentially before the nature of the contamination is known, means there does not appear to be any alternative to a simple procedure such as this. However a number of issues arise.

- While removal of clothes is a sensible way of removing a significant amount of any contamination, there may be situations where it is too slow. It might be more efficient to decontaminate people by hosing first, particularly if numbers are large. Some experimental evidence should be obtained with a representative sample of different types of agents.

- The detergent must provide efficient washing, especially for the oily nature of chemical toxins.

- No assistance should be given to contaminants penetrating the skin.

- No, or minimal, foaming should occur if detergent is to be added to the water supply.

- The optimum temperature of the water supply and for performance of the detergent needs to be considered.

- As decontaminants are likely to be only used once, they might be able to contain more powerful agents than repeated use formulations. Components such as oxidising or chlorinating agents could be added that might facilitate the destruction of some toxic agents.

The requirements are so completely different from the military scenario, where the focus is on personal protection equipment to prevent individuals becoming contaminated, that little useful extrapolation can be made from the military experience. They are also such that it should be possible to produce standard detergent solutions and protocols for their use and equip first responders accordingly. It is, however, important to consider variants of whatever procedure might be standardised for different types of contamination, ie chemical warfare agents, industrial spills (where there is some experience already available), and biological agents. Systematic experimental investigation of the options is required, especially of the interaction of contaminants and decontaminants with skin, but the difficulties of designing experimental protocols that can be extrapolated with confidence to real situations should not be underestimated.

Contaminated casualties may arrive at hospitals and adequate facilities should be available at designated receiving hospitals for decontamination prior to admission. This may require a separate building for reception to ensure the treatment area is maintained free of contamination.

5.3 Decontamination of buildings

5.3.1 Interior

Decisions about whether decontamination of the interior of buildings is necessary will depend on the nature of the contamination. Good ventilation over time will be all that is necessary following contamination by gases and very volatile liquids. Other more persistent agents will require specific treatments that may depend on the nature of the building contents and the urgency of returning the building to its normal use. With the notable exception of anthrax, live biological agents die off rapidly on exposure to sunlight.

There are a number of important issues that need consideration and/or investigation.

- For decontamination of buildings, time should be allowed to identify the agent accurately and to select the most appropriate decontaminant for that agent relevant to the interior fabric of the building. Much experimental work is needed to provide background information for decision-making. Inherent in determining the level of contamination will be the reliability of the sampling strategy adopted. Experience gained from military decontamination studies might not be entirely relevant.
- In general, there is unlikely to be a need for a building to be decontaminated immediately and time should be allowed to bring the most effective decontaminant from a central source, so that emergency services need not store supplies at each and every depot.
- Gaseous oxidising and chlorinating gases can be effective decontaminants for many chemical and biological agents, but there is a need to evaluate such procedures, especially with regard to damage to the contents of building, such as computing equipment, and to establish the correct criteria for their use.
- Whether there is a need to decontaminate and whether the decontamination has been successful will depend on whether any toxic substance is present in sufficient quantity and form to be transferred to people by inhalation, by mouth or by contact with the skin. There is a need on an agent-by-agent basis to provide estimates of safe levels of contamination. It must be recognised that it will be difficult to design experimental protocols to provide meaningful data about realistic scenarios. The surfaces of the interiors of buildings, which will mainly be paintwork, are sometimes porous and often highly retentive of organic contaminants. At safe levels for reoccupation such surfaces might retain significant amounts of toxic agent, but factors such as slow release of the agent and its slow degradation by air, and the role of exposure length of the occupants, would need to be thoroughly assessed. There is also the considerable problem of public perception and confidence in the advice offered (see chapter 6).
- The selection of decontaminants will depend not only on the toxic material but also on whether it is essential to avoid damage to the fabric and contents of the building. Although excessive use of water should be avoided, this need not rule out water-based cleaning, especially foam- and possibly also gel-based formulations, and the use of more specific agents such as enzymes.
- It is essential that the sampling and analytical procedures used to show that a building is safe, together with the appropriate toxicological data, give those who live and work in the building the confidence that it is safe.
- Cost-effective methods of making decontamination of buildings easier might usefully be investigated, along the lines of ensuring that new buildings are designed to help rather than hinder decontamination procedures.

Many of these issues had to be dealt with following the deliberate release of anthrax spores in letters in the USA, where the clean-up requirement was for no spores to remain in the environment. In the United States 23 facilities were contaminated, and 20 of these have so far been decontaminated at a cost of $800m, producing 3000 tons of contaminated waste. Anthrax spores exist naturally in certain environments and can be an occupational hazard in the leather and wool industries, particularly with imported raw materials.

5.3.2 Exterior

Other issues relate to the exterior of buildings and to urban environments in general. One is the problem of immediate containment. For example, a heavily contaminated surface or pools of volatile liquids on the ground might cause significant down-wind hazard. Good computer models can help in the assessment of the hazard and decontamination protocols available for dealing with liquid pools.

Surfaces often found on the exterior of buildings, such as concrete, stone or brick, have an enormous effective surface area due to their porous nature. Rain, air and sunlight will tend to degrade any organic agent on a surface over time, so simple washing of the exterior along the lines of present procedures used for cleaning old buildings should be satisfactory. In serious cases detergent might also be used, which would have the possible benefit of incorporating specific cleaning agents, such as bleach or enzymes. The extent to which a given detergent might assist penetration of the washings through the material should be assessed. Although surface contamination might be removed, some agents might remain at appreciable levels within the pores of a building material and yet be safe. Rather than attempt to remove them by drastic means it might be best to leave them or to seal them in by some appropriate surface coating. The presence of any such agents would need to be taken into account if the building was to be altered or demolished in future, especially with regard to long-lived biological agents.

The main issue is the decision about when clean-up has been achieved. This is not straightforward, and involves consideration of, for example, how the wide range of possible agents will disperse over different types of exterior surfaces and whether this would change following simple washing procedures. Given that most contaminant would be retained on parts of the surface inaccessible to people, estimates should be made of the amount of agent that could be removed by a person coming into direct contact with the building, such as by placing a hand on the surface. These estimates should be used to fix the criterion of safety of access. An alternative based on the total amount of toxic agent on the whole surface of the building would be inappropriate. Any subsequent building work on a previously contaminated building would have different safety criteria for the exterior structure.

5.4 Secondary contamination of vehicles

In some cases, casualties and equipment may contaminate vehicles used for transport to treatment areas. It will be important that ambulances and other vehicles be monitored for contamination and, if necessary, methods be available to decontaminate them adequately and prevent secondary contamination of subsequent passengers.

To prevent (or remove) secondary contamination of ambulances will require rapid and efficient methods of decontamination of the interior of the vehicle. This is an issue where military expertise from the battlefield should be directly useful, for decontamination and possibly for better design, eg avoiding crevices where capillary action can concentrate contaminants.

5.5 Current technologies and strategies

The expertise in decontamination is held by a number of groups. The most obvious are the official groups, eg the Health Protection Agency (HPA), Ministry of Defence (MoD), and overseas groups, particularly in the USA. For the problems that arise in the civil environment, much applicable knowledge might be found in those industries involved in all types of industrial cleaning, decontamination of plant (pharmaceutical and food industries), personal care products and household cleaning goods.

Current technologies and strategies for decontamination adopted by the HPA use water-based formulations including detergents, bleaches and oxidizing agents. The principle of decontamination they adopt is to reduce the amount of pathogen to a level at which it can no longer cause harm. In many cases, this can be readily achieved by washing with water and surfactant, which has been demonstrated to remove up to 99.9% of organisms from surfaces. Additional protection can be achieved by adding hypochlorite to the wash solution, which also serves to inactivate material in the run-off water. If surfaces are heavily soiled, physical cleaning is essential to ensure that the surface is clean: disinfectants do not reliably penetrate encrusted material or heavy deposits of organic material.

MoD research is focused on military needs: the emphasis on personnel has rightly been on protection rather than personal decontamination and the material decontamination procedures that have been developed assume that water will be in short supply. The emphasis has therefore been on formulations with a low water content that are especially suitable for decontamination of equipment and on the development of reactive formulations. Examples are:

- Active surfactant formulations to overcome solubility problems - a microemulsion based formulation has been approved for service.

- Microemulsion formulations to cope with capillary trapping (self-agitating surfactant-less middle phases) or thickened chemical agents.

- Reactive coatings, eg self-cleaning paints, novel systems based on nanoparticulate oxides that catalytically destroy chemical agents.

- Reactive gases such as hydrogen peroxide vapour.

The MoD has also explored active clinging foams as a means of dealing with agents on vertical surfaces and has identified a system based on a commercial pressure washer dispensing an active chlorine formulation for cleaning of buildings. Although MoD research has been focussed on military needs, its experience and expertise in handling and removing chemical and biological agents is considerable, such as Gruniard Island (Manchee et al 1983), and should be fully utilised in any new research initiative. An extensive account of liquid phase cleaning agents currently in use (ie 'proven' decontamination technologies) and in development can be found in the Counter Proliferation Program Review Committee Report to Congress (CPRC 2003).

Current agents are based on oxidative solutions such as hydrogen peroxide, peroxyacids and potassium peroxymonosulphate, which are well established for disinfecting biological warfare agents. They are attractive for several reasons: (i) they act on chemical and biological agents; (ii) they are less toxic to individuals and the environment than chlorine-based decontaminants; and (iii) they form less toxic, more manageable reaction products. There are, however, concerns about the toxicity of some tried and tested oxidative decontaminants such as formaldehyde.

Formulations currently being developed are aimed at ease of distribution and application and at the treatment of chemical and biological contaminants in a single application. The main developments are as follows.

(i) *Solution phase chemistry*. The aim is to develop organic or aqueous-based decontamination solutions to replace aqueous bleach and to reduce logistical burdens associated with operational decontamination of external building surfaces. One formulation could combine existing enzyme, peroxy- and catalyst technologies. Technologies under development include the following:

- Non-toxic, non-corrosive stable foam (Sandia 2004). This requires minimal logistics support, and a single decontaminating solution can be used for both chemical and biological agents. It can be deployed rapidly, causes minimal health and collateral damage, and is relatively inexpensive. Trials have indicated that the foam kills anthrax spores at least to some degree (and partially neutralises thickened soman, VX and distilled mustard gas) although it is not clear whether this is through sporostatic (preventing germination rather than killing the spores) or sporicidal control.

- Peroxymonosulphate oxidisers applied in the form of a gel. Gels maximise the contact between the decontaminating reagent and the contaminant and allow decontamination of objects that would be destroyed by decontaminants with high water content or corrosive gases. Systems currently being developed are based on a commercial oxidizer.

- Surfactant based decontaminating solutions. The aim is to incorporate peracid chemistry into surfactant based microemulsions to give a system that is not corrosive or hazardous to the user or the environment. The low interfacial tension of microemulsions enhances their ability to enter contaminated porous materials and hence bring the reactive components into contact with the chemical agents. Peracids break down into weak acid and water and have many forms used in the laundry industry, with a range of solubility and surface active properties

(ii) *Gas phase chemistry*. The most promising gas phase agents for application to decontamination of the external surfaces of buildings are thought to be ozone and chlorine dioxide, both of which are very destructive of chemical and biological agents and of much else. Aerosols fall between solution and gas methods in that they are dispersions of liquid (or solid) droplets, eg hydrogen peroxide fogs. Electrostatic charging might enhance decontamination as charged aerosols have the ability to penetrate the less accessible regions of an object. The aim is to produce a battery operated backpack, UV photoactivated liquid decontamination system.

Finally, the many technologies available in the range of industries identified above, ie those involved in all types of industrial cleaning, decontamination of plant (pharmaceutical and food industries), personal care products and household cleaning goods, constitute a considerable body of knowledge directly and immediately relevant to civil decontamination and a resource of research techniques that would be valuable in the development of really effective methods of decontamination. For example, a high proportion of the items from the 2002 CPRC Report to Congress, some of which do involve industrial input, could be rapidly developed from existing industrial capability in the UK. In addition:

- The development of personal care products has required extensive research on the interaction of materials with skin using aqueous and non-aqueous methods of application. Apart from contributing to the relevant knowledge base, this type of work has generated high throughput testing methods that could be used in extending this knowledge to optimise personal decontamination.

- Industrial cleaning of smooth surfaces (eg ceramic, metal and others) is highly developed and includes a wide range of methods from the application of liquid bacteriocidal formulations containing many different active agents, through foams with a chlorine dioxide release formulation, to electrostatically assisted cleaning with hydrogen peroxide aerosols.

- The food, pharmaceutical and cleaning industries also have extensive experience in the assessment of cleaning techniques (and cleansing systems); the question of 'what is safe?' is one that they constantly address. The nuclear industry also has similar experience, although here detection and assessment of cleanliness present quite different issues, where there is considerable experience of decontaminating radiological incidents (eg NRPB 2002).

5.6 Conclusions and recommendations

There needs to be an extensive programme first to bring together existing knowledge about options for decontamination of people, buildings and the wider environment, and second to measure the effectiveness of decontamination formulations against a range of toxic chemical and biological materials. We therefore recommend the following:

- A more coordinated research programme targeting decontamination strategies needs to be initiated, ideally coordinated by the proposed new centre. It must emphasise technologies optimised for decontamination of the civilian environment. Consultation with industries with relevant experience of decontamination strategies and quantification of cleanliness is particularly important.

- There should be extensive experimental investigation of decontamination procedures for a wide range of toxic chemicals. Since decontamination formulations are likely to use similar chemically reactive species, such as chlorine, peracids and peroxides, the programme should obtain empirical results rather than a detailed mechanistic understanding, although the nature of efficient contact of contaminants with different surfaces might require a more fundamental approach. It is recognised that this will need specially equipped laboratories. The military experience with highly toxic materials will be essential here, as is the experience of the personal products industry for wide-scale assessment techniques.

- A research programme is needed to assess contact hazards from contaminated surfaces, particularly when the levels of contamination are low but not zero, as is likely to be the case in most circumstances. The standards of cleanliness required by different procedures varies and devising of criteria of cleanliness forms a vital component of decontamination, which will be very relevant to the assessment of clean-up following a chemical or biological incident.

- As more and more options for decontamination kits become available in the market place to potential end users (ambulance services, fire brigades, airport authorities, postal services, rail authorities), it is important that end-users are fully aware of the strengths and weaknesses of each option. In particular, end-users must know how to obtain the best results. We recommend that the proposed new centre 'kite mark' the various methodologies both to assist end-users in the choices they must make and to standardise some of the decontamination protocols. If the proposed new centre is not established then an appropriate Government department, such as the Home Office CBRN Team, should take the lead.

- It is important that NHS Trusts and Ambulance Trusts are aware of the risks of secondary contamination and put measures in place to avoid it in hospitals, ambulances and among first responders. Validated decontamination facilities are needed for hospitals and transport vehicles.

6 Decontamination and justified return: communication issues and scientific decision support

Summary

At present, there is little fully-fledged science-based guidance for informing decisions on returning localities to use or buildings to re-occupation following a deliberate release of a chemical or biological agent. Many ambiguities seem to exist over how detailed and specific advice will be obtained in practice if an incident takes place. An important related problem for decision support is a lack of reliable information on the background levels of many chemical or biological agents or substances that cause interference with detection systems. In face of the inevitable scientific uncertainty that will exist, the perception of risk, communication of risk and informing the public about an unexpected chemical or biological incident will be complicated issues to deal with. Collaboration between experts in national and local Government, natural sciences, psychology and social science is required, in addition to public consultation to address these issues.

Adequate expertise exists in the UK for tackling the difficulties associated with a chemical or biological agent incident and with the challenges that will arise in urgent decision-making. This expertise should be used to improve and strengthen advice capabilities and decision support, and the urgent mobilisation of available academic and industrial resources should be a priority. Advantage can be taken, at least initially, of existing industrial and medical protocols, guidelines and regulations.

6.1 Introduction

In the event of a terrorist chemical or biological incident, there will be a need to verify the effectiveness of personal decontamination and environmental clean-ups before a decision can be made that people can return to 'normal' life, infrastructure can be put back into service or a public area re-opened for ordinary use. Once such an incident has taken place, the main issue can be effectively summed up by asking 'How clean is safe enough?'.

The issue is how science, engineering and technology can best contribute to the challenge of determining when something is clean enough to be 'safe'. We recognise that a decision about 'safe enough' will also involve political considerations and will be influenced by public acceptance.

6.2 Exposure limits and 'safe dose'

Acceptable exposure limits are available for some chemical air pollutants such as ozone, carbon monoxide, sulphur dioxide and nitrogen oxides. These limits refer to air concentrations. For most other substances that might be occasionally found in air, there are no established concentrations that have been determined acceptable for the general public, with the notable exception of some chemical warfare agents.

Thus for the majority of toxic industrial chemicals, any of which might be released in a terrorist attack, there are no reported concentrations to which officials might refer to determine who is at risk from exposure to the agents and who is safe. However, there are exposure limits that have been determined acceptable for some 600 to 700 chemicals to which people may be exposed at work. These occupational exposure limits are reviewed on a regular basis and could form the basis for determining acceptable exposure concentrations for the general public. The important point to bear in mind is that occupational limits assume exposure of an individual for only 8 hours in every 24. This allows the person an interval before the next exposure and will ensure that much of the chemical clears the body before the next exposure, thus preventing significant accumulation. For individuals exposed for the whole 24 hours in each day there will be no such interval. Thus lower exposure limits will be needed than those considered acceptable in the occupational setting. An initial approach to establishing acceptable limits for the public may be to divide the occupational limits by a factor of 10. However, this approach may not be safe for all chemicals and a higher safety factor of 100, or even greater, may be necessary. This approach could be used without great cost to establish safe exposure limits for the public for the 600 to 700 identified chemicals.

There is more of a problem for the other thousands of chemicals in use. However, not all of them will be available in sufficient quantity to constitute a threat to the public should terrorists try to get hold of them. For most chemicals on the market there is some established information about their toxic properties. It is possible to get an indication of the toxicity of a chemical from toxicokinetic data, the nature of its toxic effect and matching the hazardous properties of these other chemicals with those for which there are established occupational exposure limits. By applying appropriate safety factors of 100 to 500, safe concentrations for the general public can be determined. This matching of hazardous properties (together with some details about the physical state of the chemical and the quantity in use) is now an established practice in industry for devising the correct control procedures for a wide range of chemicals of a known hazard. The Health and Safety Executive has devised this control approach which is available on the agency's website, known as COSHH Essentials.

Contamination limits for agents on surfaces will depend on a combination of the properties of the particular surface and of the agent. The situation is more complex than it is for air concentration limits. With surfaces it is the quantity of agent that can be dislodged and taken up by an individual that determines the risk. It can be assumed that the permissible contamination limits will be much greater for agents on surfaces (however they adhere) than they will be for the air. It is important to remember, however, that surface limits will be expressed as mg/square metre whereas air concentrations will be mg/cubic metre. Because of the uncertainties caused by the huge variety in properties of agents and surfaces, it will be considerably harder to determine acceptable contamination limits for agents on surfaces than for limits in air. For agents adsorbed on surfaces the most likely routes of exposure would be through direct contact with the skin or exposure to vapour. Re-aerosolisation of agents is a much lower risk and something that could be disregarded. Thus situations can be managed by monitoring air concentrations and limiting skin contact.

6.3 How clean is safe? - scientific issues

Independent verification that decontamination has been successful, and that safe levels have been achieved, will be required. The public is unlikely to accept reassurances from parties directly involved in the decontamination activities or who might have a vested interest in their being undertaken, eg suppliers of decontaminants. There is a need for a separate, impartial and authoritative body or source of advice for this specific purpose. The proposed new centre would be an appropriate body to provide this advice.

The difficulties of persuading the public to return following decontamination were seen following the US anthrax letter incidents in 2001. The technical challenges associated with decontamination following these incidents were discussed in chapter 5.3.1. None of the postal sorting offices involved has yet re-entered service, even though they have apparently been decontaminated completely: people remain unconvinced this has been achieved. There are, therefore, inescapable psychological facets to the response to any chemical or biological contamination incident.

The whole topic of 'how clean is safe?' needs to be addressed by an interdisciplinary team, including members of the general public, representatives from national and local Government, natural scientists, psychologists and social scientists. Even with access to all the available information this is not a trivial problem, and requires adequate funding and suitable investment in preparatory work.

6.4 How clean is safe? - psychological issues

Following a deliberate release, understanding what is perceived by the population at large to be clean enough to be 'safe' involves the psychology of risk acceptability. This is inextricably linked to the communication of risks. Scientific input and advice can play a central part in this dialogue, but it will not necessarily be decisive or definitive. Two main psychological perspectives can be brought to bear on this aspect of the problem: empirical research on reactions to risk, and risk communication as one part of an entire decision process.

Insights into reactions to risk provide guidance, for example as to what affects and influences public trust in any advice proffered, which types of risk are most likely to be seen as unacceptable or extreme, whether information about probabilities will be understood, and why comparisons between different risks are sometimes misleading. This, essentially psychological, perspective can be extended by considering the wider context – for example, the role of the media will be crucial. Not only do newspapers, television and radio inform the public but, perhaps more importantly, they effectively determine why some risks rather than others become major public 'issues'.

The second psychological perspective considers risk communication as an element of the overall decision process. Pointers to good practice are available, based on well-established research that can be adapted to individual circumstances: success in communication involves much more than just the choice of words and numbers (UK Resilience 2004). 'Value judgements' pervade both risk and benefits, especially personal rather than societal risks. Decision-makers, potential beneficiaries and victims typically have different viewpoints, making a variety of social and political value judgements unavoidable. For many people, involuntary, unjust or inescapable aspects of their situation are not just fright or dread factors, but characteristics of unacceptable exposure. Thus their response to risk is intimately bound up with wider values. Dispassionate or isolated scientific facts about the objective risk in any particular case might have little impact on a person's views about its generic acceptability.

It is known, for instance, that having to deal with releases of certain chemicals, such as dioxins, can easily cause additional decision-making difficulties to arise: they attract a high 'dread' factor, because of their supposed extreme carcinogenicity and because of precedent notoriety. But dioxins are difficult to measure at low concentrations, and getting people to accept assurances about them at what might be termed normal levels of safety proves to be very difficult at the best of times, let alone if such chemicals have been maliciously dispersed into a populated area.

Public confidence will be increased if people feel they have a definite sense of control, or if they are given the means and information to check conditions for themselves. For personal decontamination, evidence given by the British Psychological Society indicates that any clues that a person has been successfully decontaminated might not be tangible. Therefore, if at all possible, equipment should be used that objectively measures and indicates the level of decontamination. To show that someone or something is 'clean', we suggest the use of an open and interactive system of multiple tests with a variety of markers or measurements. At present such equipment is not readily available, and may not be for several years. This approach can help generate a 'catalogue of reassurance'. This is preferable to relying on bald professional assurances or single diagnostic indicators. The alternative is to use take-it-or-leave-it assurances by an official expert, which are often unhelpful and counter-productive, no matter how often they are repeated.

These points all lead to the expectation that there could be major difficulties in communicating risks and risk assessments to affected persons and the general public after a terrorist incident. This will be particularly so when trying to convince the wider population that an area is clean after decontamination, or that affected individuals are free from contamination. Communicating risks requires more than dealing with scientific concerns: engaging with representative members of the public to identify other concerns is also necessary (Stern and Fineberg 1996; Slovic 2000). The experience gained in collaborations between chemical companies and residents living near chemical production sites can be looked to for guidance.

An Economic and Social Research Council programme *The domestic management of terrorist attacks* (ESRC 2004) has been set up to look specifically into people's reaction to terrorism, and a forum is being promoted for the Government and various areas of the media to discuss the media's response to a terrorist incident. Technical experts and scientists should also be involved in this dialogue, and all should work together to find ways to communicate a range of views on hazards and risks in a balanced and creative way.

6.5 Communicating risk in the decision process

Behavioural science research can be useful for revealing public understanding of the risks of terrorism and the benefits of alternative programmes to confront the threats. Behaviourally realistic assessments of risks, with and without alternative response strategies, can guide priority setting consistent with an understanding both of the science and of public values. However, the public will need almost total confidence in any detection and decontamination systems in order to be convinced that, when these indicate something is 'clean', it really is 'safe'.

In respect of 'informing the public' generally, information that accurately reflects risk is less likely to cause apprehension, whilst vague and non-specific information is more likely to cause anxiety. Concerns over genetically modified food and bovine spongiform encephalopathy (BSE) are useful analogues for understanding the way people think about and deal with risks, and the kinds of factors that influence the perception of chemical and biological risks.

In the context of a terrorist incident itself, experiences from other types of disaster could be relevant, depending on the nature of the incident: the way in which the public reacts to, and interacts with, say, a fire in an industrial complex is one obvious source of guidance. In this regard, the National Steering Committee on Warning and Informing the Public (NSCWIP) has been encouraging improvements in the arrangements for warning the public of any imminent or actual threat to life, health or property and of ways to inform them of the appropriate action to take.

Although initially set up without funding, and motivated mainly by the emergency services and chemical industries requirement to prepare incident response plans for the public, NSCWIP's remit has broadened to include other disaster situations such as flooding, chemical tanker spills and terrorist incidents. In considering several industrial case histories, NSCWIP was concerned that the information that licensees were required to provide to the public was not achieving the desired effect, so the Committee produced a more generic message that could be applied to a wider range of situations.

They promoted the general message 'Go in, stay in, tune in'. This is often termed 'shelter advice', and is based both on exposure-uptake experiments and on the premise that, if the public shelter themselves as an immediate response, this should assist in controlling the situation by leaving the way clear for the emergency services to work more rapidly. Also, if people are at home or indoors, advice can be transmitted to the greatest number most efficiently via radio, TV, text messaging or paging (NSCWIP 2004).

Whilst the Government has apparently endorsed this advice in principle (Hansard 2003), it seems reluctant to promote the concept more widely. Several reasons have been suggested. It might be the Government fears a repeat of the outcome of the 'Protect and survive' campaign of the 1970s, which aimed to increase public preparedness for a nuclear attack; then, the advice given gained no credibility whatsoever with the public, mainly because of media ridicule.

In the light of more recent experience with media coverage of scientific issues, for example the controversy over MMR, the measles mumps and rubella vaccine, the Government might be concerned that the media could misconstrue messages about how to respond to a terrorist incident, causing excessive public anxiety. However, the experience of the BSE crisis demonstrates the danger of concealing information, and many in the chemical industry have found that being open and honest is a better way to deal with situations involving technological threats and risk.

This is underpinned by research on the effectiveness of technical and scientific information that was provided by safety-critical industries in various circumstances. It has been found that many people just do not accept unquestioningly the information they are given in an emergency: they either tend to be sceptical of it, or at least wish to know more about the reasoning behind the advice before acting on it. Others can turn plain inquisitive about an incident, and wish to approach the hazard: this famously, but fatally for some, happened with the Mount St Helens volcano eruption in 1980 and, more notoriously, during the fire at Chernobyl, when workers and their families from the plant living in nearby Pripyat stood in the open and watched the fire as radioactive debris fell on them, despite being aware of the dangers of exposure. Some might even move closer to the threat in order to actively investigate it for themselves. Messages need to be layered so that those who want to learn more easily can do so. This can be achieved by having an information website resource that can provide audiences with different levels of detail.

It seems evident from the NSCWIP work that the public should be made more aware of the chaos and immediate confusion that is likely to arise should a terrorist chemical or biological incident occur. People should have information on how and when advice will be provided, and if suitable guidance is given beforehand the public may well respond more appropriately when they feel obliged to apply natural intuitions to an abnormal situation.

6.6 Decision-making on decontamination issues

Some of the key issues that warrant further scientific attention in relation to decision-making on physical, chemical or biological decontamination activities are:

- Effectiveness of existing detection and decontamination measures, and alternative approaches.

- Current status of methodologies for assessing exposure, vulnerability, dose, risk, cost-benefit, value-of-life and consequence, especially in near real-time.

- Current arrangements for mobilising and optimising expertise and ways to enhance the role and contribution of scientific advice to decision-making.

- Issues surrounding statistical and probabilistic methods for representing scientific uncertainty, expert judgement, and the implications of scientific uncertainty, statistical test performance (false positives, negatives, etc) for assessment and decision-making (see annex 4).

- Scientific questions relating to risks that cannot be shown to be significant, given existing knowledge and scientific understanding; and when, and how, to apply the 'Precautionary Principle'.

If detection and decontamination responses are to be optimised, there is a wide range of science-related topics for which additional thought and investigation would be desirable.

One fundamental issue underlying any consideration of the management of the whole decontamination process is scientific uncertainty and the reliability of available data. For risk-informed decision-making, intensive sampling can be used to reduce uncertainty in threat characterisation, and to reduce the likelihood than an inappropriate decision is made, but significant further work needs to be done on all these issues. As noted in chapter 2, there will be vital scientific contributions to be made at every stage: before, during and after the event.

Confirmation that decontamination has been effective, and that a safe return to use is justified, will probably require inputs from several specialist agencies, as well as the body or bodies responsible for health and safety at the locations or premises concerned, as discussed in chapter 2.2.3. Thus, to support the goal of a justified return to normal use, there will be need to integrate into a complete, science-informed decision process:

- A structured framework for the inclusion of all scientific and technical information.

- Numerical models for mapping the spatial extent, intensity of initial contamination and timescale forecasting, and for tracking decontamination progress.

- Quantitative risk or cost-benefit analyses of decisions using science-based evidence.

When it comes to using decontamination measurement data for decision-making, the National Radiological Protection Board (NRPB) has done some valuable work in producing a decision-support software package for estimating the consequences of decontamination options for radiological incidents in inhabited areas. Though there are considerable differences between radiological and chemical or biological incidents, this package could, in principle, be adapted for application to the latter. However, before derivative versions of the software could achieve a sufficient degree of effectiveness for use, it will be necessary to develop explicit databases and other inputs, specific to the problems associated with the chemical and biological agent incidents.

The approach adopted by the NRPB package is appealing as a template because it provides decision support by incorporating all key factors: dose, cost, timescale and waste generation, as well as estimating the consequences for a range of different scenarios. This total approach allows the decision-maker to scope the extent and scale of the problem, and to identify some options that can or should be excluded and others that should be developed for chemical or biological terrorism incidents. While all the various inputs of scientific fact and technical information ought to be actively taken into account for risk-benefit analysis, there will also be a need to state the scientific uncertainty that attaches to any assessment of consequence. Ideally, this uncertainty should then be communicated to policy makers, incident managers and the general public.

Any successful decontamination will have to address the concerns of the key stakeholders: the public, Government and regulators. This will be in addition to undertaking the specific approach adopted for the particular incident, be it destruction, removal or in situ cleaning. Science has a role to play in the fostering of public confidence in detection systems and decontamination methods, as part of the decision process. Ultimately any decision to return will be a personal choice, so it must be ensured that the public are well informed and their concerns have been adequately addressed (Stern & Fineberg 1996).

6.7 Conclusions and recommendations

There is a clear need for all scientific and technical information to be integrated into a complete, science-informed structured framework for decision processing. The proposed new centre would be well situated to coordinate this activity. The NRPB radiological incident software is an example of good practice and should be adapted to chemical and biological incidents to the best extent possible.

Criteria for safe exposure levels for chemical and biological agents should be developed and estimates made on best available evidence. Also background levels of many chemical or biological substances or agents that might be used as malicious contaminants or cause interference with detection systems should be determined where appropriate, as recommended in chapter 4.5.

Dialogue between scientists, psychologists and the general public should be encouraged to improve the communication and public understanding of hazard and risk issues in relation to terrorist incidents, and any insights should be proactively incorporated into decision support. The currently separate efforts of the NSCWIP to improve ways of warning and informing the public should be engaged more widely in these challenges.

7 Organisational issues – a proposal for a new centre

Summary

During our deliberations we became very aware that although there is much knowledge and expertise available in the UK, some of which has been acquired in a military context, no single Government Department appears to have full responsibility for determining how this expertise can best be utilised. We propose a centre to coordinate, commission and direct the work required, with overarching responsibility and a suitable budget.

7.1 The challenge

To establish coherent strategies and procedures to deal with any chemical or biological incidents, all available expertise must be well coordinated and directed. We are convinced that the current organisation could be considerably improved.

The evidence from Government Departments and agencies assumed that other unspecified bodies could provide relevant technical information and advice. However, a very considerable amount of work is needed to fill the many gaps in existing data, understanding and procedures, and there is also a need for a clearly identified source of advice.

A considerable number of Government interdepartmental meetings, many coordinated by the Home Office CBRN Team, have done much to improve overall awareness of the information needed. However, little new data collection work has been commissioned. Such work is essential in helping those responsible for dealing with the consequences of a chemical or biological incident to give good advice based on technical knowledge. For example, despite a perceived need for a decontaminant for buildings contaminated with anthrax, little practical work has been done to evaluate the effectiveness of gaseous decontaminants in this context.

The preceding chapters have identified many areas requiring new technical work, including:

- Developing improved methods for detecting, monitoring, identifying and providing medical treatment against chemical and biological agents.
- Ensuring concepts of use for detection systems are clear, so equipment and procedures can be designed accordingly.
- Assessing and coordinating protocols for medical responses.
- Translating laboratory techniques into robust equipment capable of being used in the field.
- Establishing appropriate criteria to evaluate detection and decontamination equipment and procedures for their use, and collecting the detailed data required to assess the efficiency of sampling and decontamination procedures, and residual contact hazards.
- Evaluating commercially developed technologies.
- Establishing maximum levels of agents below which it is appropriate to permit return to normal use following an incident.
- Providing expert advice regarding chemical or biological incidents for Government department and agencies, first responders, NHS Trusts and national and local emergency planners.
- Investigating how scientific uncertainties and technical difficulties impinge on all issues about responding to chemical and biological incidents and how they are formalised to allow rational decisions to be made.

7.2 A proposed solution

The type of organisation best suited to coordinate, commission and direct the work listed in chapter 7.1 is a centre with overarching responsibility and a suitable budget. The budget required by the centre will depend on the timescale envisaged for the work to be done and on the sophistication of the equipment and materials it aims to produce. Based on information received from a number of sources, we estimate that a reasonable figure would be of the order of £20 million per year, and that five years would be needed to train staff and undertake the initial work programme required. After this initial period the funding should continue but the level would need to be reassessed. The centre would not be responsible for directly funding fundamental scientific research with potential applications in this field, since the Research Councils currently have responsibility for this. However, it is important that the centre work with the Research Councils to identify research with potential applications in detection and decontamination. A small, but very important, component of the work could be carried out in universities.

If such a centre with its access to diverse expertise were not established, then it would be extremely difficult for the relevant parts of Government to coordinate the research and collection of data we have identified. Without this the UK will not gain the benefit of the existing but widely dispersed expertise.

Much of the work requires handling highly toxic chemical and biological agents and needs to be done in facilities designed for that purpose. The technical staff carrying out the work to collect the data must be well trained and experienced in handling highly toxic materials. At present most of the expertise for this work resides with the Health Protection Agency (HPA) and Defence and Science Technology Laboratory (dstl). dstl Porton Down has the capability to handle the broadest range of chemical and biological agents, although most of their current work is for the Ministry of Defence (MoD) and has not been targeted for use in a civil context. In contrast, HPA focuses on improving civilian health. Although HPA has the necessary laboratories to handle highly toxic biological materials, its facilities for handling toxic chemicals are under-developed at present. This highlights the need for more collaboration between HPA and dstl in order to improve the UK's resilience against a deliberate or accidental release of a chemical or biological agent. Such collaboration should aim to maximise the capabilities to handle the greatest range of agents and scenarios, rather than simply duplicating facilities.

The centre would bring together existing expertise by working with dstl, Health Protection Agency, Home Office, Department for the Environment Food and Rural Affairs, Environment Agency, Cabinet Office, Department of Health, Office of the Deputy Prime Minister, Department for Transport, the Research Councils, Office of Science and Technology, Department of Trade and Industry, National Health Service, first responders, the academic community and industry. Some of these Departments would continue to take the lead on particular issues but would coordinate their efforts with the new centre. Pooling the expertise from these diverse groups will maximise potential synergies. It is important that the centre has a dedicated budget to establish an extensive network of academic collaborators. An outward looking approach will be essential for success. This approach will include discussing preparedness, coordination and communication strategies with those responsible for other types of emergencies, such as radiation hazards, flooding, severe weather, transport accidents, industrial accidents, animal disease, food and water contamination and infectious diseases. A panel of expert, independent scientists should advise the centre, helping to guide the programmes and provide external scrutiny. The membership of such a group could be drawn from existing panels, and the Royal Society would be happy to suggest potential additional members.

The centre should be located to maximise overlaps with key partners. This might best be achieved by operating a number of different sites. One possibility is that the centre could have a small unit based in or near London to deal with liaison issues between Government Departments and other organisations concerned with responding to chemical and biological incidents. The main part of the centre for dealing with technical issues, determining the work needed and placing the necessary contracts, could be located at an existing research centre, possibly at Porton Down, but it must be independent of the dstl management.

It is important that the technical team should be outward looking, prepared to work with the academic community, industry and the research councils where appropriate and also seek to make full use of developments and potential funding in the US, Europe and elsewhere. Co-locating the centre with a large research centre like dstl Porton Down would allow the technical staff to take advantage of the innumerable contacts of the current staff with fellow scientists in the academic community, industry and in other countries. These scientific contacts will enable the technical team to act as a truly informed and intelligent customer capable of placing work where it can be done most effectively. As discussed in chapter 6, dialogue between scientists, psychologists and the general public should be encouraged to improve the communication and public understanding of hazard and risk issues in relation to terrorist incidents. The proposed centre should coordinate this dialogue.

The considerable need for the centre to establish the maximum levels of agents below which it would be appropriate to permit a return to normal use following an incident was discussed in chapter 6. Also, the centre would be a clearly identified source of expert advice on chemical or biological incidents for Government Departments and agencies, first responders, NHS Trusts and national and local emergency planners. Both of these functions would give decision-makers vital information during an incident. In addition, the centre would be able to advise the Cabinet Office on dealing with accidental releases of chemical and biological agents or natural outbreaks of infectious diseases, where appropriate.

In its response (Home Office 2004) to the House of Commons Science & Technology Select Committee report on the scientific response to terrorism (House of Commons 2003) the UK Government rejected the recommendation to establish a 'Centre for Home Defence'. The Government proposed undertaking a one-off exercise to identify the research required in this area. We do not believe that this would provide the required evaluation work, risk communication, information sharing and co-ordination we have clearly identified in our report. Also, it is not clear who would be responsible for commissioning work under the Government's proposed research programme. The Government also asserts that it would be prohibitively expensive to construct the specialist facilities required. Our suggestion of co-locating the new centre with existing laboratories with these facilities, such as Porton Down, would minimise the costs of establishing the centre.

7.3 Recommendation

We recommend that a fully funded centre be established to coordinate, commission and direct the work required to improve the UK's capabilities to minimise the impact of any civil chemical or biological incident.

Such a centre would undertake the following detailed activities:

- Obtain any missing data to ensure procedures and protocols for detection, sampling, decontamination and medical treatments are based on the best possible technical information.

- Regularly update the procedures planned to manage the consequences of chemical and biological incidents in line with improvements in equipment and technical data.

- Evaluate all equipment and materials available to ensure suitability for the purpose described in their operating instructions by providing 'kite marks' or agreed industrial standards.

- Share information effectively between Government Departments and agencies, the academic community, industry and other interested parties including the public.

- Ensure that improvements are made to equipment and materials and that these are made available to the response agencies.

- Liase with the HPA on surveillance of outbreaks of unusual disease.

- Establish maximum levels of agents below which it is appropriate to permit a return to normal use following an incident.

- Work with the academic community, industry and the research councils where appropriate and seek to make full use of developments and potential funding in the US, Europe and elsewhere.

- Provide a clearly identified source of expert advice regarding chemical or biological incidents for Government Department and agencies, first responders, NHS Trusts and national and local emergency planners.

8 Main conclusions and recommendations

8.1 Introduction

Science, engineering and technology will be able to reduce the threat from chemical and biological agents. How this is coordinated and organised is crucial to the successful utilisation of developments in detection, decontamination, sampling and risk communication, as highlighted in chapter 7. Without political will and cost-effective implementation, organisational and technological innovation cannot deliver their full potential to make the UK safer.

It is currently not practical to constantly monitor the entire civilian population against unannounced chemical or biological attack. The difficulties preventing such an approach include the vast amounts of data it would generate, which could not be practicably analysed, and the logistical difficulties in setting up a network of appropriate monitors. Realistically, only a limited number of target locations can be monitored.

There is considerable expertise in dealing with chemical and biological agents in military scenarios. Whilst there are many differences between potential military and civilian incidents, some of the extensive military knowledge could be translated to a civilian context.

8.2 Organisation and procedure

R1 **The UK Government should establish a new centre to coordinate and direct the work required to improve the UK's capability and to minimise the impact of any civilian chemical or biological incident.**

R2 **The centre's main functions would be as follows.**

- **Determine, commission and direct the work required on planning, preparedness, research and development related to detection and decontamination.**
- **Assess and disseminate protocols and procedures for detection, sampling and decontamination.**
- **Evaluate detection and decontamination equipment and establish agreed industrial standards.**
- **Ensure information is shared effectively between different Government Departments and agencies, the academic community, industry and other interested parties, including the public.**
- **Establish the maximum levels of agents below which it is appropriate to permit a return to normal use following an incident.**
- **Work with the academic community, industry and the research councils where appropriate and seek to make full use of developments and potential funding in the US, Europe and elsewhere.**
- **Provide a clearly identified source of expert advice regarding chemical or biological incidents for Government Department and agencies, first responders, NHS Trusts and national and local emergency planners.**

It has become clear that the current system does not utilise the extensive expertise in local and national Government, first responders, the academic community, industry and others to the greatest benefit to the UK. In order to harness that expertise, we recommend that such a centre has a significant, ring-fenced budget to commission work to develop and evaluate detection and decontamination equipment. The budget required by the centre will depend on the timescale envisaged for the work to be done and on the sophistication of the equipment and materials it aims to produce. Based on information from a number of sources, we estimate that a reasonable figure would be of the order of £20 million per year. It is important that the centre works with the Research Councils to identify promising research relevant to detection and decontamination. An outward looking approach would be essential for the success of such a centre, as would collaborations with other countries. If such a centre were not established then it would be extremely difficult for the appropriate parts of Government to be sufficiently aware of the diverse expertise to allocate this funding. Without this budget the UK will not gain the benefit of the existing but widely dispersed expertise.

The centre would bring together the existing expertise by working with Defence Science and Technology Laboratory (dstl), Health Protection Agency, Home Office, Department for the Environment Food and Rural Affairs, Environment Agency, Cabinet Office, Department of Health, Office of the Deputy Prime Minister, Department for Transport, the Research Councils, Office of Science and Technology, Department of Trade and Industry, National Health Service, first responders, the academic community and industry. A panel of expert, independent scientists should advise the centre, helping to guide the programmes and provide external scrutiny. The membership of such a group could be drawn from existing panels, and the Royal Society would be prepared to suggest potential additional members.

The centre should be located to maximise the overlaps with key partners. For example, the centre will need laboratories for handling highly toxic materials and it would be preferable for the centre to use existing facilities, such as Porton Down, rather than construct new ones. The centre should also address the pressing need for investigation of the ways scientific uncertainties and technical difficulties impinge on all issues in responding to a chemical or biological incident, and how they are formalised for rational decision support at all stages. Dialogue between scientists, psychologists, politicians and the general public should be encouraged to improve the communication and public understanding of hazard and risk issues in relation to terrorist incidents, and any insights should be proactively incorporated into decision support. The efforts of the National Steering Committee on Warning and Informing the Public should be utilised in these challenges.

R3 We recommend that the next edition of the Cabinet Office document '*Dealing with disaster*', which is expected to pay more attention to dealing with chemical and biological incidents, clearly spells out the concepts of use for detection systems, so equipment and procedures can be designed and implemented accordingly.

In particular, this updated document should cover the scope for better coordination of pre-event action plans, scientific responses at the time of an incident, and timely implementation of scientific advances.

R4 Realistic exercises should be undertaken involving first responders, emergency planners and some civilians in order to test and develop the correct reactions to an incident.

In addition to providing a considerable measure of reassurance to the public, such exercises would be an integral part of staff training and preparedness. The proposed centre would advise first responders and emergency planners in running such exercises.

8.3 Detection

R5 We recommend that future work on detection systems should be concentrated on three objectives:

- **Exploit new and existing science, engineering and technology for robust detection of chemical and biological agents.**
- **Develop point detectors for use by first responders at the scene of a suspected incident.**
- **Establish what information on background interferences and natural variability of agent levels might increase the reliability and sensitivity of different detection systems and decision making. Where appropriate the relevant data should be collected.**

R6 The work on detection would best be coordinated and directed by the proposed new centre. If the proposed centre is not established then we recommend that an appropriate Government department such as the Home Office CBRN Team take the lead.

Considerable research is being undertaken on fledgling technologies by parts of the academic community that have little or no experience of working on military or security related projects. It is essential that this research be allowed to develop so that new potential technologies can be assessed, particularly in cross-disciplinary areas. This should include networking and data fusion activities and instrument development activities focused on solving real problems in a real environment.

One of the most urgent needs is for point detectors for first responders. We recommend that this should be a top priority of the research and development programme. Mobile or hand-held instruments for use by first responders at the scene of an incident would be extremely advantageous. The ideal instrument would be remote to avoid contamination of emergency staff.

Sampling methodologies must be consistent with detection methods and take into account the need for evidence gathering. The logging and storage of samples must be appropriate for the nature of the agent to be detected and will require liaison with the testing laboratories.

8.4 Decontamination

R7 With respect to decontamination studies, we recommend the following four priorities:

- **Undertake a detailed review of the various options for the decontamination of people, buildings, vehicles and the wider environment.**
- **Assess the efficacy of decontamination procedures and technologies.**
- **Assess contact hazards from contaminated surfaces.**
- **Develop and implement techniques for avoiding secondary contamination in hospitals and ambulances.**

R8 We recommend work on decontamination be coordinated and directed by the new centre, working in collaboration with relevant UK industries where appropriate. If the proposed centre is not established then we recommend that an appropriate Government Department such as the Home Office CBRN Team take the lead.

This is an area where collaboration with appropriate UK industries would be extremely beneficial. For example, there is considerable expertise amongst detergent manufacturers. Human surface decontamination is still rudimentary: clothes are bagged and plenty of soap and water applied. More research is needed to determine the best technologies for generic cleansing of skin.

There needs to be an extensive programme first to bring together existing knowledge and second to measure the effectiveness of decontamination formulations against a range of toxic chemical and biological materials. There is a need for rapid environmental decontamination at the incident site, using generic methods because the identity of the agent is usually unknown. Robust monitoring methods are also required to determine when the environment is acceptable for reuse.

8.5 Medical issues relating to detection and decontamination

R9 The occurrence of a chemical or biological incident may first become apparent through those affected reporting medical symptoms. Such reporting can therefore play a crucial role in the detection and subsequent decontamination of chemical and biological agents. We therefore recommend:

- **Increasing training of clinicians in CBRN-related subjects by Medical Schools, led by the General Medical Council, to improve recognition of the relevant symptoms in individuals.**

- **Using medical intelligence analysis, in conjunction with the Health Protection Agency (HPA) and NHS, to improve recognition of a chemical or biological event at the level of the population and thus strengthen the resilience and the effectiveness of responses.**

- **Establishing systems for the long-term follow-up of exposed populations, with the Department of Health.**

R10 These recommendations would best be integrated with the work undertaken by the proposed new centre.

Evidence based diagnostic techniques and appropriate training of medical personnel are important for detecting chemical or biological exposure. It is also vital to validate treatments for the effective consequence management of adverse effects on health. The treatment of unusual casualties will require special training for initial medical responders in the community, hospitals and health protection teams. Increased training should be extended to undergraduate and postgraduate medical training so that all doctors are aware of relevant toxicological and infectious diseases. This training should be delivered in a systematic approach and available to all institutions through electronic as well as traditional teaching methods.

There should be improved coordination of national and local electronic health surveillance systems to detect clusters of illness/symptoms and unusual diseases. Surveillance data should be real time and the HPA will have a key role in this development. The HPA and the NHS should utilise medical intelligence as it has the potential to make significant contributions to resilience and the effectiveness of responses. We welcome the announcement that the HPA is planning to establish a medical intelligence unit (Home Office 2004).

There are few data on the long-term risks to health in populations exposed to chemical agents. Agents such as mustard gas are suspected carcinogens, but the long-term effects of organophosphates are still unclear. Consequently, it will be important that exposed populations are identified and subjected to close long-term clinical follow-up.

8.6 Mathematical modelling

R11 The proposed new centre should assess the current and future capabilities of mathematical modelling to provide real-time information to inform first responders and emergency planners.

The types of models that should be assessed include those to determine the extent of the initial contamination and potential re-dispersion, chemical plume dispersal for a range of built-up and open environments, predict the effectiveness of cleanup strategies and identify the potential impact on the civilian population. These models need to yield results in as near to real time as possible and should be tested against on-the-ground measurement of chemicals and simulates to validate and improve them.

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* Dr Lightfoot was not involved in finalising the recommendations of this report owing to his appointment during the study as Director, Emergency Response Division, Health Protection Agency.

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Annex 2 Individuals and organisations giving evidence

We sought evidence from a variety of organisations and individuals, and also received a number of useful unsolicited contributions. We are very grateful to all who participated.

Evidence submitted at meetings of the working group

Dr Rebecca Bowden, Office of Science and Technology
Adrian Dwyer, British Transport Police
Ian Howell, Unilever Port Sunlight
Martin Jones, Unilever Port Sunlight
Professor Dick Lacey, Police Scientific Development Branch
Dr David Langley, Cabinet Office
Dr Ian Lawston, Home Office
Dr Robert Maynard, Senior Medical Officer, Department of Health
Dr Paul Norman, Chief Scientist, Chemical and Biological Defence, dstl
Dr Dominic Tildesley, Chief Scientist, Unilever Port Sunlight
Graham Turner, Unilever Port Sunlight
Professor Gordon Walker, University of Staffordshire

Meetings with the Chair of the working group

Mark Barker, Assistant Director Civil Protection, Cambridgeshire County Council
Sir David King FRS, Chief Scientific Advisor, Office of Science & Technology
Sir Keith O'Nions FRS, Chief Scientific Advisor to the Ministry of Defence
Professor Ron Atlas, University of Louisville
Professor David Fisk FREng, Chief Scientific Advisor, Office of the Deputy Prime Minister

Meetings with sub-groups of the working group

Professor Rex Britter, University of Cambridge
Sir David Omand, Permanent Secretary, Cabinet Office
Professor Anatoly Vorobjev, Moscow Sechenov Medical Academy
dstl Porton Down (Dr Andy Bell, Dr Stuart Brewer, Dr Matt Chinn, Dr Norman Govan, Dr Rick Hall, Dr Martin Pearce, Dr Richard Scott, Dr Brian Warburton)
Dr Gordon Woo, Risk Management Solutions Ltd

Evidence acquired by correspondence

(i) Organisations

Antec International Ltd
Acqua Lider
British Medical Association
British Psychological Society
British Transport Police
Cambridge Environmental Research Consultants Ltd
Casella Stanger on behalf of the London Fire Brigade
Cranfield University
Department for Environment Food and Rural Affairs
Department of Trade & Industry, Foresight Directorate
dstl Fort Halstead
dstl Porton Down
Foreign & Commonwealth Office
Health Protection Agency
Home Office
London Ambulance Service NHS Trust
McBride plc
Metropolitan Police, CBRN Co-ordination Unit
Ministry of Defence
National Radiological Protection Board
Office of Science & Technology

Office of the Deputy Prime Minister
PROTECT Institute, UMIST and University of Manchester
Research Councils UK
Royal Mail
Science Applications International Corporations (SAIC), San Diego
Smiths Detection
Society for General Microbiology on behalf of the Bioscience Federation
Steris Limited
US Army Soldier and Biological Chemical Command's Homeland Defence Business Unit
US Department of Homeland Security, Combating Terrorism Technology Support Office

(ii) Individuals

Dr Cam Boulet, Defence R&D Canada
Dr Tina Carlsen, Lawrence Livermore National Laboratory
Dr Eric Eisenstadt, US Defense Advanced Research Projects Agency's Defense Science Office
Dr Homme Hellinga, Department of Biochemistry, Duke University Medical Centre
Professor Paul Kaye, Science & Technology Centre, University of Hertfordshire
Dorothea Paterno, US Army
Dr Ellen Raber, Lawrence Livermore National Laboratory
Dr Mark White, Health and Safety Executive
Professor Brendan Wren, Pathogen Molecular Biology Unit, London School of Hygiene & Tropical Medicine

Annex 3 Mathematical modelling of chemical and biological dispersions

A3.1 Introduction

Following a release of a chemical or biological agent those dealing with the incident will want to know how far and how quickly a contaminant will spread, what its maximum concentration is and where this will be. The agent will be carried by natural winds and other air flows such as those generated by traffic, further explosions or currents associated with collapsing buildings, as occurred on 11 September 2001 in New York. Increasing urbanisation, concern about sustainability and quality of life, and desire to increase preparedness for a terrorist incident have all contributed to considerable progress in mathematical modelling of this area.

Mathematical models have a number of applications at all stages of an incident. Pre-event modelling can inform strategic planning. During an incident, models are vital for defining the 'hot zone'. Post-incident models describing the distribution of an agent will inform the sampling strategy, as raised in chapter 3.4, and determine when it is appropriate to undertake a justified return.

A3.2 Recent modelling work

Dispersion depends on the meteorological conditions near to the ground and on the details of the terrain, such as whether it is flat, hilly or close to a coast, and the arrangement of the buildings at and near the release site. Dispersion depends on the separations between buildings, and the size of the buildings relative to the spaces (streets) between them. There are a number of reviews summarising recent modelling work (Hunt, Carruthers & Daish 2004, Hanna & Britter 2002, Britter & Hanna 2003). In addition, considerable work has been undertaken at dstl Porton Down on the development of the urban dispersion models.

Many research projects have been undertaken to uncover the fundamental fluid mechanical and meteorological principles involved. Most of the models have been compared reasonably successfully to wind tunnel experiments and large scale empirical observations. From these models three distinct spatial ranges that must be carefully considered have been identified: city-wide, local neighbourhood and smaller street/building scale.

This work has led to the development of very large scale computational fluid dynamics codes that make detailed predictions over the whole range of scales. Such calculations provide essential insights for informing the judgements needed on how to respond to an incident. In practice, such computational fluid dynamics calculations take many hours to complete, and are strongly dependent on the details of terrain, building layout and local meteorology. Simpler and faster models are being developed based on the results of these large calculations. These simpler models provide data in real time, which has already been usefully incorporated into prediction scenarios and emergency response systems.

This approach is consistent with requirements identified by the Government for computer modelling support in a civil emergency: planning model should deliver predictions fit for purpose, whilst operational models need to be fast. Operational models need to be able to accommodate observations and additional measurements in as close to real time as possible. dstl Porton Down has produced a number of models, including the urban dispersion model that has been developed over a ten year period through funding from MoD. This model has been validated and results from it have been used operationally on a number of different occasions in the last few years.

Very recently, there have been a number of (relatively) large field studies undertaken in urban areas, specifically with a terrorist incident in mind, in order to compare the results of the various computational fluid dynamics calculations and physical models against real observations. These have taken place in a number of US and European cities including London; and a large field experiment is currently being planned for New York. One of the important results from these studies is that the concentration of a contaminant can peak and then begin to fall within half an hour, which is typically the minimum response time for the emergency services. It is also important to note two different timescales can operate for dispersion of an agent: a shorter timescale associated with its transport outside buildings, and a longer timescale when the agent becomes trapped within a building and then acts as reservoir for slow release of the contaminant into the open air.

From the civil decision maker's perspective, any model should provide the right level of resolution, and must assist their understanding of the 'dynamics' of the total system, allowing prompt comparison of alternative responses, their effectiveness and optimisation. The fundamental need is to use computer modelling to increase resilience.

Sophisticated numerical modelling often involves complex computer programs and cannot be properly used and interpreted without considerable training. Without adequate training these models could easily be misinterpreted with dangerous consequences. Consequently, they must be managed and run by specialists, especially in any critical emergency situation. Even simpler dispersion models need to used and interpreted with care.

A3.3 Conclusions

Models are required that are as near to real time as possible, which should be tested against on-the-ground measurement of chemicals and simulates to validate and improve them. Models are needed in following four areas:

- Determining the extent of the initial contamination and potential re-dispersion.
- Predicting the dispersal of chemical plumes in built-up and open environments.
- Identifying the effectiveness of alternative cleanup strategies.
- Assessing the potential impact on the civilian population.

A3.4 References

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Hunt J C R, Carruthers D J & Daish N C (2004) *Dispersion from Accidental Releases in Urban Areas.* Report to the UK Atmospheric Dispersion Modelling Liaison Committee. Report No. ADMLC/2002/3. Cambridge Environmental Research Consultants Ltd: Cambridge

Annex 4 Scientific uncertainty, scientific advice and decision support for risk management

Summary

In the UK, official documents do not detail the issues and challenges involved in decision-making in the face of scientific uncertainty, especially in emergency situations such the deliberate release of a chemical or biological agent. Scientific uncertainty is ubiquitous and unavoidable in such circumstances, and must be fully and properly incorporated into decision support procedures. Enhanced techniques already exist for doing this but these are not widely used in governmental settings.

Expert judgement will have to be used in some form as part of the critical decision process in an emergency. For maximum benefit to the decision-maker, the pooling of expert scientific opinion should be formalised and structured, and make use of optimal scoring rule techniques.

Increasing exposure to public accountability and legal ramifications can significantly prevent such advice being given. These factors need to be considered when obtaining unbiased and high quality advice when setting up a decision support framework for responding to chemical or biological incidents.

A4.1 Background

The Royal Society initiated public discussion of many issues connected with risk in the 1980s and continued in the 1990s (Royal Society 1981 & 1992). A number of important discussion documents and position papers on the technical and scientific aspects of risk assessment and management have emerged from the Government and its agencies in the last ten years.

These documents do not detail the issues and challenges involved in decision-making in the face of scientific uncertainty, especially in an urgent emergency situation. Perhaps not surprisingly, there is virtually nothing about these concerns when dealing with a terrorist chemical or biological attack. Indeed, this particular aspect of the decision-making problem is apparently absent from international academic and technical literature, even though structures, pathways and flowcharts identifying the key decisions involved at different stages have been proposed.

The Government has dealt with public safety, risk and risk management, both generally (HM Treasury 1996 & 2002; HSE 1999) and in relation to the specific issues of nuclear power stations (HSE 1988), bovine spongiform encephalopathy (Phillips 2000), and foot and mouth (Anderson 2002). These led to the guidelines provided by the Office of Science and Technology (OST 2001) for scientific advisory committees.

A4.2 Scientific uncertainty

The whole subject of scientific opinion and uncertainty and the relationship to decision-making is very topical, receiving increasing attention in many areas. A recent UK technical report on climate change (UKCIP 2003) provides a wide-ranging and useful review of many of the approaches, techniques and problems. This review includes the various forms that scientific uncertainty takes and different ways to determine, quantify and express scientific uncertainty.

Scientific uncertainty is a complex subject and the understanding of it is still evolving. Research in the cognitive and psychological sciences has shown that individuals are not good estimators of probabilities or what confidence limits should be attached to uncertain data.

The use of science in emergency situations differs from its more usual role in one crucial respect: in an emergency scientists might have to make immediate recommendations that affect public safety. The traditional scientific approach involves making observations, conducting experiments, and developing explanatory models. Consequently, the usual response to significant scientific uncertainty is to undertake further research to reduce it. Progress is dependent on many factors and often takes a considerable amount of time. This means scientists might be viewed as being ill-equipped to deal with urgent crisis situations, especially when these have a very strong political component.

The available scientific data for responding to a crisis will inevitably be incomplete, insufficient and uncertain. For decision support it is vital that the available information can be used most logically and effectively for assessing and stating hazard or risk levels. The application of certain elementary principles for the rational treatment of uncertainty helps, especially where responsibility for advice might rest mainly on the subjective judgment of a few scientists, or even with a single scientist. The basic principles are common to decision-making in many key walks of life, including the law and medicine. Evidence based medicine (eg Sackett et al 2000) is a recent concept for the formalised integration of best research evidence with clinical expertise and patient values in medical practice. Similar principles apply to the use of forensic science in the courtroom (eg Robertson & Vignaux 1995), although there have been difficulties in using this approach in the UK (Balding 1996). The principles are logical rather than mathematical and should be accessible to the whole spectrum of scientific expertise. The basic principles involved are in an emerging speciality with the over-arching title of evidence science (Aitken 1995; Jeffreys 1961).

There are many sources of information available on the subject of scientific uncertainty, the ways it can be handled in different circumstances, and the myriad issues to confront. Best practice is a product of supporting any critical assessment process that is used in response to that threat. Exploring and adopting the best available techniques for appraising uncertain scientific evidence should be a priority for decision support in this context.

A4.3 Scientific advice as a component of decision-making

The assessment of risks in 'low-probability/high-consequence' events is a decision-making process that will inevitably involve expert judgement. The relative importance of expert judgement, compared with expert knowledge based on hard data, would vary from case to case, according to the quality and quantity of the available information. In situations where there will always be numerous uncertainties, it is particularly important to formalise the use of expert judgement to the maximum possible extent.

As in early studies of the formalised use of expert judgement (eg in earthquake studies in the eastern US), judgements might be combined analytically through the practice of weighting the probability distributions assigned by individual experts. A number of algorithms exist for combining such judgements (varying from simple averaging, through self-weighting, to scoring experts according to performance on test calibration questions). Alternatively, collective judgements might be formed into a consensus through discussion. It is this latter, decision-conferencing, approach (informed, where appropriate, by other studies) that has generally been adopted in traditional government for resolving questions on scientific issues where decisions have to be made in the face of uncertainty.

Where a broad spread of expertise in synergistic disciplines is involved, the decision-conferencing approach to the use of expert judgement provides one framework to tackle complex issues in a comprehensive and coherent manner. Individual specialists interrogated singly might find difficulty, if not reluctance, in expressing informed judgement on technical issues in different fields of scientific endeavour, even if all are relevant to the subject at issue. Effectively, the adoption of the decision-conferencing approach is an expression of support for the principle of collective expert judgement; the benefits of this approach might be manifest in narrower confidence limits on scientific estimates than would be obtained by approaches which assign equal ('democratic') weight to the opinions of individuals, irrespective of the scientific worth and validity of their opinions. The main drawback to the decision-conferencing approach is one that is recognisable with committees of all kinds: the potential for one or more individual members to manipulate the agenda, discussion or outcome of deliberations conducted under committee rules.

An alternative formulation to decision-conferencing for a group of experts is to use a procedure based on mathematical scoring rules, to arrive at what can be described as a 'rational consensus', where account is taken of the fact that not all experts are equally well-informed or informative in their judgements. A methodology has been developed for doing this numerically (Cooke 1991), which represents a significant improvement on previous opinion pooling schemes.

Cooke (1991) has laid down five central principles as essential for sanctioning the use of this expert judgement scheme in quantitative risk analysis and related decision-making. These principles echo the basic tenets of the scientific method, and can be summarised as follows:

(1) *Reproducibility.* The scientific basis for the analysis must be fully specified and the input data and other information used must be made explicit for scientific peers to review and reproduce.

(2) *Accountability.* The source of an expert opinion must be ultimately identifiable, if required. Accountability implies that every subjective probability or statement of belief can be traced through documentation back to the individual supplying it.

(3) *Neutrality.* The method for evaluating expert opinions should encourage experts to state their true opinions.

(4) *Fairness.* All experts are treated equally at the outset, with analysis of specific technical expertise providing the rational basis for preferring one opinion above another.

(5) *Empirical control.* Wherever possible, a methodology for using expert opinion must incorporate some form of empirical control, to permit evaluation of performance on the basis of known or possible observations. Without such empirical control, it might be argued that one subjective probability is as good as another.

Neutrality might appear trite, but is of paramount importance for deriving the best possible scientific advice in the face of uncertainty, and is one that is commonly violated in practical risk assessment applications. It is well known that group biases, peer pressure or media exposure can exert significant influences on the way many people express their views in public, on committees or in other open fora, and that their true opinions might be moderated or compromised in consequence. These influences can be minimised by sharing all sources of information and data amongst the group, and then obtaining the views of each individual expert privately by an independent facilitator.

The outcome of this fully-structured approach is a rational combination of the collective views of the group by weighted pooling, the results provided being sometimes referred to as those of a 'synthetic decision-maker'. (As such, these rarely reproduce the exact view of any individual contributor.)

Extensive quantitative empirical trials with many differing sets of experts in many fields have found that a group view, synthesised in this way, almost invariably converges towards the correct or known result in the face of otherwise widely scattered individual opinions. While this is a reassuring and important quality, the other invaluable attribute of this approach is that it also quantifies the spread of scientific uncertainty that exists amongst the expert group.

The collective views of any expert group can be acquired in a formalised, auditable and defensible manner, promoting the true expression of their scientific opinion in a procedure which, while not offering relief from their responsibility as scientists, can insulate them from some of the pressures and consequences associated with direct, individual attribution. This approach gives scientists some protection against personalisation in difficult issues or difficult situations, which should be an important encouragement to participate in decision support activities, especially in the growing 'blame culture' and increasing litigiousness of modern society.

A4.4 Conclusions

The way scientific advice and uncertainty are handled within Government might not have changed significantly, but progress has been made in some other areas such as climate change.

At all stages of dealing with detection and decontamination problems arising from a chemical or biological incident, technical doubts and scientific uncertainties will crop up. Important assumptions will have to be made, whether these are in respect of the identification of an agent, for instance, or the setting of levels justifying a return to use or occupation. The following topics can be singled out and prioritised for investment of effort:

- Investigating, modifying and adopting the best available techniques for appraising uncertain scientific evidence for decision support.

- Extending this approach to include a fully structured, formalised procedure for eliciting expert opinion in the same context.

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