The Problem of Chemical and Biological Warfare

Volume II

CB Weapons Today

SIPRI

Stockholm International Peace Research Institute

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SIPRI

Stockholm International
Peace Research Institute

SIPRI is an independent institute for research into problems of peace and conflict, with particular attention to the problems of disarmament and arms regulation. It was established in 1966 to commemorate Sweden's 150 years of unbroken peace.

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Contents of the Study

Volume I. The Rise of CB Weapons

A description of the main lines of development in the technology underlying CBW and in the constraints affecting use of CB weapons. The period covered is approximately 1914–1945, although more recent developments in CW technology are also described. In addition, the volume includes an account of all instances known to SIPRI when CB weapons have been used in war, or when their use has been alleged; in this case the time-span is 1914–1970.

Volume II. CB Weapons Today

A description of the present state of CBW technology and of national CBW programmes and policies. It also includes a discussion of the attractions and liabilities of CB weapons, and of the consequences, intentional or unintentional, that might follow their use.

Volume III. CBW and the Law of War

A description of the legal limitations on use of CB weapons. It comprises discussions of the field of application of the Geneva Protocol, particularly as regards non-lethal chemical weapons and anti-plant agents, of the existence, development and scope of the prohibition of CBW provided by the customary law of war, and of the application to CBW of general principles of the law of war. It also reviews the juristic works in this field.

Volume IV. CBW Disarmament Negotiations, 1920–1970

A review of the activities of the League of Nations and United Nations in extending and reinforcing the prohibitions concerning CB weapons, including a report of recent negotiations for international CB disarmament. The volume also contains an account of those instances when formal complaints of the use of CB weapons have been made to the two world organizations.

Volume V. The Prevention of CBW

A discussion of possible measures that might be adopted to prevent future CBW. The volume describes steps that might be taken to strengthen the legal prohibition of CBW, and the problems and possibilities, including those of verification, involved in the negotiation of CB disarmament.

Volume VI. Technical Aspects of Early Warning and Verification

A technical account of SIPRI research on methods of early warning and identification of biological warfare agents, together with a description of two experimental SIPRI

projects on CB verification. The first project concerns the non-production of BW agents and involved visits to biological laboratories in several countries; the second concerns the non-production of organophosphorus CW agents and summarizes the results of a symposium.

The birth of this study of chemical and biological warfare can be traced back to 1964, when a group of microbiologists who were concerned about the problems of biological warfare started meeting under the auspices of Pugwash. After some meetings it became evident that there was need for more intense study than could be achieved through occasional gatherings of people who were busy with other work. In 1966-67 SIPRI, which was then starting up, decided to take on the task of making a major review of biological warfare. The study was soon extended to cover chemical warfare as well.

The aim of the study is to provide a comprehensive survey of all aspects of chemical and biological warfare and of the problems of outlawing it more effectively. It is hoped that the study will be of value to politicians, their advisers, disarmament negotiators, scientists and to laymen who are interested in the problem.

The authors of the report have come from a number of disciplines-microbiology, chemistry, economics, international law, medicine, physics and sociology and soldiery-and from many countries. It would be too much to claim that all the authors had come to share one precisely defined set of values in their approach to the problem. Some came to the problem because they were concerned that the advance of science in their field should not be twisted to military uses; others because they had taken a scholarly interest in the law or history of CBW; others because they had particular experience of military or technical aspects of it. What is true is that, after working together for a period of years, they have all come to share a sober concern about the potential dangers of CBW.

At an early stage it was necessary to face the question whether, if we assembled a lot of information on CBW and published all that we thought was relevant, we would risk contributing dangerously to the proliferation of these weapons. This proposition was rejected on the grounds that the service we could do by improving the level of public discussion was greater than any disservice we might do by transmitting dangerous knowledge. Secrecy in a field like this serves mostly to keep the public in ignorance. Governments find things out for themselves.

While the study has been in progress there has been much discussion of the subject. A group of experts appointed by the Secretary-General of the

United Nations has produced a report on *Chemical and Bacteriological (Biological) Weapons and the Effects of their Possible Use.* In the United States a rising tide of concern about CBW has given rise to Congressional hearings; a policy review, commissioned by the President, has led to the unilateral renunciation by the United States Government of biological weapons and to the decision to renounce first use of chemical weapons and to seek ratification of the Geneva Protocol. At the United Nations and at the Disarmament Conference in Geneva, CBW has received a lot of attention. A convention prohibiting the development, production and stockpiling of biological and toxin weapons has been concluded. Negotiations over a chemical disarmament treaty continue.

In response to an invitation from the UN Secretary-General, early drafts of parts of this study were circulated to his group of experts in February 1969. These drafts were also made available to the World Health Organization for the preparation of its own submission to the UN group of experts; this submission, together with the subsequent WHO publication based upon it, *Health Aspects of Chemical and Biological Weapons,* was prepared by a group of consultants that included Julian Perry Robinson from SIPRI.

The authors are conscious of the problem of avoiding biases. A disproportionate part of the information we have used comes from the United States. This is partly because the United States has been very active in the field of chemical and biological warfare in the post-war period. It is also because the United States is much more open with information than most other countries.

Since this is a team work and since, like most studies of this size, it grew and changed shape and changed hands in some degree as it went along, it is not easy to attribute responsibility for its preparation. The authorship of each part is indicated at the start of it, but these attributions do not convey the whole story. The team of people who produced the study met together often, shared material, exchanged ideas, reviewed each others' drafts in greater or lesser degree, and so on. So it is a corporate product, and those who wrote the final drafts sometimes had the benefit of working papers, earlier drafts, ideas or material provided by others.

At first, Rolf Björnerstedt was briefly in charge of the study. After an interval, Carl-Göran Hedén took over. When he had to return to the Karolinska Institute—from which he has continued to give us his advice and help—Robert Neild assumed responsibility for the project. The other members of the team have been Anders Boserup, who from the earliest stages has found time to come frequently from Copenhagen to help on the project, Jozef Goldblat, Sven Hirdman, Milton Leitenberg, Åke Ljunggren, Theodor Nemec, Julian Perry Robinson and Hans von Schreeb.

The work on rapid detection of the use of biological warfare agents (Volume VI) was undertaken separately from the main study by Konstantin Sinyak, who came from the Soviet Union to work at the Karolinska Institute in Stockholm, and Åke Ljunggren, who went from Sweden to work at the Microbiological Institute in Prague. Both worked in close contact with Carl-Göran Hedén who contributed a study on automation. We are indebted to the two host institutes for the facilities and help they generously provided.

Felicity Roos and Connie Wall acted as editors for this volume of the study, and undertook the formidable task of preparing the comprehensive bibliography. The index was prepared by Tom Perlmutter.

A great debt is also owed to many people outside the institute—too many to name—for the help they have given us. This includes those who attended the early Pugwash meetings on biological warfare, those who attended meetings at SIPRI on biological and chemical warfare, those who wrote working papers for us, those who gave their time to the biological inspection experiment and many people who have visited us or helped us with advice and material at different times. It includes people from many countries, East and West, and many disciplines. It includes people with many different kinds of expertise. The amount of help they gave us—and it was far greater than we had expected at the start—was clearly an expression of their concern about the problem. We are grateful to them all. The responsibility for what is said is, of course, ours.

December 1972

Frank Barnaby
Director

ATTRIBUTION

This volume was written by Julian Perry Robinson with the assistance of Carl-Göran Hedén and Hans von Schreeb.

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Introduction

Volume I of this study closed with a discussion of the military significance of chemical and biological warfare (CBW) at the time of World War II. Because CB weapons were not employed on any significant scale during that war, it seemed reasonable to ask whether the attention that continued to be given them subsequently was not a passing aberration—a phenomenon determined more by the momentum of past events or by institutional conservatism than by contemporary military requirements. Since CBW had seemingly become obsolete by the 1940s, what significance did it have within the very different military environment of the 1970s? What priorities did it merit in a world menaced by nuclear warfare?

It is to these questions that the present volume is mainly addressed. CBW has continued to play a minor role in the conduct of military operations over the past thirty years. However, as a result of discoveries made during the 1940s and early 1950s, weapons of greatly increased destructiveness and military utility have now emerged. It is still not entirely clear how well these fulfill military requirements, but it seems indisputable that they are substantially more adaptable to contemporary military theory and practice than were their predecessors of World War II. For this reason alone, CBW remains a serious cause for concern.

The volume comprises four main chapters, and has seven appendices associated with it. The first chapter is a description of present-day CB weapons, of their modes of action, and of the countermeasures available against them. The second chapter describes how CB weapons differ in operation and military effects from other categories of weapon, how they might be employed in different forms of warfare, and what their overall value might be to different types of country. The third chapter is a review of national CBW policies and programmes around the world. The final chapter is concerned with the future status of CBW, describing CBW-related research and development activities and possibilities, and discussing them in relation to the objectives and priorities of CB disarmament negotiations. The appendices are to appear as separate *SIPRI Research Reports.*

We cannot say with confidence that the overall picture presented in this volume is complete, even in outline. The information available to us on the various matters discussed is often sparse and uneven. Moreover, on

the technical and military sides, the major part of our information has come from the United States, so that there is a risk that we may have adopted an unduly American perspective on the subject. We have been conscious of these problems, and have done what we can to cope with them.

The issue of secrecy obtrudes strongly upon any discussion of CBW. As in most military matters, governments tend to keep secret the details of their technical programmes, contingency planning and general preparedness for CBW. The usual reason given is that if secrecy were not maintained, potential enemies might stand to benefit. Whether necessary or not, secrecy cannot fail to impede disarmament negotiations. In the CBW area, an abnormal degree of technical sophistication is required of the negotiators and policy-makers involved, and, perhaps at least as important, of their critics. It is for this reason that the present volume extends as fully as it does into technical and other detail. In countries where there is a long-standing familiarity with CBW matters, much of this may appear unnecessary and superficial; but for other countries, as the world moves further towards CB disarmament, we hope that our attempt to dissipate some of the secrecy will serve a useful purpose.

A difficult dilemma has confronted us in this task. In collecting together and publishing material necessary for a clear understanding of the problems of CB disarmament, might we not in fact be compromising our objective by disseminating information that could promote proliferation of CB weapons? Elsewhere we have argued that the service we could do by improving the level of public discussion would be greater than any disservice in transmitting dangerous knowledge. As far as hard facts go, there is rather little in the present volume that has not been openly published before, in one place or another. The available information is scattered throughout a great many different types of publication, as a glance at the bibliography will indicate—technical, scientific and military journals, patent specifications, press and committee reports, parliamentary debates, service manuals, and so on. For people not familiar with this type of literature, the information it contains on CBW is difficult and laborious to assimilate. What we have done is to bring a proportion of it together into one place. The view that we are at the same time assisting potential CB weapons-users ignores the fact that such people are as capable as we are of uncovering the information they need, probably a good deal more so, given our limited resources. If anything, our study indicates the extent to which information about CB weapons has already become disseminated around the world and available for nefarious activities.

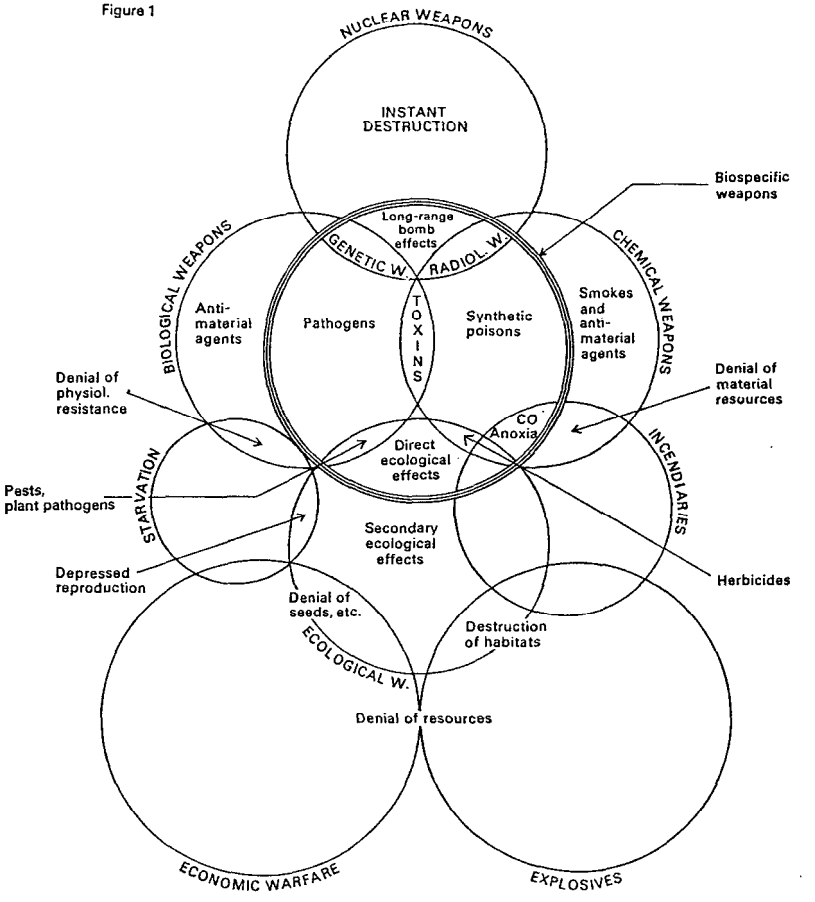
As the previous volume of this study will have shown, "CBW" is a term that covers many different techniques of fighting. Its scope is large,

for poisons and "germs"—the agents of CBW—could find applications throughout the entire spectrum of conflict, from the global war at one end, to the sabotage or terrorist activities of dissident groups at the other. The same applies to most other methods of combat, however, and it may be asked why it is any more useful to make a special category of CBW—to study one particular technique of warfare in isolation from the many other techniques alongside which it might be used—than it is to generalize about "bullet warfare", say, or "explosive warfare".

The fact that it is common practice to do so within military manuals is a better reason than appears at first sight. The combat potential of CBW agents has never aroused much enthusiasm in high military circles. Interest has centred on explosives, projectiles and other means of physical destruction, leaving CBW outside the mainstream of military theory and practice. CB weapons have thus become isolated into a special category where an array of moral and legal proscriptions that is unique among armaments has become associated with them, and which conserves their isolation. They are sometimes grouped together with nuclear weapons on the grounds of their mass-destruction capabilities, even though some types of CB weapon clearly do not have such a capability. The feature which the two categories also have in common is their unorthodoxy, and the singular attitudes of fear, odium and abhorrence that they can arouse. It is argued in Volume V of this study that one of the basic considerations in CB disarmament negotiations must be to sustain this character of unconventionality, to perpetuate the isolation of CBW from accepted military theory and practice, and to reject any measures that might weaken this. Once the inhibitions about CBW are lowered, its potentialities could attract a greatly increased investment of military effort and prestige.

In general terms, the range of activities that can be described as "CBW" is clear enough: the use of poisons or microbes to damage an enemy in war. It is difficult to be more precise, though, for complications arise whose complexity depends on the requirements made of the definition. What precisely is a "poison", for example: is it something that kills or something that merely debilitates? All substances are harmful to living organisms in large enough quantities. This is the case, for example, with chemicals—such as smoke-screening agents—which are used for military purposes but which are not normally regarded as CW agents. Is the poisoning of enemy crops an act of CBW? Most people would probably regard it as such, but what about less specific damage to an enemy's biosphere, and where is the borderline to be drawn between CBW and other forms of environmental pollution? Here one may note the present concern in Sweden about possible damage to agriculture sustained from air-pollutants

Figure 1



drifting over from neighbouring countries in Europe.[1] It is not difficult to conceive of accusations of CBW being made in connection with other such situations, whether they are real or imagined, particularly if current pollution problems continue to increase at their present rate. Neither is it difficult to envisage the governments of neighbouring countries that are in intense economic competition with one another not being over-scrupulous about controlling the discharge of industrial wastes into the air-streams or river waters that cross their common border. Pesticide employment could

[1] Sweden. Ministry of Foreign Affairs and Ministry of Agriculture. *Air pollution across national boundaries. The impact on the environment of sulfur in air and precipitation.* Sweden's case study for the United Nations Conference on the Human Environment. Stockholm, 1971.

pose similar problems. Myxomatosis virus, to take an extreme example, was employed as a biological control agent in a small area of France in 1952 to check the rabbit population; the disease subsequently decimated the rabbit population throughout most of Europe, including animals bred for meat and furs.

These complexities are illustrated further in figure 1. This diagram takes as its point of reference the property of *biospecificity* that is displayed by nearly all categories of CB weapon—the capacity of CB weapons, that is to say, for damaging human, animal or plant life with relatively little concomitant damage to inanimate objects. Because this property is the most characteristic feature of CB weapons, it holds out particular promise for purposes of definition. However, biospecificity is largely a matter of degree; most other categories of weapon or techniques of warfare can also affect vital functions directly, although other effects usually preponderate. It is when the effects of these weapons overlap with those of "biospecific weapons" that definition becomes difficult.

The need for precise definitions arises mainly in connection with possible disputes about the scope of international law concerning CBW and in the delimitation of CB disarmament proposals. For the present, we continue with the somewhat loose set of definitions used in Volume I. These encompass "tear gases" and chemical herbicides within the category of CW agents alongside the traditional "poison gases", but exclude chemical smoke and incendiary agents. The distinction between CW and BW, where it is made, is the distinction between poisoning and disease, between toxic agents and infective agents.

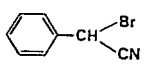
Square-bracketted numerals in the text are literature citations. They are identified in the list of references beginning on page 333.

STRUCTURAL FORMULAE OF SOME OF THE CHEMICALS REFERRED TO IN THE TEXT

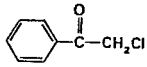
Nerve gases

Structural formulae for selected nerve gases and related organophosphate and carbamate anticholinesterase agents are given in table 1.4, pages 54–58.

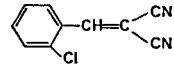
Irritant agents



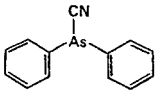
α-Bromobenzyl cyanide



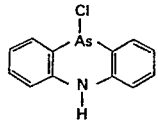
ω-Chloroacetophenone (CN)



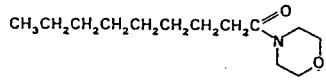
2-Chlorobenzalmalononitrile (CS)



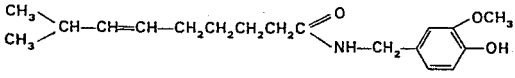
Diphenylcyanoarsine (DC)



Adamsite (DM)

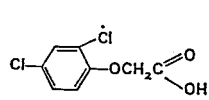


Pelargonic morpholide

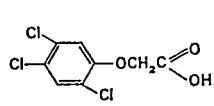


Capsaicin

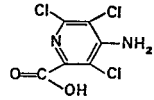
Herbicides



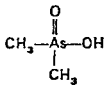
2,4-D



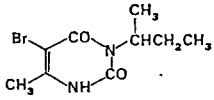
2,4,5-T



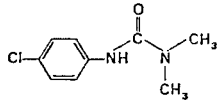
Picloram



Cacodylic acid

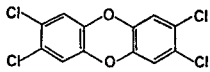


Bromacil

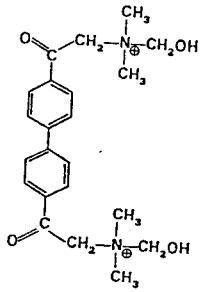


Monuron

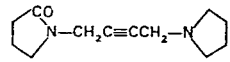
Candidate casualty agent are related compounds (see Chapter 4)



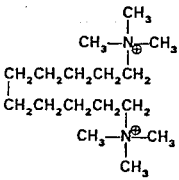
Dioxin



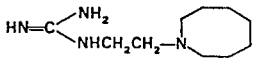
HC-3



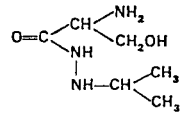
Oxotremorine



Decamethonium



Guanethidine



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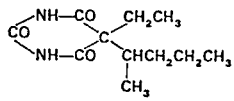
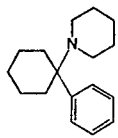
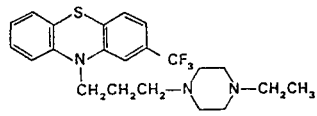


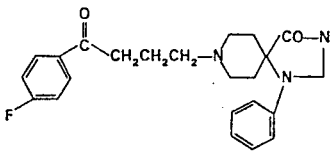
Pentobarbital



Phencyclidine



Fluphenazine



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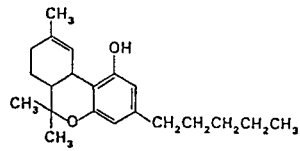
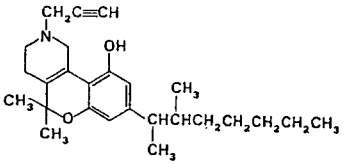


Δ1-Tetrahydrocannabinol



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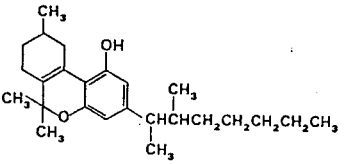

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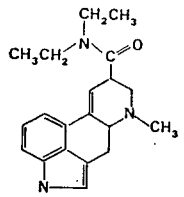
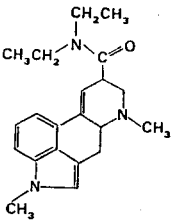
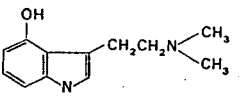


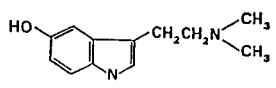
LSD



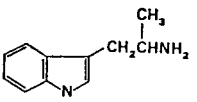
MLD



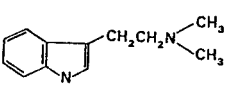
Psilocin



Bufotenine



α-Methytryptamine



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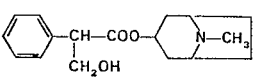
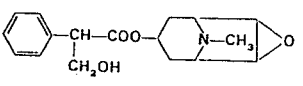
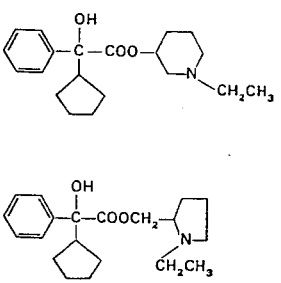


Atropine



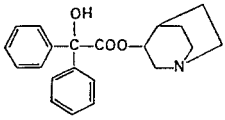
Scopolamine



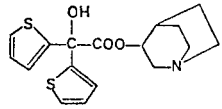
30 percent

70 percent

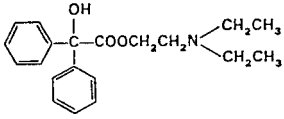
Ditran



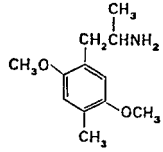
3-Quinuclidinyl benzilate (BZ)



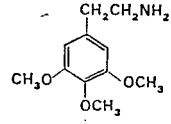
3-Quinuclidinyl 2′,2′-thenilate



Benactyzine

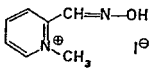


STP

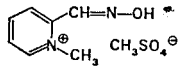


Mescaline

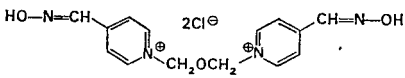
Some oximes used in the treatment of nerve-gas poisoning



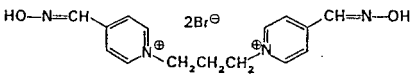
Pralidoxime iodide (2-PAM)



Pralidoxime methosulphate (P2S)



Obidoxime (LüH-6 or *Toxogonin*)



TMB-4

Chapter 1. Modern CB weapons and the defences against them

CB weapons, the implements of CBW, are the means whereby toxic or infective agents can be used to harm an enemy, his animals or his plants. There are many different types. Some are designed for the mass-destruction of life over wide areas, and others only for localized effects. Some are intended to kill, others to disable temporarily. Some can be used by the individual, while others require the concerted action of aircraft or missile crews. It is to be noted, however, that the range of CB weapons that has been developed does not necessarily coincide with the range that has aroused significant military interest. There are many instances in weapon technology where the designers' enthusiasm for a new weapon has far exceeded that of its potential users, and CBW technology is certainly no exception.

In this chapter we describe the main features of present-day CB weapons and the principal forms of protection that have been developed against them. Volume I of this study provides a historical background.[1]

I. *Modern CB weapons*

A CB weapon has two principal components: a payload of CBW agent, and a munition for getting it to the target. The military utility of the weapon will largely be determined by the former, but the latter will determine its military effectiveness. The munition has both to convey the agent safely to the target and to distribute it in such a way that the agent makes sufficient contact with the people, animals or plants that comprise the target to poison or infect them.

Broadly speaking, there are four ways in which toxic or infective agents may be introduced into an organism, and CB weapons have been designed that exploit each of them. First, the agent may enter the organism via the natural intake of water or nutrients. Plants may be damaged after absorbing chemical agent from contaminated soil. People or animals may

[1] *The Problem of Chemical and Biological Warfare.* Volume I. *The Rise of CB Weapons* (Stockholm: SIPRI, 1971), pp. 25–124.

be poisoned or infected after consuming contaminated water or food. For the latter purposes, the CB weapon might consist of no more than a small phial of highly potent agent that could be emptied into food-processing or water-treatment equipment by a saboteur. The range of applications of this type of weapon is, of course, limited. Much the same is true of the second means of penetration by an agent, that of direct injection. CB weapons of this type—agent-coated bullets, darts or flechettes, for example —are essentially assassins' weapons, although development programmes have been conducted in the past with the aim of adapting them, and such things as contaminated shrapnel or fragmentation weapons, to regular combat use. A flesh-wound from a contaminated projectile may be fatal. Direct injection is also the means used in biological weapons based on living disease-vectors: here the agent is carried in the body of an infected insect (or some other arthropod) capable of transmitting the disease when feeding on human or animal subjects. In this case, the weapon comprises a container for delivering the vectors, infected mosquitoes perhaps, to the target area, and then releasing them over it. The employment of such vector weapon-systems is known in the United States as "entomological warfare" [1].

Of much wider utility in CBW are weapons that disseminate the agent in a form suited for inhalation, or for contact with the surfaces of the organisms under attack. Many toxic chemicals and microbial pathogens can invade through the lungs. Their effects may then manifest themselves in the respiratory tract, or elsewhere in the body following absorption into the blood. Plant pathogens, but few human or animal ones, and many toxic chemicals can also invade through surface tissue, that of skin or eyes or leaves. CB weapons in this category—aircraft spray tanks, for example—broadcast their agent payload over the target area (bulk dissemination); they are the CB weapons that have the greatest range of military applications.

Bulk dissemination depends greatly on weather and other local conditions for maximum effectiveness. Winds and other forms of atmospheric turbulence may have a profound influence on many (but not all) types of CBW operation. With favourable weather, an attacker may be able to contaminate the air over large areas with CBW agent; under unfavourable conditions the agent may become dissipated too rapidly to be effective, or may fail to reach its target. In the early forms of CW practised during World War I, clouds of windborne poison were discharged at the enemy from compressed-gas cylinders, but the wind sometimes changed during the attack, blowing the gas back on to the attacker. Use of this method, known as the "drifting-cloud" or *off-target* technique, declined in favour of *on-target* attacks, in which the gas was projected in containers that released

their contents directly over the target area. Weather conditions are better understood now, and therefore more predictable than they were during World War I, so that off-target attacks may be no less likely in future CBW than on-target attacks. They are particularly suited to surprise or clandestine operations, for the approach of windborne CBW agent may remain unnoticed until too late.

For a CB weapon to be suited to off-target attack, it must disseminate its payload in a form that can remain airborne for adequate periods of downwind travel. The rate of fall-out of the agent from the cloud must therefore be small. This will be the case if the agent can be disseminated as vapour. It will also be the case with very small droplets or particles of the agent. The smaller a particle, the more slowly it falls through the air, and to all intents and purposes particles that are smaller than 5 or 10 microns (a micron is a thousandth of a millimetre) in diameter behave like vapour. Such suspensions are known as *aerosols*;[2] fogs and smokes are familiar examples of dense (i.e., visible) aerosols. A CB weapon suitable for offset attacks must disseminate a high proportion of its payload as vapour or as aerosol.

Particles or droplets that are small enough to travel long distances downwind do not impact readily on surfaces in their path. Instead they tend to be carried over the surfaces on air-current streamlines. For this reason, aerosolized CBW agents (as opposed to coarse sprays or mists) will penetrate an organism in appreciable quantities only if inhaled; they cannot create a significant contact hazard, for example, to a man's skin. Generally speaking, then, the respiratory hazard created by an off-target CBW attack is likely to be much more serious than the percutaneous hazard.

On-target attacks do not rely so heavily on cloud transport, so that significant contact effects may be possible, as well as inhalation effects. To achieve the former the agent must be disseminated as relatively large liquid droplets, at least 70 microns or so in diameter. But droplets of this size are too large to enter the lungs in significant quantities, so that smaller particles or vapour must also be present if there are to be inhalation effects (unless the agent is one that can penetrate the lining of the upper respiratory tract). Particles do not generally get so far down the respiratory tract as the lungs if they are larger than about 5 microns in diameter, but if they are smaller than about 1 micron they tend to be swept out again on exhalation. CB weapon designers have to take these size ranges carefully into account.

[2] Although "aerosol" is now a familiar—and much abused—term, it was originally coined by a British CW specialist during World War I to describe the agent smoke produced by a particular kind of chemical weapon [2].

Because on-target attacks do not rely so heavily on cloud transport, their effectiveness is much less dependent on the prevailing weather conditions than that of off-target attacks. In cases where contact effects are the primary objective, it may be feasible for the attacker to disregard the weather altogether. However, even though the weapons he would be using would be designed to disseminate their payloads in rather large droplets, a certain proportion will invariably appear as aerosol or vapour, and this will drift with the wind.

A good deal of energy has to be applied to a payload of CBW agent in order to break it up and disseminate it over a target. The agent must be capable of withstanding this without degradation, i.e, without losing activity. This limits the number of candidate CBW agents that are suited to bulk dissemination. Other limits are imposed by the possibility of the agent becoming degraded in the atmosphere. Common air pollutants, for example, and also the ultraviolet wavelengths of sunlight, can act as powerful disinfectants for many microbial pathogens. Likewise, many toxic chemicals are rapidly destroyed by oxygen or moisture. Thus, while there are many thousands of substances toxic or infective enough for CBW purposes, few of them can meet the stability requirements of bulk dissemination.

Dosage is another factor that complicates bulk dissemination. A CBW agent will not harm an organism until a certain minimum dose has been taken up from the applied dosage. Agents vary in potency, some being effective in much smaller doses than others. In addition, different species, and different members of the same species, may vary greatly in their susceptibility to an agent. Whatever the effective dose, time must elapse before it is taken up by the organism, i.e., before a sufficient quantity of the agent has penetrated the lungs or surface tissue. Thus, an agent that is disseminated as aerosol or vapour will not have any effect if the cloud is swept away too fast by air currents. Broadly speaking, the dose of agent inhaled from a cloud is directly proportional to the time of exposure and to the concentration of agent in the cloud: if the concentration is low, the agent must be present over the target area for a longer time than if the concentration is high.

For respiratory-effect agents, it is convenient to express the effective dose in terms of the product of exposure time and agent concentration, the so-called "Haber product" or *Ct-dosage.* However, as the actual dose of agent absorbed from a given Ct-dosage depends on such factors as the particle size of the agent and the breathing rate of the subject,[3] this is

[3] A man at rest breathes air at a rate of about 10 litres per minute, but if he is strenuously exercising himself, his breathing-rate may rise to 70 l/minute or more.

not at all a precise specification, nor one for which different experimenters are likely to reproduce identical values. Furthermore, because of the intra-species variations in susceptibility mentioned above, it is not possible to specify a reproducible "minimum effective dose" for a given agent in a given species. Instead it is necessary to define the dose or dosage that has a specified probability of producing a particular effect—the dose that will produce the effect in a specified percentage of the challenged population. Fifty per cent probabilities are commonly used: the term *ECt50*, for example, indicates the Ct-dosage having a 50 per cent probability of effect. Where the effect is death, the term *LCt50* is used: an LCt50 dosage is one that is likely to kill half the population exposed to it. Likewise, the *ED50* and the *LD50* are the absorbed doses of agent that have a 50–50 chance of effect or of lethality. Where the effect is militarily-significant incapacitation, the ED50 and ECt50 become the *ID50* and *ICt50*.

For some agents, less than twice the dosage may increase the casualty rate from 5 to 50 per cent (or from 50 to 95 per cent), but for others, a factor of a hundred or more may be involved. In other words, the difference between a dose having a negligible chance of effect and one having a virtually certain chance may vary among different agents between a factor of less than ten and a factor of more than ten thousand. This may have great importance in CBW. The concentration of agent in a cloud will generally be larger near the centre than at the periphery. If the aim is to cause a large number of casualties over a small area with a given weight of agent, an agent with a small ECt95/ECt5 ratio will be preferred; but if a lower overall casualty rate over a larger area is the objective, a large-ratio agent would be more suitable, even though both agents might have the same ECt50. Most infective agents have very large ratios; but toxic agents generally have small ones, particularly if the ED50 is very small.

The Ct-dosage concept is important to CB weapons employment, imprecise though it may be scientifically. If an attacker knows how long his enemy is likely to remain exposed to an agent—before being able to protect himself, for example, or before being able to leave the contaminated area—he can calculate how high an agent-concentration must be used, and therefore how many weapons are needed. Should he be able to reckon on a 5-minute exposure time, say, up to ten times fewer weapons would be needed than for a half-minute exposure time. CW doctrines

When running, a man may thus absorb seven times more agent from a given Ct-dosage than if he were standing still. Where effective-dose estimates of CBW agents are given in this chapter in terms of Ct-dosages, a state of mild activity is assumed (corresponding to a breathing rate of 10–20 l/min.).

distinguish between *surprise dosage* and *total dosage* attacks. In the former, the agent is disseminated over the target in sufficiently large quantity for the concentration to be high enough for effective doses to be inhaled within one or two breaths of air. In the total dosage attack, only enough agent is used to ensure that by the time the cloud has dispersed or moved away from the target area—tens of minutes, or perhaps more—the accumulated Ct-dosage will have reached effective levels. The former maximizes surprise; the latter minimizes weapons expenditure.

These dosage considerations apply both to the respiratory and to the contact effects of an agent. However, because surface tissue is a more effective barrier than lung tissue, the percutaneous ED50 of an agent is usually larger than the respiratory ED50 (so is the oral ED50). Although an ED50 may in some cases be absorbed through the skin from an airborne agent concentration, the latter must generally be far too high to be militarily feasible. For this reason, the significant variable in questions of percutaneous dosage is not the airborne concentration of agent but the mass actually impinging on the skin. The absorbed percutaneous dose depends primarily on the size and number of droplets striking the skin and the length of time for which they remain in contact with it. The basic requirement is that the agent should not evaporate faster than it can penetrate the tissue. Likewise there may be enough time for the victim to remove the droplets before an effective dose is absorbed from them.

CBW agents

For a chemical or a biological material to be attractive as a CBW agent, it must have other properties than an intense toxicity or virulence. It must be stable enough to retain its potency during storage, during dissemination and in contact with environmental chemicals. It must be easy to produce in large quantities, preferably from indigenous materials. The uses envisaged for it may demand a particular type of toxicity or pathogenicity, or volatility or lability. Thus, while many hundreds of thousands of toxic chemicals and pathogens have been examined as candidate CBW agents, very few have seemed satisfactory.

Table 1.1 lists all the toxic agents that are known either to have been used in wars during the twentieth century, or stockpiled for such use. It also includes a few agents which, although not definitely known to have been stockpiled, are known to have been seriously considered for possible standardization or procurement in recent years; other such agents are described in chapter 4.

The agents listed are grouped into broad categories according to their

Table 1.1. Toxic chemicals that have been developed into CW agents[a]

Chemical name	Common name[c]	Remarks
Antipersonnel agents		
Physiochemicals: sensory irritants		
Ethyl bromoacetate	EBA	Minor WWI lachrymator, sometimes used in civilian tear-gas weapons
Ethyl iodoacetate		Major WWI lachrymator
Chloromethyl chloroformate		Minor WWI lachrymators used in admixture
Dichloromethyl chloroformate		
Chloroacetone		Minor WWI lachrymator
Bromoacetone	*BA*	The lachrymator most heavily used during WWI
Bromomethylethyl ketone		Major WWI lachrymator, sometimes used in civilian tear-gas weapons
Iodo-acetone		Minor WWI lachrymator
Acrolein		Minor WWI lachrymator
N-ethylcarbazole		Minor WWI agent
Xylyl bromide		Major WWI lachrymators, generally used in admixture
Xylylene bromide		
Benzyl bromide		
Benzyl iodide		Minor WWI lachrymators used in admixture
Benzyl chloride		
o-Nitrobenzyl chloride		Minor WWI lachrymator
α-Bromobenzyl cyanide	BBC (*CA*)	Major WWI lachrymator, stockpiled during WWII
ω-Chloroacetophenone	CAP (*CN*)	Post-WWI lachrymator, stockpiled in WWII, widely used in civilian tear-gas weapons
o-Dianisidine chlorosulphonate		Minor WWI sternutator
Diphenylchloroarsine	*DA*	WWI sternutator, stockpiled during WWII
Diphenylcyanoarsine	*DC*	WWI sternutator, stockpiled and used (in China) during WWII
10-Chloro-5,10-dihydrophenarsazine	Adamsite (*DM*)	Post-WWI sternutator, stockpiled during WWII, sometimes used in police weapons
Phenyldibromoarsine		Minor WWI agent
N-(4-hydroxy-3-methoxybenzyl)-8-methylnon-*trans*-6-enamide	Capsaicin	Occasionally used since WWI in civilian tear-gas weapons
Pelargonic morpholide		Post-WWII developmental algogen
2-Chlorobenzalmalononitrile	*CS*	Post-WWII respiratory algogen, heavily used in Viet-Nam War and by police forces
Dichloroformoxime	Phosgene oxime (*CX*)	A nettle gas apparently stockpiled during WWII
Non-irritant physiochemicals		
Staphylococcal enterotoxin B	*PG*	A toxin stockpiled since WWII
Psychochemicals		
3-Quinuclidinyl benzilate	*BZ*	Stockpiled today
Lung irritants		
Chlorine	*Cl*	Extensively used during WWI, generally in admixture with phosgene
Bromine		Minor WWI agent sometimes used with chlorine
Methyl chlorosulphonate		Minor WWI agent
Ethyl chlorosulphonate		Minor WWI agent
Phenylcarbylamine chloride		Minor WWI agent

Table 1.1. Continued

Chemical name	Common name[c]	Remarks
Bis(chloromethyl) ether		Minor WWI agent
Bis(bromomethyl) ether		Minor WWI agent
Trichloronitromethane	Chloropicrin (*PS*)	Major WWI agent, stockpiled during WWII generally in lachrymatory compositions
Perchloromethyl mercaptan		Minor WWI agent
Thiocarbonyl chloride	Thiophosgene	Minor WWI agent
Carbonyl chloride	Phosgene (*CG*)	Major WWI agent, heavily stockpiled during WWII[b]
Trichloromethyl chloroformate	Diphosgene (*DP*)	Major WWI agent, stockpiled during WWII
Hexachlorodimethyl oxalate	Triphosgene	Post-WWI developmental agent
Cadmium oxide		Developmental WWII agent, studied in connection with incendiary bombs
Blood gases		
Hydrogen sulphide		Minor WWI agent
Methyl cyanoformate		Minor WWI agents used in admixture
Ethyl cyanoformate		
Cyanogen bromide		
Cyanogen chloride	*CK*	Minor WWI agent
Hydrogen cyanide	Prussic acid (*AC*)	Minor WWI agent, stockpiled during WWII
Arsine	*SA*	WWI agent, stockpiled during WWII
		Developmental WWII agent; known as *Mithrite* in France
Vesicants		
Dimethyl sulphate		Minor WWI agent
Phenyldichloroarsine	*PD*	WWI agent, stockpiled during WWII as mustard-gas additive
Methyldichloroarsine	*MD*	Said to have been used during WWI
Ethyldichloroarsine	*ED*	WWI agent
Ethyldibromoarsine		Minor WWI agent used as mustard-gas additive
2-Chlorovinyldichloroarsine	Lewisite (*L*)	Stockpiled during WWII, and used by Japanese in China in admixture with mustard gas
Bis(2-chloroethyl) sulphide	Mustard gas (*H*)	Major WWI agent, heavily stockpiled during WWII[b]
1,2-*Bis*(2-chloroethylthio)ethane	Sesquimustard (*Q*)	Developmental WWII agent: the most potent vesicant known
Bis(2-chloroethylthioethyl) ether	*T*	Stockpiled during WWII as mustard-gas additive
Bis(2-chloroethyl)ethylamine	*HN-1*	Stockpiled during WWII on small scale
Bis(2-chloroethyl)methylamine	*HN-2*	Stockpiled during WWII on small scale
Tris(2-chloroethyl)amine	Nitrogen mustard (*HN-3*)	Stockpiled during WWII
Nerve gases		
Ethyl NN-dimethylphosphoramidocyanidate	Tabun (*GA*)	Large amounts manufactured during WWII
iso-Propyl methylphosphonofluoridate	Sarin (*GB*)	Heavily stockpiled today
1,2,2-Trimethylpropyl methylphosphonofluoridate	Soman (*GD*)	Allegedly stockpiled today
Ethyl S-2-di*iso*propylaminoethyl methylphosphonothiolate	*VX*	Heavily stockpiled today

Table 1.1. Continued

Chemical name	Common namec	Remarks
Lethal toxins		
Botulinal toxin A	***X***	Stockpiled after WWII
Ricin	***W***	Developmental WWII agent; about 1700 kg produced in the USA
Saxitoxin (Shellfish poison)	***TZ***	Stockpiled in small quantities since WWII
Antiplant agents		
2,4-Dichlorophenoxyacetic acid	2,4-D	Used as defoliants and herbicides in Viet-Nam War, generally in admixture with one another
2,4,%Trichlorophenoxyacetic acid	2,4,5-T	
4-Amino-3,5,6-trichloropicolinic acid	Picloram	
Dimethylarsinic acid	Cacodylic acid	Used against rice and other crops in Viet-Nam War
5-Bromo-3-sec-butyl-6-methyluracil	Bromacil	Staudardized military soil sterilant
3-(p-Chlorophenyl)-l,l-dimethylurea	Monuron	Standardized military soil sterilant

Notes:
[a] That is to say, toxic chemicals that have either been used or stockpiled for use as CW agents, or which have been closely studied as candidate CW agents.
[b] Also said to have been used during the Italo-Ethiopian War and the Yemeni Civil War.
[c] The italicized entries are the US Army symbols.

toxic effects. In chapter 2 below, another classification is given in which the agents are grouped according to their military functions; anticipating this, it may be noted here that the "sensory irritants" of table 1.1 are all *harassing agents,* a category that encompasses police-type "riot-control agents", while, apart from the "antiplant agents", the other substances listed are all *casualty agents.* Among the latter, the "psychochemicals" and the "non-irritant physiochemicals" are *incapacitating agents,* so called because the casualties they cause are likely to be predominantly nonfatal. The characteristics of the categories in table 1.1 are as follows.

The chemicals are first grouped into *antipersonnel agents* and *anti-plant agents.* No chemicals are known to have been developed specifically as *anti-animal agents,* although many antipersonnel agents are also harmful to animals, and might possibly be used as such, for example, against draught animals such as horses or mules.

Among the antipersonnel agents, the physiochemicals are capable of producing temporary disablement in people exposed to them. They are unlikely to kill, except when used in dosages much higher than necessary to cause disablement. They include the *sensory irritants* which disable for little longer than the period of exposure; their effects are due to the reflex response of the body to the intense sensory irritation which they cause.

Some produce severe pain; these are called *algogens.* Some mainly irritate the eyes, provoking eye-closure and profuse secretions of tears: these are known as *lachrymators* or "tear gases". Some mainly irritate the inner surface of the nose and upper respiratory tract, provoking fits of violent sneezing and coughing: these are known as *sternutators* and some of them are called "vomiting agents", either because of the violent vomiting they can induce secondary to coughing, or because of their irritant effects on the stomach. Some can irritate the skin, causing strong itching or stinging sensations: these are known as *orticants,* or some of them more expressively as "nettle gases". Most of the irritants listed in the table can produce more than one of these different effects.

The *non-irritant physiochemicals* disable for longer periods than the sensory irritants, having a central rather than a peripheral action on the body. Their actions may resemble in a more intense form certain of the adverse side-effects of therapeutic and other drugs—fainting fits, vomiting, convulsions, paralysis, etc.—and some of them were first encountered in this context. So far, there seem to be very few of them that fulfil conceivable military requirements.

Related to the centrally-acting physiochemicals, and in some cases overlapping with them, are the *psychochemicals.* These are drugs that cause temporary mental disturbances (e.g., depression and tranquilization, mania, amnesia and hallucinations) which can profoundly affect behaviour. Again, there seem to be few chemicals in this category that could adequately fulfil military requirements.

The other antipersonnel chemicals in table 1.1 are intended to cause serious injury or death. The *lung irritants* or "choking agents" do this by irritating and damaging lung tissue, thereby impeding oxygen uptake from inhaled air, and asphyxiating their victims. The *blood gases* interfere with cell respiration; after entering the blood circulation through the lungs, they are thought to block the mechanisms that control the exchanges of oxygen and carbon dioxide between blood and tissue. The *vesicants* or "blister agents" are general tissue irritants than can burn or blister the skin; if inhaled, they act as lung irritants. The *nerve gases* interfere with the transmission of nerve impulses in various sectors of the nervous system; this can disrupt several vital bodily processes, including breathing. The *lethal toxins* include intensely active naturally occurring poisons that can kill in a variety of ways.

The antiplant agents listed in table 1.1 are not divided into categories, even though the uses that have so far been made of them in war call for three quite distinct types of action on plants. It is not only the chemical agent that determines whether these actions occur; they also depend on

the mode of application and the species of plant under attack. First, there is defoliation, where the objective is not necessarily to kill the plants but only to remove their foliage. This may be secured in some types of plant (woody or deciduous ones) by chemical interference with the mechanisms that normally bring about seasonal leaf-falls. In plants that do not shed their leaves, it may be secured by a chemical treatment that causes the leaves to dry out, thus becoming shrivelled and brittle, and easily detached by wind or rain. Chemicals in the former category are known as *defoliants*; in the latter, as *desiccants*. Second, there is herbicidal activity, in which the plant is poisoned to death. Many different chemicals can act as *herbicides*, including defoliants and dessicants. Third, there is the action of *soil sterilants*, in which the growth or regrowth of plants is prevented or retarded by chemical treatment of the soil in which they might grow.

Apart from their enormous potency on a weight-for-weight basis, pathogens are less likely to make attractive CBW agents than are toxic materials. Being living organisms, pathogens are more sensitive to the stresses of dissemination and of exposure to the atmosphere. Only rarely are they hardy enough to withstand prolonged periods of bulk storage, although since rather small quantities may suffice for military operations, the storage period need not be so long as for toxic agents. In addition, an infective agent must be capable of overcoming whatever natural immunity its intended target might possess.

By now, probably all known species of pathogenic micro-organism—some two hundred in all for human beings—have been examined in BW laboratories. Table 1.2 lists the species to which, judging from publications in the open scientific literature, the greatest BW interest has so far attached. The species are grouped according to their taxonomy into *viruses*, *rickettsiae*, *bacteria* and *fungi*.[4] It is conceivable, but unlikely, that other categories of micro-organism could find application in BW: the *protozoon* causing malaria is one such possibility. A BW agent classification based on military considerations is given in chapter 2.

[4] *Viruses* are the smallest living organisms known (although whether they can really be called "living organisms" is a moot point since they can only grow as parasites in the cells of other living organisms). They are too small to be seen under the normal microscope, and consist essentially of strands of nucleic acid encapsulated within sheaths of protein; some also contain lipids and carbohydrates. *Rickettsiae* are larger than viruses, but like viruses can grow only within living cells. *Bacteria*, larger than rickettsiae, do not normally need living tissue for their growth. They are single-celled organisms, ranging in size from less than 1 micron to some tens of microns in their largest dimension. *Fungi* are single- or multicelled plant-like organisms, with cells ranging from 3 to 50 microns in size.

Table 1.2. Pathogenic micro-organisms studied as potential BW agents

Name of disease	Causative agent	Death rate in untreated cases of natural disease (*per cent*)
Antipersonnel agents		
Viruses		
Influenza		*0–1*
Psittacosis	*Chlamydia psittaci*	*10–100*
Russian spring-summer encephalitis	(RSSE virus)	*0–30*
Yellow fever		*4–100*
Dengue fever		*0–1*
Chikungunya		*0–1*
Venezuelan equine encephalomyelitis[a]	(VEE virus)	*0–2*
Rift Valley fever[a]	(RVF virus)	*0–1*
Rickettsiae		
Epidemic typhus	*Rickettsia prowazekii*	*10–40*
Rocky Mountain spotted fever	*Rickettsia rickettsii*	*10–30*
Q fever[a]	*Coxiella burnetii*	*1–4*
Bacteria		
Plague	*Pasteurella pestis*	*30–100*
Anthrax[a]	*Bacillus anthracis*	*95–100*
Glanders[a]	*Actinobacillus mallei*	*90–100*
Melioidosis	*Pseudomonas pseudomallei*	*95–100*
Cholera	*Vibrio comma*	*10–80*
Typhoid	*Salmonella typhosa*	*4–20*
Dysentery	*Shigella* spp.	*2–20*
Tularemia	*Francisella tularensis*	*0–60*
Brucellosis[a]	*Brucella* spp.	*2–5*
Fungi		
Coccidioidomycosis	*Coccidioides immitis*	*0–50*
Anti-animal agents[b]		
Viruses		
Foot-and-mouth disease (cattle)	(FMD virus)	*3–85*
Rinderpest, or Cattle plague		*15–95*
Vesicular stomatitis (cattle)		*15–95*
Newcastle disease (poultry)		*10–100*
Fowl plague		*90–100*
African swine fever		*95–100*
Hog cholera		*80–90*
Rickettsiae		
Heart-water, or Veldt sickness (sheep and goats)	*Rickettsia ruminantium*	*50–60*
Fungi		
Aspergillosis (poultry)	*Aspergillus fumigatus*	*50–90*
Lumpy-jaw (cattle)	*Actinomyces bovis*	*50–90*

Likely mode of dissemination	Remarks
Aerosol	
Aerosol	
Aerosol or tick vectors	
Aerosol or mosquito vectors	Standardized BW agent
Aerosol or mosquito vectors	One infected-mosquito bite can cause disease[c]
Aerosol or mosquito vectors	
Aerosol or mosquito vectors	Standardized BW agent
Aerosol or mosquito vectors	
Aerosol	
Aerosol or tick vectors	
Aerosol	Standardized BW agent
Aerosol or flea vectors	Allegedly used by Japanese in China
Aerosol	Standardized BW agent
Aerosol	3 200 inhaled bacteria may cause disease[c]
Aerosol	
Water contamination	Like *Salmonella* and *Shigella*, allegedly used by saboteurs in China and Manchuria during late 1930s
Aerosol or water- or food-contamination	100 ingested bacteria may cause disease[c]
Water- or food-contamination	Oral infectious dose is about 5 000 organisms in the case of *Sh. flexneri* 2a[d]
Aerosol	Standardized BW agent
Aerosol	1300 inhaled bacteria may cause disease[c]; *B. suis* a standardized BW agent
Aerosol	
Aerosol or water- or food-contamination	
Aerosol or water- or food-contamination	Intensively studied during World War II
Aerosol or water- or food-contamination	
Aerosol or water- or food-contamination	Intensively studied during World War II
Aerosol or water- or food-contamination	A rare infection of chickens caused by a strain of influenza virus
Aerosol or water- or food-contamination	
Aerosol or water- or food-contamination	
Aerosol or tick vectors	
Dust or food-contamination	
Food-contamination	

Table 1.2. Continued

Name of disease	Causative agent	Death rate in untreated cases of natural disease (per cent)
Antiplant agents		
Viruses		
Tobacco mosaic		
Sugar-beet curly-top		
corn stunt		
Hoja blanca (rice)		
Fiji disease (sugar cane)		
Potato yellow dwarf		
Bacteria		
Rice blight	***Xanthomonas oryzae***	
Corn blight	***Pseudomonas alboprecipitans***	
Sugar cane wilt (gumming disease)	***Xanthomonas vasculorum***	
Fungi		
Late blight of potato	***Phytophthora infestans***	
Coffee rust	***Hemileia vastatrix***	
Maize rust	***Puccinia polysora***	
Powdery mildew of cereals	***Erysiphe graminis***	
Black stem rust of cereals	**Puccinica graminis**	3-90
Rice brown-spot disease	***Helminthosporium oryzae***	
Rice blast	***Pyricularia oryzae***	50-90
stripe rust of cereals	***Puccinia glumarum***	

Notes:

[a] Might also be used as anti-animal agents: anthrax (cattle, 40-80 per cent death rate); glanders (horses, 50-100 per cent death rate); brucellosis (cattle, low mortality); VEE (horses, 30-90 per cent death rate); and RVF (sheep, 20-95 per cent death rate); the glanders agent was allegedly used for this purpose by German saboteurs during World War 1.

[b] Most of these diseases can affect several types of animal; in cases where the name of the disease does not indicate it, the most susceptible or likely animal target is noted in parentheses.

[c] According to Rothschild, J. H., *Tomorrow's weapons.* New York, 1964.

[d] Du Pont, H. L., Hornick, R. B., Libonati, J., Snyder, M. J., Formal, S. B., Study of Shigella vaccines in man. *Symposia series in immunobioiogical standardization* 15: 213-18, 1971.

It is important to note that because BW is almost completely untried in the field, there is little experience from which to rank the properties that are desirable in a BW agent, or to judge the rankings favoured by different BW theoreticians. Dangerous BW agents might therefore also exist among species not included in table 1.2. The defence authorities of one country might reject a particular pathogen from consideration as a potential BW agent, but those of another country might not do so. Moreover, for each species of potential agent there may be different strains that vary widely in aggressive properties. For example, one well-known laboratory maintains stock cultures of no less than 120 different strains of the plague agent [3]. Furthermore, as is described in chapter 4, currently

Likely mode of dissemination	Remarks
	Airborne transmission occurs naturally Vector-transmitted naturally (leafhoppers)
	Vector-transmitted naturally (leafhoppers)
	Natural wind-borne transmission observed
	Responsible for the Irish potato famine of 1845-1869 Responsible for the elimination of coffee from Ceylon in 1880s Trans-atlantic airborne transmission has been observed
Aerosol or dust	P. ***graminis trifici*** a standardized BW agent
	Standardized BW agent

developing techniques of genetic manipulation permit new strains to be bred in which certain properties can be intensified or attenuated. Strains of a particular species may be accessible that have increased virulence, storage stability, resistance to antibiotics, or some other property that is considered attractive for BW.

Properties of selected agents

The properties of representative CBW agents are described in the following pages. Table I.3 collects together quantitative information on their respective potencies.

2,4-Dichlorophenoxyacetic acid (2,4-D) and related chemicals

2,4-D is a chemical herbicide that was initially developed during secret World War II programmes in British and US military and agricultural laboratories [4-5]. Other herbicides that are now well known, such as 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), were also first developed then. In the US military programme, these substances were envisaged as poten-

Table 1.3. Estimated potencies of selected CBW agents

Toxic agents

Agent	Agent aerosolized or vapourized over target				
	To incapacitate		To kill		
	Respiratory ICt50 *mg-min/m³*	Time to effect	Percutaneous LCt50 *mg-min/m³*	Respiratory LCt50 *mg-min/m³*	Time to effect
2,4-D	n.a.	n.a.	n.a.	n.a.	n.a.
Cacodylic acid	n.a.	n.a.	n.a.	n.a.	n.a.
Agent CS	20[c]	seconds	n.a.	61 000	delayed
Agent BZ	110	1/2–4 hrs	n.a.	*200 000*	delayed
Phosgene	1 600	3–12 hrs	n.a.	3 200	3–24 hrs
Cyanogen chloride	7 000	1/2–1 hrs	n.a.	11 000	1–15 min
Hydrogen cyanide	n.a.	n.a.	n.a.	5 000	1/2–15 min
Mustard gas	200[g]	4–6 hrs	10 000	1 500	4–24 hrs
Tabun	100[h]	1–10 mins	40 000	400	10–15 min
Sarin	55	1–10 mins	12 000	100	2–15 min
Soman	25[h]	1–10 mins	10 000	70	1–15 min
Agent VX	5[h]	1–10 mins	1 000	36	4–10 min
Botulinal toxin A, crude dry[f]	n.a.	n.a.	n.a.	0.1	12–24 hrs
Shellfish poison	n.a.	n.a.	n.a.	*5*	1/4–1 hr
Staphylococcal enterotoxin B	0.5	2–4 hrs	n.a.	*200*	delayed

Infective agents

Disease	Species	Strain	Respiratory ED50 *cells/man*	Respiratory ECt50[k] *mg-min/m³*	Time to effect *days*
Tularemia	*Francisella tularensis*	Schu S4	25	0.001[l]	2–5
Anthrax	*Bacillus anthracis*	...	20 000	0.1[m]	1–4
Plague	*Pasteurella pestis*	...	3 000	...	3–4
Q fever	*Coxiella burnetii*	AD	10	0.001[n]	18–21
VEE	VEE virus	...	25[o]	0.001[p]	2–5
Rice blast	*Pyricularia oryzae*	...	n.a.	n.a.[b]	1–4

Notes:

[a] For forest defoliation.

[b] To kill rice plants: the corresponding contamination-density needed with agent preparations of *Pyricularia oryzae* conidia is about 0.1 kg/km².

[c] The harassing dosage is smaller, 1–20 mg-min/m³.

[d] CS-1 or CS-2 preparations used for terrain denial.

[e] These agents are unlikely to be used deliberately as water contaminants.

[f] From reference [1397].

[g] For eye injury.

[h] Official Swedish estimates [326]; these appear to be much the same as the US ones for the respiratory

Agent sprayed or dusted onto target			Agent used as water- or wound-contaminant	
Density of contamination needed for military effect *kg/km²*	Time to effect	Percutaneous LD50 in man *mg/man*	Parenteral LD50 *mg/man*	Oral LD50 *mg/man*
2 000[a]	1–16 weeks	n.a.	n.a.	*30 000*[e]
400[b]	2–4 days	n.a.	n.a.	*100 000*[e]
25 000[d]	seconds	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	50[f]
10 000	4–6 hrs	4 500	n.a.	*50*
2 000	1 hr	1 000	n.a.	*40*
n.a.	n.a.	1 700	n.a.	10[f]
2 000	1/2–1 hr	1 000	n.a.	*10*
100	1/2–1 hr	15	*0.3*	*5*
n.a.	n.a.	n.a.	0.00007	0.07
n.a.	n.a.	n.a.	*0.05*	0.5
n.a.	n.a.	n.a.	n.a.	n.a.

effects of nerve gases, although for the percutaneous effects they are about an order of magnitude smaller. The "F-gas" of this source is an unspecified V-agent, apparently one of rather greater toxicity than VX.

[i] From reference [77].

[j] A preparation comparable with the ones referred to on page 61 n. 21.

[k] Calculated from the figures quoted in the preceding column, assuming a respiratory challenge of agent-infested particles in the 1–5 micron diameter size range, 50 per cent retention in the respiratory tract, and a breathing rate of 10 litres of air per minute. The estimates do not take into account post-aerosolization biological decay, but they do accommodate the fact that most of the inhaled dosage will comprise organisms killed during the dissemination process, together with the harmless components of the biological-weapons payload (growth medium, etc.). The assumptions made to this effect are indicated in the footnotes below.

[l] Assuming a dry-powder preparation containing 4×10^{11} bacteria per gram, of which 95 per cent die during dissemination.

[m] Assuming a micronized-powder preparation containing 8×10^{10} spores per gram, of which 50 per cent die during dissemination.

[n] Assuming a slurry of whole-egg culture containing 2×10^{10} rickettsiae per ml, of which 90 per cent die during dissemination.

[o] The figure is reckoned to be in the range 1–100 mouse intracerebral LD50 doses (MICLD50).

[p] Assuming a wet preparation containing 2×10^{10} MICLD50/ml, of which 80 per cent are lost during dissemination.

Sources:

With the exception of the italicized entries, and where other publications are cited, the figures given are either US Army estimates [60, 589] or are taken from the text of this chapter. The italicized entries are educated guesses based on published animal or other data in cases where other estimates are not available.

tial anti-crop agents for destroying Japanese rice cultivations, and as defoliants for possible use on natural vegetation during the Pacific islands campaigns. Of these substances, 2,4,5-T was the first to be used for military purposes. It was used by the British in Malaya during the early 1950s; this is described briefly in Volume I of this study.[5] Since then, herbicides have been used on an enormous scale in the Viet-Nam War for defoliation and crop destruction.[6]

In its civilian applications—for example, as a selective herbicide for broad-leaved weeds—2,4-D is generally used as a salt in dilute oil/water emulsions, although a variety of other preparations are available commercially. In its military applications, it has usually been used in highly concentrated formulations, for example as its n-butyl ester in 1 : 1 admixture with the corresponding 2,4,5-T ester (as in the agent *Orange* used in the Viet-Nam War), or as salt in admixture with picloram—another herbicide—in a 50 per cent water solution (agent *White*). Ester formulations have the advantage that rain falling immediately after application does not reduce effectiveness. For military defoliation, typical application rates are around 20 kilograms per hectare. Heavier applications, of around 60 kg/ha, are needed if 2,4-D or 2,4,5-T are to destroy rice crops, but other chemicals have been used that are more efficient for this purpose. Cacodylic acid (the active ingredient of agent *Blue*) is one of them: it is effective at application rates of around 4 kg/ha [10].

Plant species vary widely in their response towards 2,4-D and its congeners. Some, for example rubber trees, are so susceptible that the rather small vapour concentrations given off from ester formulations may be severely damaging. Others may be completely resistant to militarily feasible dosages. When used for military defoliation, the effectiveness of the agents thus depends on the type of forest cover against which they are directed. Mangrove forests may be almost completely defoliated (and usually killed) within a week of application. More complex tropical rainforests may not show significant defoliation until after a period of several weeks or sometimes months, and the defoliation, which will never be complete, may soon be succeeded by refoliation [11].

The chemical anti-plant formulations so far used in war have a low acute toxicity for mammals. For all of them it is estimated that the lethal dose for man would be several grams [11–12]. Much less is known about

[6] See Volume I, p. 163. See also [6–8]. Some of the earliest US aircraft spray systems employed in the Viet-Nam War were renovated items from the stockpile that had been built up (but never used operationally) by the US Air Force during the latter stages of the Korean War [9].

[5] See Volume I, pp. 162–85 and 209–210.

their chronic toxicity, and accumulating evidence about chronic damage caused by 2,4,5-T, notably as regards birth defects, eventually led to its withdrawal from military use in Viet-Nam, after some 25 000 tons had been sprayed over the country. The long-term effects of chemical antiplant agents are discussed in appendix 6.

2-Chlorobenzalmalononitrile (CS)

CS is a sensory irritant that acts as a respiratory algogen. It is widely used by police forces as a "riot-control agent". Some 7 000 tons of it have also been used in Indo-China as a military harassing agent. Volume I of this study includes a brief historical account of its development, together with a description of its use in the Viet-Nam War.[7]

CS is a water-insoluble, white crystalline solid with a faint peppery smell. It is simple to manufacture. Currently available CS weapons disseminate it either as a spray of solution or as a cloud or dust of pre-ground powder, or as an aerosol generated thermally from pyrotechnic compositions. When purchasing it in bulk from US chemical manufacturers during the late 1960s, the US Army paid between $6.6 and $10.7 per kilogram, depending on formulation [13]. The formulation known as *CS1* comprises micronized CS powder mixed with a few per cent of an antiagglomerant; depending on weather conditions, it remains active for up to five days when dusted on the ground. *CS2,* which comprises CS1 treated with a silicone water-repellent, may persist for as long as 45 days [828].

Depending on dosage, the effects[8] of airborne CS may range from a slight prickling sensation in the eyes and nose to gripping pains in the chest, running nose and coughing, which in turn may lead to retching and vomiting. Stinging or burning sensations are experienced from all exposed surfaces. These effects occur almost instantly. Few people will voluntarily tolerate the symptoms produced by concentrations higher than 2 mg/m^3 for more than a minute or two, although after repeated exposures, tolerance can develop to concentrations below about 10 mg/m^3. The symptoms mostly pass within a few minutes after exposure to concentrations at these levels. Skin symptoms may sometimes be longer lasting. Particularly in humid or windy weather, skin damage may follow

[7] See Volume I, pp. 69–70, 108–109 and 185–209.

[8] For fuller accounts of the effects of CS in man, see the reports [14] of the UK Home Office Himsworth Committee, the published reports from the British Chemical Defence Establishment [16–17, 1590–1591], and from the Swedish chemical defence laboratories [18], together with the experimental studies [401–405, 1242] and review articles [400] published from the US Army laboratories at Edgewood Arsenal. There is also a substantial body of literature on the effects of CS under the combat conditions of the Viet-Nam War; some of this is cited in Volume I of this study.

heavy exposures to CS (dosages that could normally be withstood only by people wearing gas-masks), and under exceptional conditions this can lead to second-degree burns and blistering. Occasionally people who have suffered skin inflammation from CS may then become allergic to it, developing eczema-like symptoms on subsequent exposures to much smaller dosages.

The dosages of CS likely to produce long-lasting damage or death in healthy human subjects are very much larger than the harassing dosage. If deaths were to occur, they would be likely to result from lesions developed in the lungs by the irritant action of CS. The safety factor, as defined by the ratio of the estimated LCt50 to the harassing dosage,[9] is in the range 10^3–10^4, and the LCt50/LCt5 ratio is thought by British workers to be small, about two or three [34]. However, it should be noted that in one reported experiment, dosages of around 0.02 LCt50 produced significant lesions in the lungs of Rhesus monkeys [35]. Moreover, little work has yet been reported on the possibility of carcinogenicity, mutagenicity or teratogenicity due to CS.

3-Quinuclidinyl benzilate (BZ)

BZ comes within the category of psychochemicals defined above. It became a standardized US Army CW agent around 1961. It is one of a group of substances, many of them glycollate esters, sometimes known as "atropinemimetics", their action on the central and peripheral nervous systems resembling that of atropine [37]. The commercially available drug Ditran is another of them. The most potent members of the group so far described in the open literature are BZ and the 3-quinuclidinyl esters of the various phenylthienyl- and dithienyl-glycollic acids [48].[10] Patents for preparing BZ were obtained by certain US chemical manufacturers in the early 1960s [39–40]. A French drug firm has also obtained patents on the agents and on several of its congeners, claiming pharmaceutical applications [41].

Currently available BZ weapons include cluster bombs and in-line bomblet dispensers for aircraft [42–44]. These appear to incorporate small thermal aerosol-generators for disseminating the BZ. In the United States, the agent is stockpiled both in bulk and in filled weapons, but apparently only in small quantities: as regards bulk agent, the current stockage is

[9] A recent US Army estimate of the human LCt50 for mildly active subjects inhaling thermally-generated CS aerosol is 61 000 mg-min/m^3 [33].

[10] The research work that led to the discovery of BZ began in the mid-1950s in a university laboratory under contract with the US Army Chemical Corps. At a recent scientific conference, one of the workers in the original team described the most potent glycollates as being "probably too dangerous to work with"; he declined to say which particular glycollates he had in mind [38].

less than 10 tons. This was procured from the US chemical industry at a price of about $40 per kilogram [45].

The effects of BZ are those of an anticholinergic psychotomimetic drug. They follow about half an hour after exposure to BZ aerosol, and reach their peak in 4–8 hours; they may then take up to 4 days to pass. During the first 4 hours, the victim's nose, mouth and throat become parched, and his skin dry and flushed. He may vomit, and his head may ache. His vision blurs, and he becomes dizzy, confused and sedated to the point of stupor. He may stagger and stumble about, talking in a slurred voice or mumbling nonsensically, failing to respond appropriately when spoken to. During the next 4 hours, when he will be feeling highly disoriented, experiencing visual and auditory hallucinations, he may be unable to move about or react effectively to his surroundings. His memory may fade. Later, his activity returns, but for the next day or two his behaviour may remain random and unpredictable, even maniacal, only gradually returning to normal. Therapeutic drugs are available that can curtail these symptoms—physostigmine, for example—but they are dangerous poisons in their own right, requiring expert administration [37, 46].

According to data given in an East German publication [47], the ICt50 of BZ aerosol is 110 mg-min/m^3, with the ratio of ECt50 to ECt5 being about two. The publication does not cite a source for its data, and no open information of corresponding precision is available from official US or other sources. A US Department of Defense spokesman has stated that the effective respiratory dose of BZ is about 2 mg [45].

To judge from the lowest reported animal LD50 [49], the LCt50/ICt50 safety factor for BZ would be of the order of 10^3.

Effective dosages of anticholinergic glycollates can be absorbed through the skin, although they will be considerably slower acting than inhaled aerosol dosages [37]. An accidental intoxication of a chemical defence worker has been reported in which a punctured rubber glove apparently admitted enough glycollate to produce severe mental disturbance [50]. The solvent dimethylsulphoxide has been shown in human volunteers to enhance the skin penetration of an anticholinergic glycollate by a factor of at least 25 [51]. Thus, although BZ is intended primarily for inhalation effects, it may also be able to create a contact hazard as well.

BZ is not regarded as an entirely satisfactory CW agent. Like all psychochemicals, its effects on groups of people under combat conditions—as opposed to isolated individuals under controlled conditions—are poorly predictable. Experiments with LSD, for example, that were conducted at the British Chemical Defence Establishment on groups of volunteers have shown that even heavily drugged soldiers may behave in a normal fashion

alongside undrugged fellow soldiers. They have also shown that, to some extent, soldiers can overcome the effects of the drug if sufficiently motivated [52]. Battlefield motivations cannot be mimicked, and unpredictable behaviour on the part of an enemy is something that most military commanders would wish to avoid.

Phosgene

Phosgene is a lung irritant. It was one of the most widely used CW agents of World War I, and one of the most extensively stockpiled of World War II. While the arrival of the nerve gases has certainly diminished its importance (the last remaining US Army stocks of the agent were sold —at about $0.03 per kilogram—in 1969 [53]), it could still hold out military attractions where nerve gases are unavailable. It is manufactured for industrial purposes throughout the world at a rate of several hundred thousand tons per year. The allegations that phosgene was used by Egyptian forces during the Yemeni Civil War in the mid-1960s are referred to elsewhere in this study.[11]

Except in cold weather, phosgene is a colourless gas. It has a smell resembling that of new-mown hay. It is easily liquified, and may be disseminated in very high vapour concentrations by rupturing containers of the liquid with a small explosive charge. Over the years since 1915 many different types of weapon have been developed for it.

Even small dosages of inhaled phosgene have a dangerously corrosive effect on lung tissue, producing long-lasting lesions that may easily become infected [54–56]. Bronchitis and bronchopneumonia commonly succeed phosgene exposures. Lethal dosages produce only a transient irritation of the eyes and throat upon inhalation, and this may be too mild to warn the exposed person against continued inhalation. He may feel no further symptoms for anything between an hour and a day. But during this latency period, the effects of the agent are building up towards a massive lung oedema. Changes are occurring in the alveoli of the lungs that allow increasing quantities of fluid to escape from the blood-stream into the lungs, thus impeding oxygen uptake. The victim is, in effect, drowning in the plasma of his own blood. Quite suddenly, he goes into a state of collapse, his face grey, his breathing hurried, shallow and spasmodic, his chest constricted, his lungs spewing up a blood-tinged, frothy exudate, in a state of extreme weakness and fearfulness until unconsciousness and death supervene. The precise mode of action of the agent is still not clear, and, while there are palliative and supportive treatments, no antidote is available [37, 57–59].

[11] See Volume V, pp. 225–238.

The LCt50 dosage for phosgene inhalation in man is estimated to be 3 200 mg-min/m³. Less than half of this dosage is likely to disable people exposed to it after an interval of some hours [60]. Because of the volatility and high vapour density of the agent, these dosages are easily attainable in the field. In animals, the LCt50/LCt5 ratio is generally rather large [61]. The agent has no effect on or through the skin.

Cyanogen chloride and hydrogen cyanide

Cyanogen chloride and hydrogen cyanide are blood gases. Both were used to a limited extent during World War I, and both were stockpiled during World War II. As with phosgene, the nerve gases, if available, have reduced the importance of the blood gases but both agents, particularly hydrogen cyanide, are difficult to filter efficiently from air, a fact which sustains their significance as CW agents. Moreover, both substances are, like phosgene, manufactured on a massive scale for industrial purposes. Hydrogen cyanide is the more lethal of the two, but cyanogen chloride has been considered superior as a CW agent because it is less inflammable, because it has a higher vapour density, and because, unlike hydrogen cyanide, it can produce casualties in small sublethal dosages [62]. Both agents differ from phosgene in that they are rapid-acting. Hydrogen cyanide has been used frequently as the lethal agent in human execution chambers.

In warm weather, cyanogen chloride is a gas, while in cold weather it is a liquid and in very cold weather a solid. It is reasonably stable on storage if polymerization inhibitors are added, and it is easily disseminated as a gas or vapour. It has a powerful lachrymatory action even at low concentrations; this tends to mask its pungent smell. Hydrogen cyanide is normally a liquid. It vapourizes readily, lacks irritancy, and has a faint smell of bitter almond, although this may often pass unnoticed. Polymerization inhibitors are needed if it is to be stored.

Small dosages of hydrogen cyanide have little harmful effect. The human body is capable of destroying the agent rapidly [63], and in theory concentrations of up to 120 mg/m³ can be withstood indefinitely. When larger doses are absorbed than can be detoxified, symptoms may set in extremely rapidly. The principal effects of the agent seem to stem from its interference with the enzyme in red blood cells that controls transport of exhaust carbon dioxide away from respiring tissue (carbonic anhydrase), although other biochemical effects have been observed (for example, on the enzyme cytochrome oxidase). The consequences of blocked carbon-dioxide transport are grave and immediate. A man who inhales a large dose of hydrogen cyanide becomes confused and dizzy within

a few seconds. He may be unable to hold his breath because of the stimulating effect of the agent on his respiration. Great weakness and muscular incoordination occur simultaneously, and within half a minute he is unconscious and beginning to be seized with violent convulsions. Except for an occasional gasp, his breathing may cease in less than a minute, although his heart may continue to beat for several minutes. After this point the chances of survival are small, whatever medical aid is given. Treatment with thiosulphate or other substances that react with cyanide in the blood may be useful, but only if administered very soon after exposure [37, 57, 64–66].

Cyanogen chloride can produce effects very similar to those of hydrogen cyanide, for it is readily converted into cyanide after entering the blood [67]. However, it is also a powerful lung irritant, so that although the dose inhaled may be insufficient to produce the cyanide-like effects described above, it may be enough to cause severe lung damage. This may lead to an oedema similar to that caused by phosgene (see page 48), but more rapid [37, 68].

The LCt50 dosages for hydrogen cyanide and cyanogen chloride are reckoned to be about 5 000 and 11 000 mg-min/m^3, respectively [62]. These are for rather long exposures, and since both agents are rapidly detoxified in the body, the LCt50 dosages depend markedly on concentration. Thus, for hydrogen cyanide it is estimated that the LCt50 would fall to 2 000 mg-min/m^3 if agent concentrations of 200 mg/m^3 were inhaled. For cyanogen chloride, it is considered that dosages of around 7 000 mg-min/m^3 have an even chance of causing militarily significant incapacitation [60]. Dosages as high as these are easily attainable in the field if massive weapons are used to disseminate the agents. Apart from the lachrymatory effect and, at high concentrations, the skin-irritant effect of cyanogen chloride, both agents are suited only to lung attack. They can be absorbed through the skin, but only when applied in militarily impracticable amounts [62].

Bis (2-chloroethyl) sulphide (mustard gas)

The vesicant agent mustard gas used to be called "the king of war gases". It was responsible for the majority of the gas casualties of World War I, and was stockpiled in enormous quantities during World War II by all the main belligerents. It must be presumed that a fair proportion of the World War II stockages are still around, although, in the case of the United States, the currently remaining stocks, said to amount to some 25 000 tons, are about to be destroyed [165], the US Army having declared mustard gas an obsolete agent. The allegations that Egyptian forces used

mustard gas during the recent Yemeni Civil War are referred to elsewhere in this study.[12]

Mustard gas is an oily liquid that freezes at 14°C. In cold weather it does not generate much vapour, but in warm weather the vapour from mustard gas lying on the ground may be dangerous. Mustard gas is not an industrial commodity, but is not difficult to manufacture provided skilled workers are available to do it. Its production cost the US Army about $2 per kilo during World War II [69]. When made by the process that has been most extensively used in the past (see appendix 4), it is brown in colour and has a pronounced smell, like that of garlic or horse-radish. Purer products, such as those resulting from processes developed during World War II, are almost colourless and have less smell. Mustard gas is slow to dissolve in water, and droplets of it tend to float for long periods on water surfaces. It soaks readily into clothing, leather, masonry, etc. [70]. A wide range of weapons have been designed for it; these generally disseminate the agent as a spray, but more complicated aerosol-generating devices have also been developed [60, 71].

Mustard gas is a general cell poison that can severely damage any tissue with which it comes into contact. If inhaled, its action on the lungs resembles that of phosgene (see above), although because its vapour concentrations are unlikely to be high, only prolonged or repeated exposures, or aerosol inhalations, will generally lead to fatal lung oedema. The military attractions of the agent reside more in its effects on the eyes and the skin [37]. Several different formulations of the agent have been developed for different purposes. In cold weather, freezing-point depressents may be needed; other vesicant agents such as lewisite, phenyldichloroarsine and agent T have served this purpose.[13] Thickeners may be added to improve the dissemination characteristics of mustard-gas weapons, and thickened mustard, through its increased adhesiveness, presents very severe decontamination problems.

As regards effects on the eyes, hour-long exposures to vapour concentrations so low as to be practically odourless may, 4–12 hours later, cause severe eye discomfort, even temporary blindness, that may last a week or more. Such dosages do not noticeably affect the respiratory tract or the skin. Higher dosages, or small droplets of the agent in the eye, cause more severe and longer lasting eye damage. The median incapacitating dosage is about 200 mg-min/m^3 for eye effects [37, 60]. Recovery from eye injuries may be subject to later relapses, and cases are reported

[12] See Volume I, appendix 1, pp. 336–41.
[13] See Volume I, pp. 62 and 80–81.

where mustard gas has destroyed vision decades after its initial effects have worn off [72–73].

As regards its effects on the skin, mustard gas is more aggressive in hot, humid weather than in cold, dry weather. The skin damage takes at least an hour to appear, sometimes as long as several days, but generally 6–12 hours. The early effects resemble those of sunburn, later developing into second-degree burns. The affected areas itch, redden and swell, and blisters begin to form, accompanied by throbbing pains. The blisters may become large, and may take as long as 4 weeks to subside. They are thin-skinned and, if they break, the exposed surfaces may easily become infected. Hypersensitivity to mustard gas is remarkably common among people who have been exposed to it. The degree to which a man is incapacitated by mustard vesication depends on where he is burned. In the right place, a single drop of mustard gas may be enough. Mustard vapour attacks moist areas of the body most severely, the neck, armpits and genitals being particularly susceptible [37]. From US experiments on volunteers during World War II, it is believed that for incapacitating skin effects the effective dosage of airborne mustard gas will generally be around 200 mg-min/m^3 in humid weather above 25°C, rising to 1 000 mg-min/m^3 in dry weather below 15°C [71]. French estimates of the incapacitating vesicant dosages are rather higher [74].

While the majority of mustard-gas casualties are likely to be nonfatal, mustard gas can kill. Weight for weight, it is in fact more lethal than phosgene or hydrogen cyanide, although lethal dosages will rarely occur in the field unless aerosol generators are used.

Sarin, VX and other nerve gases

The early history of the nerve gases is described in Volume I of this study.[14] They are the most potent casualty agents yet developed for chemical warfare. Modern nerve-gas weapons are thought to be at least an order of magnitude more powerful than weapons based on such older agents as phosgene or mustard gas. While certain other chemicals are more toxic, none possess so aggressive a combination of toxicity, stability, ease of dissemination, rapidity of action and percutaneous effectiveness. The nerve gases represent a threat that is surpassed by no other group of CW agents.

The nerve gases are organophosphorus compounds.[15] There are two

[14] See Volume I, pp. 71–75.

[15] Very recently, however, some authorities have begun to apply the term "nerve agent" to certain other candidate CW agents which, although not organophosphorus compounds, have a similar action on the human nervous system [75]. See note 17 below. Prior to World War II the term "nerve gas" was occasionally applied to such candidate CW agents as tetraethyl lead.

principal groups of them: the "G-agents", which are esters either of the NN-dialkylphosphoramidocyanidic acids, such as *tabun*, or of the alkylphosphonofluoridic acids, such as *sarin* and *soman*; and the "V-agents" which are esters of S-2-dialkylaminoethyl alkylphosphonothiolic acids, such as *edemo* and *VX*. The large-scale manufacture of nerve gases requires sophisticated chemical technology, as is described in appendix 4. They are liquids that lack irritancy and all but the faintest smell. Under normal weather conditions, sarin evaporates readily, being about as volatile as kerosene, but liquid VX, comparable with engine oil, generates very little vapour. Table 1.4 gives details of the chemical structure and toxicities of some of the better known nerve gases; it also includes information on a number of related chemicals of great toxicity that appear to be candidate CW agents.

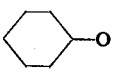
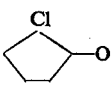
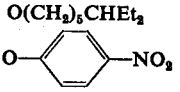
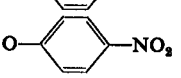
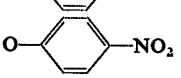
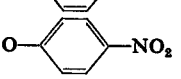
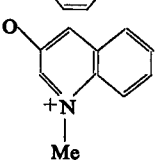
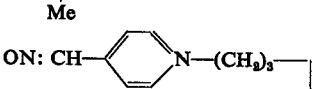
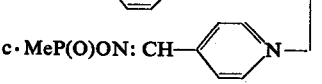
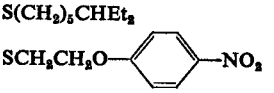
There are several dozen nerve gases that seem suited to chemical warfare. Sarin and VX are the two that the US Army, for instance, has chosen to stockpile, its current stocks being measurable in tens of thousands of tons. The production costs were about $3 per kilogram for sarin (during 1954–1956) and $5 per kilogram for VX (during 1961–1967) [45]. US nerve-gas weapons include artillery shells, rockets for multiple rocket launchers, spray tanks, bombs and bomblet weapons for aircraft, and tactical missile warheads [42–45, 60]. According to some Western officials,[16] the nerve gases which the Soviet Union has stockpiled are tabun, soman and a substance code-named *VR-55*.

The nerve gases inhibit cholinesterase enzymes, and thus come within the category of "anticholinesterase agents".[17] Although they affect several different enzymes, their principal effects on the body follow from their action on the acetylcholinesterase contained in body tissue. This enzyme is responsible for destroying acetylcholine after it has performed its function of transmitting nerve impulses within certain parts of the nervous system, or between nerve endings and various organs of the body, including muscles. Inhibition of tissue acetylcholinesterase can thus block nerve function and cause accumulation of acetylcholine. The enzyme is vital to the body but it is present in the tissue only in minute amounts; because the nerve gases combine with relatively few other substances that occur in the body, minute amounts of them may therefore be lethal. The V-agents have an even greater acetylcholinesterase specificity than the G-agents, and because there are fewer nonessential blood or tissue compo-

[16] For further details, see pp. 175–177 below.

[17] Certain other anticholinesterase agents which are not organophosphorus compounds are candidate CW agents, and are occasionally referred to as "nerve agents". Examples include several intensely toxic aromatic carbamates. For information on these, see Volume I, p. 65 and tables 1.4 and 4.2 below.

Table 1.4. Anticholinesterase activity and toxicity of selected organophosphates and carbamates

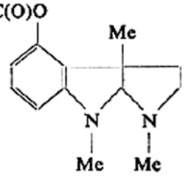
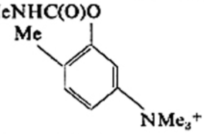
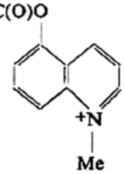
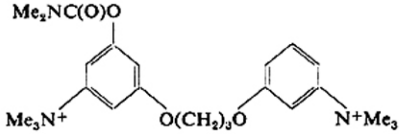
Chemical structure					Potency as an inhibitor of acetylcholinesterase[a]	
Organophosphates (General formula: a—P(=b)(—c)—d)					Assay conditions (T°C, pH, *t* mins)	I pI_{50}[b]
Substituents				Common name[f]		
a	b	c	d			
^{i}PrO	O	^{i}PrO	F	DFP, dyflos, *PF–3*[d]	25, 8, 30	6.6
Me	O	^{i}PrO	F	sarin, *GB*[e]	25, 8, 30	8.9
Me	O	$Me_3C \cdot CH(Me)O$	F	soman, *GD*[e]	25, 8, 30	9.2
Me	O		F	*GF*	25, 7.7[g]	*10.1*
Me	O		F			..
Me	S	$Me_3C \cdot CH(Me)O$	F	thiosoman	25, 7.7[g]	*8.9*
Et	O	^{i}PrO	F	ethylsarin, *GE*	n.s.	8.1
Me	O	$Me_3N^+ \cdot CH_2CH_2CH_2O$	F	MFPhCh	25, 7.5	11.0
EtO	O	Me_2N	F	fluorotabun		..
EtO	O	Me_2N	CN	tabun, *GA*[e]	25, 8, 30	8.6
^{i}PrO	O	Me_2N	CN		25, 7.5	8.9
^{i}PrO	O	^{i}PrO	N_3		25, 7.7[g]	*6.8*
EtO	O	EtO	$O(CH_2)_5CHEt_2$		38, 7.4, 10[g]	6.3
^{n}AmO	O	^{n}AmO			25, 7.7[g]	*7.9*
EtO	S	EtO		parathion[f]	n.s.	4.9
Et	O	EtO		armin[d]	25, 7.7[g]	*7.9*
Me	O	^{t}BuO			25, 7.7[g]	*9.6*
EtO	O	EtO		Ro 3–0422	37, 7.4, 20	9.4
Me	O	^{i}PrO		[k]	25, 7.4[h]	*10.3*
Me	O	$Me_3C \cdot CH(Me)O$		[k]	25, 7.5[g]	*12.6*
EtO	O	EtO	$OP(O)(OEt)_2$	TEPP	25, 7.5	7.5
EtO	O	EtO	$SP(O)(OEt)_2$			..
EtO	O	EtO	$S(CH_2)_5CHEt_2$		38, 7.4, 10[g]	6.8
Me	O	EtO			25, 7.5[g]	*7.4*

Lethality in laboratory animals (acute LD50 values in $\mu g/kg^c$)					
II	III	IV	V	VI	
mice		rats	rabbits		
ip	*sc*	*iv*	*iv*	other	Authorities
4 000	4 000	(1 200)	340	..	I [1398] II [1399] III [918] IV [1400] V [1401]
590	200	63	17	33 (gp, *im*)	I [1398] II [1378] III [979] IV, V [1365] VI [1385]
620	160	50	..	75 (m, *iv*)	I [1398] II [1378] III [979] IV [1402] VI [1589]
..	400	..	..	..	I [1403] III [1388]
..	..	..	..	42 (gp, *im*)	VI [1385]
..	..	..	..	..	I [1403]
690	400	..	..	..	I, II [1399] III [1404]
50	..	..	6	..	I [1405] II, V [1406]
2 500	..	..	..	..	II [1399]
600	270	(110)	63	150 (m, *iv*)	I [1398] II [1004] III [979] IV [1400] V [1407] VI [1404]
460	..	..	..	..	I, II [1004]
..	..	..	..	..	I [1403]
27 400	..	..	..	..	I, II [1408]
..	..	..	..	..	I [1403]
10 000	16 200	3 200	..	..	I [77] II [1409] III [918] IV [1410]
..	360	..	..	390 (m, *iv*)	I [1403] III [979] VI [504]
..	..	..	..	..	I [1403]
..	40	..	..	24 (m, *iv*)	I [1411] III [966] VI [1412]
..	..	..	..	..	I [1413]
..	..	..	..	..	I [492]
740	500	..	100	400 (gp, *im*)	I [1414] II [1405] III [918] V [1401] VI [1385]
..	55	..	..	..	III [1415]
4 500	..	..	..	..	I, II [1408]
..	..	..	..	..	I [491]

Table 1.4. Continued

Chemical structure: *Organophosphates* (General formula: a—P(=b)(—c)—d) Substituents					Potency as an inhibitor of acetylcholinesterase[a]	
a	b	c	d	Common name[i]	Assay conditions (T°C, pH, *t* mins)	I pI_{50}[b]
EtO	O	EtO	SCH_2CH_2SEt	isosystox	37, n.s., 30[f]	5.5
Me	O	EtO	SCH_2CH_2SEt	Gd–7	40, 7[g]	*5.6*
EtO	O	EtO	$SCH_2CH_2S^+(Et)Me$		37, n.s., 30[f]	8.3
Me	O	EtO	$SCH_2CH_2S^+(Et)Me$	Gd–42	40, 7[g]	*9.2*
EtO	O	EtO	$SCH_2CH_2S^+(Et)CH_2CH_2SEt$		37, n.s., 30[f]	9.3
EtO	O	EtO	$SCH_2CH_2NMe_2$	217AO	25, 8	7.9
Me	O	EtO	$SCH_2CH_2NMe_2$	medemo	25, 8	8.8
Me	O	^iPrO	$SCH_2CH_2NMe_2$	37SN	25, 8	8.1
EtO	O	EtO	$SCH_2CH_2NEt_2$	amiton, *VG*	37.5, 7.4, 30	7.9
Me	O	EtO	$SCH_2CH_2NEt_2$	edemo, *VM*	25, 8, 30[f]	9.5
Et	O	EtO	$SCH_2CH_2NEt_2$	918SN, *VE*	25, 8, 120	9.2
Me	O	HO	$SCH_2CH_2NEt_2$	S27		..
Et	O	HO	$SCH_2CH_2NEt_2$	921SN	25, 8, 120	7.4
Et	O	EtO	$SCH_2CH_2N^iPr_2$	*VS*		..
Me	O	EtO	$SCH_2CH_2N^iPr_2$	*VX*[e]		..
EtO	O	EtO	$SCH_2CH_2NMe_3^+$	phospholine[d]	25, 8	8.4
Me	O	EtO	$SCH_2CH_2NMe_3^+$	33SN+	25, 8	9.1
Me	O	EtO	$SCH_2CH_2NPhMe_2^+$			..
EtO	O	EtO	$SeCH_2CH_2NEt_2$	seleno–amiton	n.s.	8.2
Et	O	EtO	$SeCH_2CH_2NEt_2$		n.s.	9–9.7

Carbamates

Chemical structure	Common name	Assay conditions	pI_{50}
MeNHC(O)O 	physostigmine	25, 8, 30[f]	7.2
MeNHC(O)O 	TL 1236		..
$Me_2NC(O)O$ 	DCMQ		..
$Me_2NC(O)O$ 	3152 CT	25, 7.4, 120	8.8

Lethality in laboratory animals
(acute LD50 values in $\mu g/kg^{c}$)

II	III	IV	V	VI	
mice		rats	rabbits		
ip	*sc*	*iv*	*iv*	other	Authorities
5 600	6 000	2 040	..	..	I, IV [1416] II, III [1399]
..	450	..	..	..	I [1417] III [979]
..	..	16	..	..	I [1416] IV [1418]
..	31	..	..	..	I [1417] III [979]
..	..	5	..	..	I, IV [1416]
530	..	..	..	..	I [1005] II [1419]
50	25	..	..	..	I [1005] II [1420] III [979]
270	..	(130)	50	..	I [1005] II, V [1420] IV [1400]
500	235	..	..	..	I [1421] II [1399] III [979]
..	22	..	..	..	I [1422] III [977]
..	..	..	..	..	I [1398]
..	..	(13)	..	..	IV [1400]
..	..	..	..	..	I [1398]
..	..	..	..	..	..
..	..	..	..	5–10 (s, *iv*)	VI [1423]
140	500	..	..	..	I [1005] II [1420] III [1424]
26	..	..	10	..	I [1005] II, V [1420]
..	53	..	..	..	III [978]
..	60	..	..	..	I, III [1425]
..	21	..	..	..	I, III [1425]
800	370	..	..	470 (m, *iv*)	I [1422] II [1426] III [1427] VI [1401]
88	64	..	..	35 (m, *iv*)	II, III, VI [1427]
..	..	..	..	40 (m, *iv*)	VI [1401]
..	..	..	5	..	I [1428] V [1429]

nents that retain them, they are more toxic on a weight-for-weight basis. This becomes most apparent in their ferocious percutaneous toxicity.

The body readily absorbs nerve gas through the lungs, the skin, the eyes or the membranes of the nose, throat and digestive system. Very small dosages may affect nerve function only within the area with which the nerve gas comes into contact, but larger dosages will penetrate to the blood circulation, thereafter producing a great variety of effects throughout the body. If death ensues, it is likely to be caused by acute oxygen deprivation following paralysis of the respiratory muscles or inhibition of the central respiratory centres.[18]

The nerve gases act extremely rapidly. A few breaths of a strong vapour or aerosol concentration may kill in less than a minute. Liquid nerve gas splashed on the skin may kill after 15 minutes. Smaller dosages will take longer to kill, although they may very swiftly disable a man. Liquid nerve

[18] Soman, which is the most poisonous of the G-agents, apparently owes its great toxicity to the ease with which it can penetrate the blood-brain barrier into the central nervous system; this may be explicable in terms of its greater liposolubility compared with, say, sarin. V-agents, such as medemo, do not penetrate the blood-brain barrier to the same extent as soman [76].

Key:

.. information not available
n.s. not specified
( ) estimated
m mice
s sheep
gp guinea pigs
ip intraperitoneal
sc subcutaneous
iv intravenous
im intramuscular
} denote routes of administration

Notes:

[a] Assayed against human erythrocyte cholinesterase, unless otherwise indicated.
[b] The larger the value, the more potent is the agent. The pI_{50} is the molar concentration of the agent required to produce 50% inhibition of the enzyme, expressed as the negative logarithm to the base ten (i.e., $pI_{50} = \log_{10}(1/I_{50})$, where I_{50} is in $mole^{-1}$). Italicized entries denote pI_{50} values calculated from reported bimolecular inhibition rate constants (k_2), assuming an incubation time of 30 minutes (i.e., $pI_{50} = \log_{10} 43k_2$, where k_2 is in litres min^{-1} $mole^{-1}$). For a discussion of the propriety of this, see R. D. O'Brien, *Toxic Phosphorus Esters* (New York, 1960), p. 78.
[c] The smaller the value, the more toxic is the agent.
[d] Used medicinally.
[e] Chemical warfare agent.
[f] Used as a pesticide.
[g] Bovine erythrocyte cholinesterase.
[h] Electric eel cholinesterase.
[i] Sheep erythrocyte cholinesterase.
[j] Human brain cholinesterase.
[k] These substances, which *in vitro* appear to be the most powerful anticholinesterase agents known, are the reaction products of methylphosphonate esters with the nerve-gas therapeutic agent, TMB-4.
[l] Italicized entries are the US Army symbols.

gas can soak rapidly through clothing, the G-agents generally faster than the V-agents (so much so that although VX is the more potent percutaneous agent in contact with bare skin, soman may be the more potent against clothed skin). The initial effects of moderate exposure to nerve-gas vapour or aerosol are a feeling of tightness in the chest with difficulty in breathing, a sudden running of the nose, pain in the eyes and a dimming of the vision. These build up in intensity and are accompanied by salivation, nausea, sweating, belching, heartburn, diarrhoea, vomiting, involuntary urination and defaecation, muscular twitching and giddiness. The muscles become increasingly weak, those of the chest becoming unable to draw enough air into the increasingly congested lungs. Paralysis may ensue, quickly followed by collapse, convulsions and death.[19]

If the drug atropine is injected immediately, some of the symptoms may be reduced, and while the drug can do nothing on its own to sustain breathing, it can increase the effectiveness of artificial respiration. Oxime-type drugs may be helpful in keeping respiration going, at least in the case of sarin and the V-agents (but not in the case of soman). Self-aid atropine and atropine/oxime treatments have been developed, but under battlefield conditions they are unlikely to save people who have received much more than a bare LD50 dose.

For sarin, it is estimated that the LCt50 dosage for mildly active men is about 100 mg-min/m^3 for 30-second or 2-minute exposures, rising to 155 mg-min/m^3 for 10-minute exposures. The LCt50/LCt5 ratio is believed to be less than two. The median incapacitating dosage is estimated at 55 mg-min/m^3, although dosages as low as 15 mg-min/m^3 may be militarily significant under some conditions [84–85]. A dosage of 1 700 mg of liquid sarin may be enough to kill a man through his skin [60]. VX is reckoned to be about three times as potent a respiratory agent as sarin, but about a hundred times as potent as a percutaneous agent [74]. The permeability to VX of the skin of different areas of the body varies considerably: that of the arms, for example, is more resistant than that of the soles of the feet, while that of the face and neck is far less resistant.

Botulinal toxins

The toxins produced by *Clostridium botulinum* bacteria are considerably more poisonous than the nerve gases. They are the causative agents of the type of food poisoning known as "botulism". They have long been

[19] Fuller descriptions of nerve-gas poisoning are available in many places [77–83], notably the manual entitled *Treatment of Chemical Agent Casualties* (January 1968 edition, pp. 13–22), published by the US Departments of the Army, the Navy and the Air Force [37].

studied as potential warfare agents, and a brief account of early work in this connection is given earlier in this study.[20]

Six distinct types of botulinal toxin are known, but the one known as "type A" seems to have attracted the most military interest. Relatively straightforward culture and harvesting techniques have been developed that permit large-scale production of this toxin [86–93]. In Sweden it has been calculated that, on the basis of cultivation-medium requirements, the toxin would cost about $400 per kilogram to make [94]. In pure form botulinal toxin type A is a white crystalline substance that readily dissolves in water when finely powdered, and attracts moisture from damp air [91]. It is a simple protein, apparently comprising a single polypeptide chain. It is less stable than staphylococcal enterotoxin (see below), being readily detoxified by heat, by mechanical stress and by oxygen [91, 95]. It can be stored in a dry powdered state for long periods without losing much activity, particularly if protein impurities are present, provided air and moisture are excluded [91, 96]. Water contaminated with it may remain highly toxic for several days [97].

Field trials have been conducted in which clouds of the toxin have been released over lines of tethered animals. Because of the rapidity with which the toxin decays in the open air, the number of animals that died was not much greater than that from an equal quantity of nerve gas. The agent therefore has no special attractions for bulk dissemination, and is more likely to be used, if at all, in covert operations where it can be employed without prolonged exposure to the atmosphere. The sabotage of water or food supplies is one such possibility. Another is its use as a contaminant for small-arms ammunition. The US Army is reported to have possessed a substantial quantity of such ammunition [98], together with a number of small aerosol-generating devices for the agent for use within confined spaces. These weapons are currently being destroyed, together with the bulk stocks of the toxin that had been built up since the early 1950s.

The symptoms of naturally contracted botulism do not generally appear until 12–72 hours after contaminated food has been eaten. The onset-time is likely to be shorter after inhalation or injection, and can be reduced by increasing the dose. The toxin seems to work by inhibiting the production of acetylcholine at certain of the sites where it is needed to transmit nerve impulses to muscles. Death generally follows from paralysis of the respiratory muscles. If the toxin is ingested, the initial symptoms are nausea and diarrhoea, soon followed by headaches, dizziness, fatigue,

[20] See Volume I, pp. 66–67.

weakness, vertigo and extreme constipation. The sight becomes disturbed, the mouth becomes dry and the tongue feels swollen. Muscles in the nose and throat become paralysed and unable to cope with the increasing accumulation of thick, choking mucus which may begin to froth from the mouth and nose. Speech becomes difficult, even impossible. The breathing becomes increasingly laboured, and muscles throughout the body increasingly weak. Convulsions and death may soon follow [99–100]. Vaccines are available, but it is not known how well these can protect against unnaturally large toxin dosages. There are no really effective antidotes, and treatment is essentially palliative and supportive. Recovery from botulism confers immunity, but of uncertain degree and duration [97].

The Swedish CB defence laboratories have estimated that the lethal dose of type A botulinal toxin for man, inhaled in aerosol form, is about 0.3 micrograms [94]. Another authority has estimated on the basis of 18 case reports of botulism, 16 of them fatal, that the human oral LD50 is about 0.4 micrograms.[21] If parenteral studies on monkeys are any indication, the dose having a large chance of causing death may not be much larger than the dose having only a small chance [99]—well within a single order of magnitude. This is also suggested by case studies of botulism in man [101].

Shellfish poison (saxitoxin)

Shellfish poison, sometimes known as *saxitoxin*, is a lethal toxin generated by certain algae. Shellfish that feed on them may become highly toxic to human beings, and, if eaten, produce a condition known as "paralytic

[21] Published estimates of the human LD50 vary widely according to the method of estimation, the route of administration and the purity of the toxin. It is generally believed that man is the animal species most sensitive to botulinal toxin [102]. After studying a range of human and laboratory-animal toxicity data, one authority has estimated that the human parenteral and oral LD50s are about 7 and 7 000 mouse-units per man, respectively [103], the "mouse-unit" being defined as the intraperitoneal dose having a 50 per cent chance of killing a mouse. If botulinal toxin were used as a CW agent, a pure preparation would probably not be used, despite its high toxicity: not only is purification difficult and expensive, but, as noted above, it also leads to a less stable product. A relatively crude preparation, such as the spray-dried, partially purified product studied in Canada during World War II, would seem to be more suitable. For this material, a mouse-unit of about 0.01 micrograms was typical [91], and was much the same as that of a dry preparation used in a reported botulinal-toxin aerosol study performed in the USSR [105], (the mouse-unit of the pure toxin is around 0.00003 micrograms [88]). Applying the foregoing estimates to it, the human oral and parenteral LD50s would be 70 and 0.07 micrograms per man, respectively. Reckoning from animal studies, the inhaled toxin would be less potent than parenterally-administered toxin by no more than one order of magnitude—or more potent than ingested toxin by two or three orders of magnitude [106]. On this basis, the human respiratory LCt50 of the crude Canadian or Soviet preparation would be about 0.1 mg-min/m^3.

shellfish poisoning". The toxin has long been of interest in military laboratories, as is described in Volume I of this study.[22]

Since the early 1950s [107], procedures have been developed for growing toxin-producing species of the algae—e.g., the dinoflagellate plankton *Gonyaulax catanella*—artificially, and for extracting the toxin from the cultures in high yield [108–109]. In contrast to the other toxins described in this chapter, saxitoxin is not a protein. It has a small molecule whose structure has just been determined [110]. It is a white solid that is readily soluble in water and attracts moisture from damp air. Saxitoxin is resistant to heat [111], but susceptible to oxygen [112].

Saxitoxin does not compare with the nerve gases as an agent for use in bulk dissemination techniques. It has been valued more as a contaminant for small-arms ammunition. Rifle-fired flechettes have been developed, for example, that can inject saxitoxin into a man with no more sensation than that of a mosquito-bite. Death may then follow in less than 15 minutes, a considerably shorter time than would be expected with botulinal toxin. As is described in appendix 2, faster-acting toxins, notably certain coelenterate toxins, have been studied in military laboratories.

In cases of paralytic shellfish poisoning, symptoms usually follow between 10 minutes and 4 hours after the toxin is ingested. The initial effects are a tingling numbness in the lips, mouth and tongue, with muscular weakness, thirst and prickly feelings in the finger-tips. This is followed by increasing muscular incoordination, with ascending paralysis. Death is generally caused by failure of the respiratory muscles. If a man survives as long as 12 hours, he has a good chance of recovering [113–114].

Estimates of the human oral lethal dose have been made from case studies of paralytic shellfish poisoning. They range from 0.2–0.3 mg [115] to 1–4 mg [116] and one author has estimated an oral LD50 of 0.5–1 mg [101], a rather greater lethality than that of the nerve gases. In experimental animals, the lethal dose by injection is normally about ten times smaller than that by ingestion [115].

Staphylococcal enterotoxin

Staphylococcal enterotoxin is responsible for the symptoms of food poisoning that follow consumption of food contaminated with *Staphylococcus* bacteria. The acutely debilitating nature of these symptoms, and the stability of the toxin, stimulated programmes for developing the substance into a warfare agent. It falls into the category of nonirritant physiochemicals defined above.

[22] See Volume I, pp. 67–68.

Several distinct types of toxin are known to produce staphylococcal food poisoning. The one most studied from a military point of view is staphylococcal enterotoxin B ("SEB"). There are strains of *Staphylococcus aureus* that generate SEB in large and easily isolable yields.

Freeze-dried SEB is a white, fluffy material that attracts moisture from humid air and readily dissolves in water. It appears to be a simple protein, made up of a single polypeptide chain. It can withstand temperatures of up to 100°C for some minutes without losing much of its activity. Freeze-dried, it is stable on storage (storage periods exceeding one year are reported), although it needs to be kept below room temperature if it is to retain all its activity [117]. Details of the weapons that have been designed for it are not available in the open literature, but it is understood that they include devices for use in sabotage and other irregular operations, together with aerosol-generating devices for large-scale use (e.g., aircraft spray tanks). The latter may also be used to disseminate the agent in admixture with certain infective agents.

Staphylococcal food poisoning in man is characterized by the sudden and often violent onset of vomiting, diarrhoea and stomach cramps. Although these effects may prostrate their victims, they rarely last for more than a day, generally less. Man appears to be more sensitive to SEB than laboratory animals. Ingestion of 50 micrograms of a 50 per cent pure preparation was, after 2–5 hours delay, more than sufficient to initiate vomiting and diarrhoea in three volunteers; the ED50 was reckoned to be 20–25 micrograms [118]. People vary greatly in their susceptibility to the toxin, however; it seems, for example, that British volunteers are less sensitive than US ones. For rhesus monkeys, it has been found that ingestion of 0.9 micrograms of pure SEB per kilogram of bodyweight has a 50 per cent chance of causing vomiting or diarrhoea, the ratio of this ED50 to the ED5 being about 40 [117]. The corresponding ED50 for aerosol inhalation is reported to be about 6 micrograms per kilogram [119]. Symptoms generally show up within 2–4 hours after oral or aerosol administration, although the latency period can be shortened by increasing the dose.

Long-lasting disorders or death from staphylococcal food poisoning are rare in man, but can be brought about in laboratory animals with doses of SEB that exceed the ED50. With a pure SEB preparation, the intravenous LD50 in rhesus monkeys was apparently around 25 μg/kg, about 250 times larger than a reported intravenous ED50.[23] Other rhesus monkeys have died after aerosol exposure to similar quantities of SEB; lung

[23] Mice are very much more resistant to the lethal effects of SEB than are monkeys, the intraperitoneal LD50 exceeding 3 mg/kg [120].

damage appeared to be the cause of death, but it was not clear whether this was due to the SEB itself or to some impurity in it [95].

From the toxicity figures, one might guess that the ICt50 for SEB aerosols in man might be of the order of 0.1–1 mg-min/m^3; the lethal dosage might be larger than this by a factor of some hundreds.

Although SEB has been a stockpiled CBW agent, the fact that it is a protein must have limited its attractions. Most toxic proteins are highly sensitive to the sort of stresses imposed by the simpler types of aerosol generator, and they tend to detoxify easily in the open air. SEB may be exceptional in these respects (in view of its stability to heat mentioned above) but there is little published information on the matter. Again, because it is a protein, it is capable of eliciting an immune response, so that suitable vaccination might provide protection against it, and immunity might build up against the effects of successive exposures. Animal studies have been conducted that support both these suppositions [121–122], and toxoids for human use are under development [123].

Francisella tularensis

Francisella tularensis is the bacterium that causes tularemia, otherwise known as "rabbit fever". This is endemic in many parts of the world. Its natural hosts include a broad range of wild animals, such as rabbits, hares and foxes. It can be transmitted to human beings in several ways: via the bites of infected ticks or flies; via contaminated water or inadequately cooked meat; and through the skin, eyes and lungs after handling infected animals. Laboratory infections are frequent. The bacteria may remain alive for weeks in water, soil, hides and carcasses, and for years in frozen rabbit meat.

The bacteria can be cultivated on a large scale, although with some difficulty. Concentrated cultures are reasonably stable during storage, but little has been published on their maintenance of virulence during storage. They require rather delicate aerosolization methods, however, for the bacteria are readily susceptible to mechanical stress [124]. They are also very susceptible to such environmental factors as temperature, humidity and sunlight, but it has been demonstrated that when contained in dry powder aerosols they are markedly more resistant than when in liquid droplet aerosols [125]. Their survival time in liquid droplet aerosols may be increased under some conditions by including certain stabilizers in the payload of the aerosol generator [126]. It has been demonstrated that the infectivity of aerosols of the bacteria is not necessarily proportional to the number of bacteria surviving; moreover, the decline of infectivity with aerosol age seems to be more rapid with aerosols generated from

stored cultures than with those from fresh ones [127]. Observations of infectivity–viability dissociation in *F. tularensis* aerosols have been made both with laboratory animals and with human volunteers [128].

The incubation period of tularemia in man is 1–10 days, being shorter after inhalation of the bacteria than after ingestion. Human volunteers subjected to a minimal infective challenge by the aerosol route developed the disease in 5 days, but a hundred-fold increase in dosage shortened the period to 2–3 days. The disease is acute, severe and debilitating, with subsequent chronic effects. Early symptoms include chills, fever and prostration, with lung complications developing that may be severe if the infection is caused by small-particle aerosols. Recovery, subject to relapses, may take 2–3 weeks or more. Some strains of the bacterium are lethal in the absence of treatment. There is an American strain that can show mortality rates of up to 60 per cent, but as normally encountered in Europe or Asia, the mortality rate of the disease is rarely higher than 1 per cent. The strain which furnished the standardized US BW agent was one capable of causing high mortality rates (30–40 per cent). Certain antibiotics provide an effective treatment, although this must be continued for rather long periods; in addition, strains of *F. tularensis* have been developed that are resistant to specific antibiotics (streptomycin-resistance was bred into the standard US agent strain of the bacterium). Vaccines are available, but they are more effective in reducing the severity of the disease than in preventing it altogether. Recovery, however, confers long-lasting immunity.

Different strains of *F. tularensis* vary greatly in virulence. Aerosol studies in human volunteers using a highly virulent strain showed that a dose of 25 bacteria contained in 1-micron diameter droplets would "regularly" infect people [130].[24] Volunteers inhaling 25 000 bacteria of this strain invariably become fevered within 2–7 days, generally 3 days [104]. Volunteers have proved to be a great deal more resistant to the ingested bacteria: whereas 10–50 inhaled organisms of this strain were enough to cause clinical infection and serological conversion, 100 million bacteria were needed by the oral route [101].

Bacillus anthracis

Bacillus anthracis, the bacterium that causes anthrax, has been studied as a potential BW agent since biological weapon programmes began. Prob-

[24] Thus, in one set of experiments, 20 volunteers were exposed to an aerosol of 0.7 micron particles containing the highly virulent Schu S4 strain of *F. tularensis*. The respiratory challenge ranged from 10 to 52 bacteria. Of the volunteers 16 gave systemic evidence of infection, becoming ill within 4–7 days [129].

ably no other human pathogen is as hardy, easy to grow and easy to disseminate.

In its natural form, anthrax is primarily a disease of herbivorous animals—cattle, sheep, horses and so on—although it can affect pigs and other animals. For BW purposes it thus has potential both as an anti-animal and as an antipersonnel agent. It can infect human beings through the skin, through the digestive system or through the lungs. Pulmonary anthrax is particularly dangerous; if it is not treated, the mortality rate may approach 100 per cent. Cutaneous anthrax, which is much more common, has a lower mortality rate. For BW purposes, anthrax bacteria are likely to be used in aerosol form, although in the past they have also been incorporated into fragmentation weapons designed to produce cutaneous anthrax through infected wounds and apparently also in devices intended for water sabotage.[25]

B. anthracis is particularly suited to aerosol dissemination because of its ability to form spores. These have a protective layer that shields the genetic material against hostile environments. Sporulated bacteria can withstand comparatively violent aerosolization methods and remain alive for long periods after dissemination. Even in direct sunlight, the spores may survive for a number of days, and they can contaminate soil for periods of decades.[26] They can be stored for years without losing their activity.

After inhaling an infective dose of anthrax bacteria, a man is likely to develop symptoms of pulmonary anthrax within 4 days. After a heavy dose, however, the incubation period may be less than a day [97]. The onset of the disease is mild and may resemble a normal cough or other common respiratory infection. Thereafter the disease progresses very rapidly, the victim develops a high fever, vomits; his head and joints ache and his breathing becomes increasingly laboured. He soon collapses and may die within 2 days or less. In chimpanzees at least, the signs and symptoms do not become characteristic of anthrax until the terminal stage of the disease, a fact which complicates diagnosis. It now seems certain that the pathophysiological responses observed during *B. anthracis* infection are due, not to the organism *per se*, but to toxins which it generates during growth within the host [131]. (These toxins have been isolated and purified, and their effects on experimental animals observed [132–135].) Anthrax is not markedly contagious, and is not transmitted by insect bites. Vaccines are available against it, but their effectiveness against massive aerosol dosages of *B. anthracis* is not known. Treatments with antibiotics, with sulpha

[25] See Volume I of this study, pp. 115–16 and 221–22.
[26] As has been demonstrated at British and US proving grounds; see below, p. 131 note 10.

drugs and with immune sera have been developed, but to be effective these have to be given at an early stage of the disease. Recovery confers some immunity.

Compared with other potential BW agents, rather large dosages of *B. anthracis* are needed to cause disease, although simultaneous challenge with a lung-irritant chemical agent can reduce the necessary dosage considerably [136]. When 1 250 cynomolgous monkeys were exposed to an aerosol of the bacteria it was determined that the LD50 was about 4 000 spores, with an LD50/LD5 ratio of more than 200 [137]. It has been estimated from human case studies that something of the order of 20 000 spores are needed to infect a man through his lungs [138–139]. On a weight-for-weight basis, therefore, the spores have much the same CBW-agent potency as the bacterial toxins described above.

Pasteurella pestis

Pasteurella pestis is the bacterium that causes plague, the great pestilence of the Middle Ages, sometimes called the Black Death. Outbreaks of it are now rare in Europe and America, although it is still endemic in wide areas of Africa and Asia. The allegations that it was employed as a BW agent by Japanese forces in China during the early 1940s are referred to in Volume I of this study.[27]

Several species of rodent provide a natural habitat for plague bacteria. Fleas are the normal vector whereby the disease is transmitted from rodents to man. Several forms of the disease are known. When contracted from the bites of infected fleas, it normally takes the "bubonic" form characterized by a swelling of the lymph nodes in the armpits and groin ("buboes"). If the bacteria invade the lungs, pneumonic plague, a far more serious form of the disease, may develop. Indeed, before antibiotics and chemotherapeutics were developed, a diagnosis of pneumonic plague virtually amounted to a death sentence [140]. These medicaments have made *P. pestis* a much lesser threat than hitherto. People suffering from pneumonic plague are highly contagious, however, and, in contrast to the other diseases described in this chapter, pneumonic plague may spread rapidly to uninfected people by direct man-to-man transmission. A number of accidental laboratory infections, some of them fatal, are reported in the literature, notably from the British and the US BW laboratories [141–143].

The cultivation of plague bacteria in large quantities presents no unusual problems beyond those of rigorous safety precautions. Refrigerated

[27] See Volume I, pp. 217–20 and 342–47.

freeze-dried cultures have been stored for up to 10 years or more without losing viability [3, 144], although virulence may decline substantially over a period of months [145]. Water contaminated with the bacteria may remain dangerous for up to a month, but in the aerosol state, the bacteria are very labile [146], so that sunlight and other environmental factors may quickly prove lethal. Decay rates ranging from 8 to 70 per cent per minute have been observed at varying relative humidities and simulated sunlight exposures [147]. The bacteria might conceivably be used for BW purposes either by bulk dissemination as aerosol, or as water or food contaminants in order to exploit the contagiousness of the disease for sabotage or terrorist purposes.

Pneumonic plague has an incubation period of 3–4 days. The onset is abrupt, with chills, high fever and extreme weakness. The eyes redden, the face becomes congested and the tongue coated. The victim may become maniacally delirious or may quickly pass into a coma. The severity of the pulmonary symptoms varies according to the size of the infected particles inhaled; if they are small, lung haemorrhages may quickly develop. Death may be rapid, sometimes within a day, more usually 3–4 days, of the initial symptoms. The mortality rate in untreated cases is 90–100 per cent. If administered promptly, antibiotics such as streptomycin or chloramphenicol will generally check the disease, although virulent antibiotic-resistant strains of *P. pestis* are known [145]. Plague vaccines are available that give good immunity for 3–12 months against moderate challenges, but they have unpleasant, sometimes prostrating, side-effects. Recovery from plague confers only temporary immunity.

Compared with some of the other pathogens described in this chapter, *P. pestis* is only moderately infectious, although some strains are far more virulent than others. In rhesus monkeys, an LD50 by aerosol inhalation of 20 000 bacteria of the virulent 139L strain has been reported [148] in contrast to 20 bacteria of *Francisella tularensis* in an aerosol of comparable particle-size [149], or about 53 000 spores[28] of *Bacillus anthracis* [150]. A human estimate of 3 000 inhaled bacteria has been quoted, however [151]. Nonetheless, because of the contagiousness of the disease, the number of casualties produced by it could be out of all proportion to the number of bacteria disseminated. But whether an epidemic would actually take hold would depend on factors beyond the control of the attacker, and also, for the present, beyond his understanding.

[28] This figure for anthrax spores was obtained during World War II work in the UK, in contrast to the other figures, which were obtained much more recently by US workers. Since different methods for estimating dosage were used, the figures are not strictly comparable. For 12 μ clusters of anthrax spores, rather than single-spore aerosols, the LD50 rose from 53 000 to 760 000 spores [150].

Coxiella burnetii

Coxiella burnetii is the rickettsia that causes Q fever, otherwise known as Nine-Mile fever or Queensland fever, a disease that is rarely fatal in man, but very debilitating. The rickettsia is highly infectious and unusually hardy in the airborne state.

Q fever is endemic in many parts of the world; sheep, goats, cattle and an extensive range of lower animals providing reservoirs for it. It is commonly transmitted via airborne droplets or dust particles that contain the rickettsia. Such aerosols may derive from dust contaminated with the faeces of infected flies, ticks or mites. They may also be generated during the handling of carcasses or hides of infected animals: an outbreak of Q fever is known to have been caused by airborne *C. burnetii* released from a sheep-fat rendering plant 10 miles upwind [152].

The rickettsiae are easy to grow in tissue culture, and concentrations as high as 20 000 million organisms per millilitre are readily attained in chick embryos. Such cultures have been stored at −50°C for as long as 5 years without much loss of viability [153]. In the aerosol state the rickettsiae are not nearly so rapidly killed by environmental factors as are most other pathogens, or at least those that do not form spores. They may survive on surfaces for as long as 2 months [97].

The incubation period of the disease is rather long, 18–21 days on average, although heavy dosages may reduce it. The effects of *C. burnetii* in admixture with incapacitating pathogens of shorter incubation period (e.g., VEE virus or *Francisella tularensis*) have been studied [153–154]. Q fever resembles severe influenza. Its onset is sudden, with chills, loss of appetite, pains in the chest, muscles and joints, and high fever. Pneumonia may appear within one week. If untreated, the symptoms may persist for 1–3 weeks, and for several weeks afterwards the patient may be too weak for normal work. The mortality rate is less than 1 per cent. Certain broad-spectrum antibiotics provide an effective treatment, and a disease-preventing vaccine has been used by slaughterhouse workers. Recovery from Q fever confers immunity for at least a year [97].

Q fever is not directly transmissible from man to man, but the rickettsia is exceptionally infectious. It has been estimated from aerosol experiments on human volunteers that a single inhaled rickettsia may be enough to cause infection, if not actual fever. Volunteers have been given inhalation doses as high as 10 000 rickettsiae; at such a dose level, the average incubation period was about 11 days, rising to 17 days at a dose of 10 rickettsiae [155].

Venezuelan equine encephalomyelitis virus (VEE virus)

VEE virus is one of the arboviruses that can affect the brain and spinal cord. Its effects are particularly harmful to horses and mules, among which it can cause high mortality. In man, however, it is rarely lethal, although acutely disabling, and is thus a potential incapacitating agent. As such, it was stocked in relatively small, but increasing, quantities (some hundreds of kilograms, so it is said) by the US Army prior to the decision to destroy the US biological-weapons arsenal.

Many species provide a natural habitat for VEE virus [156], which is said to have a wider host range than any other pathogenic micro-organism [97]. Usually it is an infection of rodents or birds, transmitted by mosquitoes. Natural airborne transmission has been observed, and implicated in a number of accidental laboratory infections [157–158]. What little has been published about its ability to withstand aerosolization or environmental stresses indicates that it is sensitive to increasing temperature and to mid-range atmospheric humidities [159–161], but that it is rather more stable in the aerosol state than most nonsporulated bacteria. It grows well in chick-embryo culture.

In man, naturally-contracted VEE generally takes between 2 and 5 days to manifest itself, but unnaturally high dosages may give shorter incubation periods. Its onset is sudden, with chills, fever, nausea, vomiting, severe aches in the head and body, drowsiness and weakness. Inflammation of the brain and spinal cord is unusual in man, the disease generally resembling influenza. The fever may last 1–4 days. Recovery is usually rapid after one week, although some patients may remain weakened for longer periods. Less than two in a hundred patients are likely to die; the 1962–1964 Venezuelan epidemic (32 000 cases, 190 deaths) suggested that children are more likely to die from VEE than adults [155]. It must be noted, however, that these remarks refer to the disease contracted through bites from infected mosquitoes; the disease might appear very different when caused by heavy aerosol dosages of the virus. Aerosol studies in animals, for example, have shown exceedingly small lethal dosages [162]. An effective vaccine is available [163], but there is no specific treatment for the disease. Recovery confers good immunity, but only in the short term.

VEE is not a contagious disease in the sense of being directly transmissible from man to man. It may, however, spread rapidly in areas where mosquitoes and biting flies are present. No estimates have been published for the infective dose of the VEE virus in man, but it is reported to be very small [164]; a single viral particle may be sufficient. The effects of

mixed aerosols of VEE virus and Rift Valley fever virus have been studied in monkeys.

Pyricularia oryzae

Pyricularia oryzae is the fungus that causes the highly destructive disease of rice known as rice blast. It can also damage certain other grass plants. It is easy to grow artificially. During growth it produces conidia, the minute seed-like spores through which it propagates itself. These constitute the potential BW agent. They are easily removed from the culture, and may be stored for long periods. When rice blast occurs naturally, the spores are detached from their parent growth by air currents, which may then transport them downwind, although as they are rather large, they are unlikely to be transported very far.[29] As a BW agent, the spores would presumably be dusted from aircraft spray tanks or sprayed as water slurries, although they could no doubt also be used by saboteurs to initiate small pockets of infection which might then spread of their own accord under the influence of wind and weather.

After a spore has settled on a rice plant it may germinate, penetrating into the plant and subsequently invading all the plant tissue. Spore-bearing stalks will later grow out of the tissue to produce new spores that may be detached and scattered by the wind. Germination requires favourable weather, however, with free water (e.g., dew or rain) being present for at least 8 hours, and the temperature rather warm. Spore production, necessary for the further spread of the disease, is maximal at about 30°C and 90 per cent relative humidity. A square centimeter of infected rice-leaf tissue can produce about 80 million spores [97].

Some varieties of rice are more susceptible to *P. oryzae* than others, and in many areas varieties are grown into which resistance to locally occurring strains of the fungus has been bred. All varieties are most severely damaged during the seedling stage. The fungus prevents normal development of the grain; and, if the infection is severe, any grain that has developed may be lost by the fungus causing the stem to break, and the grain-bearing head to fall off. Major outbreaks of rice blast have caused crop losses as high as 90 per cent [97].

It seems that for one *P. oryzae* spore preparation that was available as a BW agent, an application rate of about 1–2 grams per hectare was envisaged [167]. In a field experiment with a particular strain of *P. oryzae*,

[29] *Pyricularia oryzae* spores are ellipsoidal in shape, about 20 microns long; in contrast, *Bacillus anthracis* spores are only about 1.4 microns long. It may be noted, however, that in the case of infectious *Puccinia graminis* spores, which are much the same size as those of *Pyricularia oryzae*, an instance is recorded where their wind transport led to serious crop losses up to 600 miles downwind [166].

an application under favourable weather conditions of 4 grams of viable conidia per hectare was capable of initiating primary infection in about half of the rice plants exposed [168].

Munitions for CBW agents

We now move on to describe some of the agent-disseminating devices that have been developed into weapons. The present description concerns only bulk dissemination munitions. It does not include the many devices that have been designed for injecting agents directly into their victims, or for using the agents as food or water contaminants. Such things are primarily sabotage weapons; a short historical account is given in Volume I of this study.[30]

A CB munition has the function of converting a payload of bulk solid or liquid CBW agent into a dispersion of particles, droplets or vapour. Definite demands will be made of the dispersion. Its overall size and shape must be reasonably predictable, so that the user of the weapon can relate it to the geography of his target; so must the concentration of agent within it. When the dispersion comprises droplets or particles, an adequate proportion of them must be neither too large nor too small. As mentioned earlier, the optimal combination of lung penetration and downwind transport occurs in the 1–5 micron diameter size range. For greatest contact effects, however, the particles should be no smaller than 70 microns in diameter [169], preferably rather larger, although if they are too large the weapon will lose area effectiveness.

Such requirements as these are by no means unique to CB weapons. Efficient spraying and aerosolization methods are needed in many fields outside CBW. Farmers and foresters have similar dispersal problems with their pesticides; so do the designers of, for example, paint sprayers or oil-fired furnaces. Some medicaments are best administered with atomizers or nebulizers; and aerosol generators are needed for laying military smoke screens. There is thus an abundance of equipment and practical expertise available for the designers of CB weapons to draw upon.[31] At a pinch, some of the equipments might be used without modification to dispense CBW agents.

The principal singularity that distinguishes mass-produced CB weapons

[30] See Volume I, pp. 109–111.

[31] CB weapons laboratories obviously keep a close watch on developments in civilian aerosol techniques. See, for example, the reports resulting from the contract between US Army Edgewood Arsenal and Stanford Research Institute for "research studies on the dissemination of solid and liquid agents". This contract even embraced a study of the means whereby puffballs and other fungi release their spores [170].

from, say, insecticide-fogging machines or ultrasonic drug nebulizers is that they must be robust and self-contained. External power sources will rarely be feasible for providing the energy needed to disperse a CBW-agent payload; and the device will generally be expected to function unattended and after periods of rough treatment. The range of spraying or aerosolizing methods at the disposal of CB weapon designers is thus considerably narrower than those used in civilian apparatuses.[32]

Explosives and pyrotechnic compositions are the energy sources most amenable to CB weapons, and it is these, together with certain pressurized-nozzle spraying devices, that are most commonly used in the dissemination of CBW agents. A high-explosive (HE) charge provides a simple, robust and intense source of thermal and kinetic energy—heat and pressure—that can disperse virtually any payload. But for some agents it will be too energetic, stressing them to the point of decomposition and loss of toxicity, or death in the case of micro-organisms. Here less powerful energy sources are needed. Pyrotechnic compositions can provide the heat without the mechanical stress, and pressurized-nozzle systems the kinetic energy without the heat. For solid agents in powder form, such energy sources may be unnecessary; simple dispersers may be used instead, based, for instance, on compressed air. Accordingly, there are four principal types of CB munition: the bursting-type, the burning-type, the spraying-type and the disperser-type.

Bursting-type munitions

The chemical-agent artillery shells first used during World War I are the prime examples of bursting-type munitions. A tube of explosive connected to a suitable fuse and detonator is aligned along the axis of the munition, which is then filled with the agent [191–194]. The larger the HE burster, the more finely will the agent be dispersed. For agents that vapourize easily, such as phosgene or cyanogen chloride, coarse dispersions, and hence small bursters, may suffice, but for less volatile substances, such as mustard gas and the nerve gases, heavier bursters are needed. In the nerve-gas projectiles currently stockpiled by the US Army, the weight ratio of HE to nerve gas is about one to two [195]. This yields a broad particle-size spectrum that ranges from finely-divided aerosol to coarse spray (thereby providing for both contact and inhalation effects: with sarin, for example, it might be expected that about half the payload

[32] Several books and review articles are available [171–175] that describe the methods which have found civilian applications, or that give useful bibliographies. The most sophisticated devices are those which have been used for laboratory aerosol studies [e.g., 176–190].

would appear as spray, and half as inhalable vapour or aerosol). The standard US Army 155 mm VX projectile scatters about 60 per cent of its payload up to 20 metres around the point of burst with about 15 per cent of the payload remaining airborne downwind of this point: one-fourth of the payload is apparently destroyed by the stresses of the explosion [196]. Many variations on this basic theme are possible. In one the HE charge is concentrated in the nose of the projectile so that when it detonates it forces the agent up into the air through the base of the munition [197–198]. This type of design, known as the "base-ejection" principle, gives greater area coverage [199], but at cost of increased particle size. It was used, for example, in a substantial proportion of the British chemical bombs and projectiles stockpiled during World War II; post-war trials with one such design[33] charged with V-agent nerve gas yielded a spray that was predominantly in the 100–150 micron diameter size range [200].

Bursting-type munitions are not suited to solid agents unless the payload is in the form of a fine powder, and even then their performance depends strongly on the physical properties of the powder. Some powders tend to agglomerate into lumps, for example, either on storage or under the influence of the explosive [201–203]. Furthermore, the milling of highly toxic or infectious substances into micron-sized powders is not merely a difficult [204] but also an exceptionally hazardous process, and one that requires sophisticated technology for efficient and safe performance. Suitable equipment has, however, been designed for the purpose [205]. Bursting-type weapons for solid particulates have been mass produced; the most well-known of them are the small "baseball" hand-grenades used by US military and police forces for disseminating CS. Powder-clumping problems can be reduced by adding "anti-agglomerants", such as colloidal silica, to the payload [206]. They can also be reduced by micro-encapsulating each powder particle within a special coating [207–209]. The micro-encapsulant may serve the additional function of protecting the agent from the thermal, mechanical and chemical stresses of explosive dissemination [170]. Other functions for micro-encapsulation in the field of CBW are discussed on pages 285–287 below.

If a candidate liquid CW agent cannot withstand the stresses of bursting-type dissemination, it is unlikely to be considered a worthwhile agent. This may not apply to solid agents, particularly those of very high toxicity; neither is it likely to be a primary consideration in the selection of BW agents, although it may be an important one. Most micro-organisms and toxic proteins are highly susceptible to thermal and mechanical stresses, but some of them can in fact withstand explosive dissemination without

[33] The Shell, Chemical, 25-pdr. B.E., Mk. 8.

excessive loss of toxicity or viability [210]. Much depends on the configuration of the components of the weapon and on the type of explosive used in it. Adequate designs have been developed for such agents as ricin[34] and anthrax spores, although those designs that are described in the open literature work best when the payload is in the form of a liquid slurry of agent, rather than dry powder [203, 211]. There is generally some loss of toxicity or viability, but agents of this type are effective in such small dosages that the cloud may nonetheless be extremely potent [97].

The principal drawback with explosive dissemination is the poor control that is possible over particle size. Except perhaps with specially treated powders milled beforehand to the right size, it is not now possible to disperse the greater part of a payload in particles or droplets less than 5 microns in diameter. Developments currently under way may possibly cope with this difficulty. One such approach has been the use of a shaped-charge central burster that concentrates the explosive forces more efficiently on the payload [212]. Another approach, in which the payload—solid or liquid—is sandwiched between two balanced HE charges, aims at dissemination by implosion rather than explosion [213]. A third approach uses a fuel-air explosive (FAX) in addition to a burster tube. The latter sets up a cloud of hydrocarbon vapour (such as ethylene oxide) superimposed on a cloud of CW or BW agent. A fraction of a second later, when the fuel has become diluted by air to the point of explosiveness, the resultant FAX cloud is detonated, thereby subjecting the CW/BW agent cloud to an intense overpressure likely to shatter its component droplets or particles [214–215]. But these approaches all appear to be still in the experimental stage, and for the present, for greatest aerosol effects, some of the other types of munitions described below are more amenable.

Burning-type munitions

If a substance of high boiling-point is vapourized into the atmosphere, the vapour rapidly condenses into a smoke—aerosol droplets or particles of around 1 micron or less in diameter [216]. This process can form the basis for relatively simple chemical munitions.[35] It is commonly used in

[34] Ricin is a toxic protein occurring in castor beans. It is described in appendix 2 and in Volume I of this study, pp. 65–66.

[35] British CW officers during World War I were among the earliest to recognize its potentialities. General Foulkes, who commanded the British Special Brigade, has recorded this anecdote: "Colonel Watson, who was the head of the Central Laboratory at Hesdin, had suggested in September 1917 the study of particulate clouds; and one of my officers, Sisson, in a spirit of investigation, put a pinch of DA which had been extracted from a German shell on the hot plate of a stove in his room at my headquarters. The result was so remarkable that everyone was driven out of the house immediately, and it was found that the latest pattern of German mask ... gave no protection whatever." [217.]

police-type irritant-agent weapons, such as the current British "CS smoke" grenades [218–221].

In the simplest burning-type munitions, the agent is blended into a pyrotechnic composition that can be ignited from appropriate fusing and which can then distil the agent into the atmosphere as it burns [222–229]. This method has its limitations. Some agents may be decomposed, and thereby rendered innocuous, by the heat. If they are to be disseminated by this method, a special pyrotechnic composition must be used that burns at a low temperature. A number of cool-burning compositions have been developed for this purpose [230–231]. If this cannot be done, or if the agent is one that is chemically decomposed by, say, the oxidant of the composition, the agent can be placed in a separate compartment above the pyrotechnic composition, using the latter as a hot-plate, and with arrangements for leading the hot combustion gases over or through the agent, perhaps via an intervening layer of coolant [232–236]. Some such method would in any case have to be used if the agent were a liquid or a low-melting-point solid.

Even this method may expose the agent to excessive thermal stress. If so, there are devices that have been developed for minimizing the amount of time during which the agent is held at a high temperature [203]. In one of these, the agent is fed into a high-velocity stream of hot gas, usually exhaust gas from a pyrotechnic composition (although rocket-motor exhausts have been exploited [170]), with which it remains in contact for no more than a fraction of a second before reaching the atmosphere [237]. This requires relatively complicated munitions, but it has the military attraction of providing a way for securing intense aerosol effects from low-volatility liquid agents. In a field-trial during World War II, using human volunteers, it was found that incapacitating dosages of mustard gas could be taken up from the cloud disseminated from a thermal aerosol generator of this type in a fraction of the usual time [203]. Further development work appears to have continued after World War II, including work on devices capable of disseminating such nerve gases as tabun [238–239]. It is not recorded in the open literature whether thermogenerators can be used with V-agent nerve gas; if they can, they would provide a means for exploiting the extreme toxicity of VX in off-target attacks.

The agent-aerosol disseminated by a second category of burning-type munition is combustion-product rather than distillate: the process of combustion is used both to produce and to disseminate CW agent. Examples of this are the toxic modifications developed during World War II for magnesium incendiary bombs [225, 240]. One approach was to make the bombs of cadmium-magnesium alloy: this burns to generate a smoke of

cadmium oxide, a highly poisonous substance reckoned to have about twice the lethal toxicity of phosgene [240].

Spraying-type munitions

Liquid agents, or liquid slurries of solid agents, can be disseminated as dispersions of varying—and reasonably well controllable—droplet size by subjecting them to shear-forces. One way of doing this, known as hydraulic atomization, is to force the liquid under pressure through a fine nozzle. Another method, known as air-blast atomization, is to allow the agent to flow in a thin stream into a high-velocity current of air or some other gas.

Except for the now obsolete cylinders of compressed toxic gas used during World War I, the simplest spraying-type munitions are aircraft spray tanks. Here the agent is ejected or simply allowed to flow under gravity into the slip-stream of the aircraft, where it is immediately shattered into small droplets. Less violent dispersion is achieved if it is ejected below the slip-stream. Many variants of this principle have been developed, both for civilian and military purposes [241–246]. For CW applications, it was originally developed as a means for securing contact effects with vesicants over rather large areas, and was first put into practice by the Italian Air Force in Ethiopia during 1936.[36] A more recent CW application has been in the dissemination of defoliants and anticrop chemicals in the Viet-Nam War. The main problem with aerial spraying is that the shear-forces on the agent may be so great that the droplets will be too small to be effective: the agent may evaporate before it reaches the ground, or it may fail to land on the intended target area in the appropriate density. For this reason, effective spray-tank delivery of contact agents (which necessitate relatively large droplets) is generally only feasible from low altitudes, 100 metres or less. Higher altitude spraying has been conducted [247] but it is less reliable and demands additional meteorological information. Moreover, the spraying must be carried out at comparatively low air-speeds, for if the aircraft is flying too fast, the spray-tank payload may be completely aerosolized, and therefore useless for contact effects. This problem can to some extent be met by adding thickeners to the payload to increase its shear-strength, thus permitting higher spraying speeds [248–251]. Where the effects sought with the agent are respiratory rather than contact—as in the case of BW-agent spraying—these particular difficulties do not arise.

CBW agent spray devices have also been developed for large free-fall weapons [252–253] and as an alternative payload for remote-controlled reconnaissance drones [254].

[36] See Volume I, pp. 142–46.

With the exception of aerial spray tanks, it might be supposed that spraying-type munitions are likely to be employed only for agents that cannot be used effectively from burning- or bursting-type munitions. For the most part, although by no means exclusively, these will be BW agents or toxins. A variety of spray designs have been developed for small projectiles and bombs.

In spraying-type bomblets, hydraulic atomization is commonly used, considerable care being taken over the design of the nozzle in order to achieve small droplet sizes. The pressure may be derived from a small compressed-gas cylinder [203] or from a piston driven by a propellant [255]. This is not a gentle process, and some toxins and BW agents may suffer considerable loss of toxicity or viability from it [256–259]. The dry-agent dispersers described below can be less rough on the agent [190], and may for this reason be preferred.

Liquid CW agents will generally be more resistant to mechanical stress, and a number of small spraying-type munitions have been designed for them. As with some of the burning-type munitions described above, they might find application where high aerosol concentrations of low-volatility agents are sought, rather than the wide-spectrum sprays disseminated by bursting-type munitions. Those that have been described in the open literature use the combustion gases developed by burning pyrotechnic compositions as a source of pressure [260–261]. In one modification of the method, applied to a spherical bomblet, the agent is contained in a rubber bag opening into a nozzle; when the munition functions, the bag is squeezed by the combustion gases [261]. A similar principle has been described for a novel rocket-propelled spraying device for spreading agricultural pesticides [262].

Disperser-type munitions

Disperser-type munitions are used for pre-sized powders of solid agents. The difficulties of processing toxic or infective materials into this form and of preventing agglomeration, have been noted earlier, but once it has been done, dissemination into dust or aerosol clouds is a relatively simple matter (which is one reason why the milling process is so hazardous).

Probably the most familiar CB munitions of this type are the portable or helicopter- or vehicle-mounted bulk dispersers for irritant agents sometimes used by police forces [222, 263]. These comprise either an air compressor or cylinders of compressed air with hoppers of agent feeding into their outlets. In the case of the helicopter units, the down-draught from the rotor blades secures wide area coverage.

Miniaturization of this type of device has proved feasible. A typical

BW dry-agent bomblet comprises a small cylinder of compressed gas arranged so that it can direct its contents up through the powdered agent, or along its surface, and out through an exit port [203, 264–265]. A recent design of irritant-agent hand grenade uses a stream of combustion gases in a similar fashion [266]. Another possibility that has been studied is the use of gelled propellant gases rather than compressed or thermally generated ones. In one device of this type, the mixture of gelled propellant (e.g., perfluorocyclobutane and colloidal silica) and agent are contained in a capsule; when the capsule is opened, the propellant immediately gasifies, carrying the agent with it through the opening. This system has the asset of retarding agglomeration of the agent particles. It has only been tried with chemical agents [267–268], and it is not known from the published literature whether living organisms other than spores can be made to survive prolonged contact with possible propellants.

In some dry-agent weapons, it may be possible to do without a propellant altogether. Dry-agent bomblets have been developed which open under barometric control at a predetermined point in their descent to scatter their contents into the air [269]. Again, there is a design of helicopter-mounted irritant-agent disperser which simply releases paper bags of powdered agent that burst open when they strike the ground [10].

One final category of disperser that may be mentioned here are the devices that have been developed for dispensing infected arthropods for use in BW vector systems. In the World War II Japanese BW programme, aircraft spray tanks were said to have been used for this purpose, dispensing fleas.[37] It seems improbable that much of the payload could have survived such a process. If vector systems are indeed a realistic possibility, small frangible bomblets would seem more suitable. Designs for such "entomological bombs" exist [43]. It may be noted that aircraft dispersal of sterilized arthropod pests is an increasingly used method of pest control. In one device, sterilized fruit flies are simply released from paper bags dispensed from the aircraft [270].

CB weapon systems

Bursting-, burning-, spraying- and disperser-type munitions have been produced in the past in sizes that range from the very small to the very large, some handling CBW agent payloads of only a few grams, others of half a ton or more. With the exception of aircraft spray systems, the current tendency in the design of CB weapon systems seems to be away from

[37] See Volume I, pp. 114–15.

large munitions, for with highly toxic or infective agents these may create uneconomical overdosages. In on-target attacks, for instance, there is little point in creating a cloud of respiratory-effect agent whose concentration exceeds one effective dose per breathful. One way of reducing overdosages is to employ a plurality of small munitions, relying on air currents to coalesce each agent cloud into a single large cloud of reasonably uniform density [271]. This technique has the added attraction of increasing area coverage for a given weight of agent, as well as reducing overdosage. It also permits effective use of agents that decay rapidly in the open air.

Weapon systems that employ this technique—ones using multiple point-source munitions—include artillery batteries or multiple rocket launchers [272–273] volley-firing chemical projectiles, and aircraft cluster-bomb systems [43]. In the latter, many small bomblets or canisters containing the agent are released from the aircraft as a single unit that breaks open during descent [194, 274–276]. This type of weapon was originally developed for incendiary bombing, initially by the British during World War I [277], and was extensively used during World War II. More recently its development has been spurred by the Viet-Nam War, where enormous numbers of cluster weapons have been used to dispense anti-personnel and other types of bomblet [278–280]. CB warheads for large rockets and missiles work in the same way [43, 281]. Area-coverage may be increased, and overdosage further reduced, either by having the bomblets ejected sideways from their cluster with a suitable propellant, or by designing the bomblets so that they are self-dispersing [282].

There are a number of ways to make bomblets self-dispersing. In one, the bomblets are small rockets, for example canisters of agent/pyrotechnic mixture or agent/gelled-propellant mixture fitted with suitable exhaust vents. When activated, these canisters skitter about on the ground, disseminating their contents over a broad area in the process [267, 283–284]. A second method is to shape the bomblets so that they become subject to Magnus lift forces during their descent to the target. A typical Magnus-effect bomblet is spherical in shape, with small vanes around its outer surface; as it falls through the air, these vanes cause the bomblet to rotate and acquire an aerodynamic lift that gives the bomblet sideways as well as downwards motion. The glide path through the air of a cluster of such bomblets thus broadens, and the area of their eventual impact pattern becomes considerably greater [271, 285]. Other shapes of bomblet can acquire Magnus lift, for example the "Flettner rotors" used for BW agent payloads [286].

A further way of achieving area-coverage without overdosage is to have the munitions disseminate their contents rather slowly so that the dis-

persion becomes suitably diluted by air currents. Weapons of this type are particularly suited to off-target attacks. One example is the aircraft spray tank, disseminating its payload across the wind upwind of the target area. Another is the in-line bomblet dispenser, also for aircraft use, which ejects a string of bomblets along the flight path that can then create an intense upwind line source of the agent [43, 287–288]. Dispensers of this type have some advantages over spray tanks, although they probably cannot cover so much area. They can be used at higher altitudes and at higher speeds, and the bomblets can penetrate tree cover to an extent which agent sprays cannot [271].

Bomblet dispensers are also suited to on-target attacks (as are aircraft spray tanks). Some of them eject small clusters of bomblets or other submunitions, rather than single ones, to increase area coverage [289–290]. One design of BW missile-warhead works in this fashion, with the warhead ejecting a succession of Flettner-rotor clusters as it passes over the target area.

In BW, the use of arthropod disease-vectors presents a further possibility for increasing area-coverage, for in a sense an infected arthropod is a minute self-dispersing weapon. It possesses the additional attractions of providing for percutaneous BW attack, and of shielding the agent from degrading environmental factors—although it is to be noted that most arthropods are themselves highly sensitive to weather conditions [97]. The allegations that Japanese forces employed this mode of BW against the Chinese during World War II, and that US forces also did so during the Korean War, are referred to elsewhere in this study.[38] The latter allegations have been categorically and repeatedly denied by US authorities, but they were in part responsible for the inception of the "entomological warfare" programme at Fort Detrick in 1953 [291]. In 1960, a US Army Chemical Corps spokesman told a Congressional committee that the programme had progressed from "concept to feasibility and from basic research to development of a completely new and potentially most effective BW weapons system" [1]. This apparently related to a combination of yellow fever virus and the *Aedes aegypti* mosquito, an insect that seeks out human hosts. (Techniques exist for infecting mosquitoes of this species with the virus—and subsequently keeping the majority of them alive for at least a month—in such a manner that single bites from 30–60 per cent of the insects are capable of initiating the disease in susceptible individuals.) An unidentified vector system is reported to have been field tested on Baker Island in the Pacific in 1965 [292]. On the face of it, however

[38] See Volume I, pp. 217–20, 224–25, 342–47; Volume IV, pp. 196–221; and Volume V, pp. 238–58.

Table 1.5. Some US CB weapons, 1940–1972[a]

Type and designation of weapon	Agent	Payload (kg)	Mechanism
Ground and naval weapons			
Weapons for the individual soldier			
Grenade, frangible, M1	AC	0.3	Impact
Grenade, riot, M6A1	CN-DM	0.11	Burning
Grenade, riot, M7A1	CN	0.17	Burning
Grenade, riot, M7A3	CS	0.12	Burning
Grenade, riot, M25A2	CS1	0.05	Bursting
Grenade, pocket, XM58	CS	0.02	Burning
Grenade, rubber, XM47	CS	..	..
Cartridge, 40 mm, E21	BZ	..	..
Cartridge, 40 mm, XM674 (*Handy Andy*)	CS	0.05	Burning
Cartridge, 40 mm, XM675	CS	..	..
Cartridge, 40 mm, XM651E3	CS	0.03	Burning
Cartridge, 40 mm, soft-nosed, XM627	CS	..	..
Disperser, dry agent, portable, M3	CS1, *or* CN1	4 9	Disperser
Disperser, liquid agent, hand-held, XM23	CS solution	..	Spray
Disperser, liquid agent, hand-held, XM30	CS solution	1.5 litre	Spray
Disperser, liquid agent, hand-held, XM32	CS solution	0.05 litre	Spray
Disperser, dry agent, back-pack, XM33	CS1	..	Disperser
Spray-gun, liquid agent, Mkl Mod 0	CN solution	200 ml	Spray
Special munition, M1	TZ	..	Flechette
Special munition, E2	N, etc.	..	Bursting
Disseminator, dry agent, E41R2	N, UL2, etc.	0.01	Disperser
Pots, generators, cylinders, dispersers			
Generator, F7-A	HD	3	Burning
Generator, 50-lb, M16	BZ	..	Burning
Generator, portable, E22	UL1	2.6	Spray
Generator, portable, E32R1	N, UL2, etc.	1.0	Disperser
Generator, E44R2	BW agent	..	..
Special munition, M5	N, PG, etc.	..	Disperser
Smoke-pot	CS	..	Burning
Smoke-pot, floating, M7	GB	..	..
Cylinder, portable, M1A2	CG	14	Spray
Disperser, dry agent, skid-mounted, M2	CS1	5 per hopper	Disperser
Disperser, portable, M106 (*Mity Mite*)	CS1, *or* Herbicide	3.2 per hopper 3 gallons	Disperser
Land mines			
Mine, land, 1-gallon	HD	4.5	Bursting
Mine, land, 2-gallon, M23	VX	5	Bursting
Artillery, mortar and related projectiles			
Cartridge, 4.2 inch mortar, M2	CG, *or* HT	2.8 2.6	Bursting
Cartridge, 4.2 inch mortar, M2A1	HD	2.7	Bursting
Cartridge, 4.2 inch mortar, XM630	CS	0.9	Burning
Cartridge, 105 mm, M60	HD	1.4	Bursting
Cartridge, 105 mm howitzer, M360	GB	0.7	Bursting
Cartridge, 105 mm, XM629	CS	0.7	Burning
Projectile, 155 mm howitzer, M110	HD	4.4	Burning
Projectile, 155 mm howitzer, M121	GB, *or* VX	3 3	Bursting
Projectile, 155 mm howitzer, XM631	CS	2.2	Burning
Projectile, 155 mm, XM693 (*Cry Pie*)	CS	..	..
Projectile, 155 mm gun, M104	HD	4.4	Bursting

Entered inventory	Remarks
1942	Became obsolete in 1944
Post-WWII	Can be rifle-fired; contains about 70 gm DM
Post-WWII	Can have a CS filling; can be rifle-fired
Early 1960s	Can be rifle-fired; $ 2.94 each in 1972 procurement
Early 1960s	A "baseball" grenade; can have CN1 or DM1 fillings; $ 3.42 each in 1972 procurement
1969	Half the size of the M7A3 grenade. ENSURE 211[b]
1972	..
..	Development curtailed in 1965
1967	Hand-fired, or fired from M79 grenade-launcher or M8 pyrotechnic pistol
1968	ENSURE 36.2
1968	Fired from M79 grenade-launcher. ENSURE 87.3; $ 4.35 each in 1972 procurement
..	Under development in 1972
Post-WWII	Modified M2A1 flamethrower
..	Under development in 1969
1971	Military version of *Mace*
1971	Military version of *Mace*
1972	..
Pre-WWII	Primarily used for shipboard CW training
..	Rifle fired; suited to other toxins, such as botulinal toxin
..	7.62 mm rifle shell with dry agent fill; 'M2XR' tested in 1969
..	Limited procurement in 1964; small rectangular can using carbon dioxide propellant
..	Under development in 1945 as a mustard-aerosol pot
Early 1960s	Component of M44 cluster, but can be used as a pot
..	User-tested in 1958; can also have OU1 or NU fills
..	Limited procurement in 1964; 8-second compressed-nitrogen payload discharge
..	Under development in 1965; a biological 'depositor'
..	Anti-convoy ground-dusting device under development early 1960s
..	ENSURE 216. For air- or ground-delivery; to generate CS aerosols for at least 15 minutes
..	Under development in 1960
1936	Became obsolete in 1946
Post-WWII	Modified crop-duster
1965	Modified petrol-engined air-compressor
Pre-WWII	Can be filled in the field
Early 1960s	Pop-up adapter-projector available
1941	645 000 M2 rounds gas-filled during WWII, about 84 per cent with mustard gas, 8 per cent with phosgene and 8 per cent with CN solutions
Post-WWII	4.5 km range
1968	4 BE canisters; 62 000 issued in South Viet-Nam during 1969–70; ENSURE 87.4
1940s	..
Mid-1950s	..
1968	3 BE canisters; 13 000 issued in South Viet-Nam during 1969–70; ENSURE 87.1; $ 70 each in 1972 procurement
1940s	..
Mid-1950s	..
..	5 BE canisters; under development in 1970. ENSURE 87.2
..	Under development in 1970
1940s	..

Table 1.5. Continued

Type and designation of weapon	Agent	Payload (kg)	Mechanism
Projectile, 155 mm gun, M122	GB, *or*	3	Bursting
	VX	3	
Projectile, 155 mm, binary chemical, XM687	GB2	..	Bursting
Projectile, 8 inch howitzer, M426	GB, *or*	7.2	Bursting
	VX	6.4	
Shell, gas, 175 mm, T223	GB, *or*	6.7	Bursting
	VX	6.0	
Shell, 5″/38, naval, Mk53	GB, *or*	1.4	Bursting
	VX	1.4	
Shell, 5″/54, naval, Mk54	GB, *or*	1.9	Bursting
	VX	1.9	
Shell, 6″/47, naval	GB	..	Bursting
Rocket, 66 mm, XM96	CS2	..	..
Rocket, 3.5 inch, shaped-charge, follow-through, M28A2	GB	..	Bursting
Rocket, 4.5 inch, T164	GB	1.5	Bursting
Rocket, 115 mm, M55 (*Bolt*)	GB, *or*	5	Bursting
	VX	4.5	
Warhead, 5 inch rocket, naval, Mk40	GB	2.2	Bursting
Multiple rocket launchers & ground-launched clusters			
Launcher, 115 mm rocket, 45-tube, M91	GB, *or*	225	(M55 rockets)
	VX	205	
Launcher, 5 inch rocket, 48-tube, naval	GB	105	(Mk40 warheads)
Launcher, 35 mm cartridge, 16-tube, E8	CS	1.2	(E23 cartridges)
Warheads for missiles and large rockets			
Warhead, 318 mm rocket, M206 (for *Little John*)	GB	31	(52 M139 bomblets)
Warhead, 762 mm rocket, M79 (for *Honest John*)	GB	177	..
Warhead, 762 mm rocket, M190 (for *Honest John*)	GB, *or*	217	(368 M139 bomblets)
	VX	210	
Warhead, guided missile, M213 (for *Sergeant*)	GB	..	(M139 bomblets)
Warhead, guided missile, M212 (for *Sergeant*)	GB, *or*	195	(330 M139 bomblets)
	VX	190	
Warhead, guided missile, M210 (for *Sergeant*)	BW agent	..	(M143 bomblets)
Warhead, guided missile, E23 (for *Sergeant*)	UL1	150	(740 E134 bomblets)
Warhead, guided missile, E27 (for *Lance*)	GB	..	..
Aircraft weapons			
Spray and disperser systems			
Spray system for drone, USD-2	UL1	24 gallons	Spray
Disperser, dry agent, helicopter, M4	CS1, *or*	23 per hopper	Disperser
	CN1	49 per hopper	
Disperser, dry agent, helicopter, M5	CS1, *or*	18 per hopper	Disperser
	CN1	40 per hopper	
Spray system, dry agent, helicopter, HIDAD	..	125 gallons	Disperser
Spray system, liquid agent, helicopter, HIDAL	Herbicide	200 gallons	Spray
Spray system, liquid agent, helicopter, AGAVENCO	Herbicide	200 gallons	Spray
Spray system, liquid agent, fixed-wing aircraft, FIDAL	Herbicide	275 gallons	Spray
Spray tank, liquid agent, A/B 23Y-1	Herbicide	..	Spray
Spray system, liquid agent, A/A 45Y-1	Herbicide	1 000 gallons	Spray
Spray system, liquid agent, A/A 45Y-2	Herbicide	..	Spray

Entered inventory	Remarks
Mid-1950s	..
..	In prototype in 1970
Early 1960s	..
..	Under development in 1962; intended for M107 Gun (SP)
1950s	..
1950s	..
..	Under development in 1957
..	Under development in 1970 as a 4-round clip for portable launcher
..	Being developed as an antitank munition in 1965
..	Under development in 1954
1960	For M91 launcher; cost US Army about $ 120 each in early 1960s
Early 1960s	4.2 km range. For Mk 105 launcher. Can take an HD payload
1960	For M55 rockets
Early 1960s	..
1967	4 cartridges per tube; 30 000 issued in South Viet-Nam during 1968–1970; ENSURE requirement no. 36.1
Mid-1960s	Originally the E20 warhead. *Little John* (16 km range) is no longer in service
Early 1960s	95 per cent functioning efficiency, 62 per cent agent-dissemination efficiency. Replaced by M190 warhead. Gives 113 hectare effective area coverage
Early 1960s	Originally the E19R2 warhead: 95 per cent functioning efficiency, 86 per cent agent dissemination efficiency. *Honest John* has 38 km range
..	Originally the E9 warhead; under development in 1964
..	*Sergeant* has 139 km range
Mid-1960s	139 km range. Originally the E23 warhead (?). Under development in 1967
..	Under development in 1967
..	Development began in 1962 and was curtailed in 1970
..	The USD-2 was a reconnaissance drone with 120 mile range
Post WWII	Helicopter-rotor down-draught spreads agent; can be used from a jeep
1950s	Helicopter-rotor down-draught spreads agent; can be used from a jeep
1965	US Navy insecticide duster adaptable to CBW agents
1960s	US Navy insecticide sprayer; used with UH-1 helicopters. One of the first herbicide spray systems to be used in the Viet-Nam War
1967	Insecticide spray system adapted for UH-1 herbicide spray operations in Viet-Nam
1960s	US Navy insecticide sprayer; used with A1-E or A1-H aircraft
..	For A-1E aircraft; under development in 1965
1962	For C-123 or C-130 cargo aircraft; internal tanks, external spray-booms
..	Large pressurized internal tank for C-123 aircraft under development in 1964

Table 1.5. Continued

Type and designation of weapon	Agent	Payload (kg)	Mechanism
Spray system, A/A 45-1	..	..	..
Spray tank, liquid agent, A/B 45-1	BW agent	..	Spray
Spray tank, liquid agent, A/B 45Y-1	BW agent	..	Spray
Spray tank, dry agent, A/B 45Y-2	BW agent	..	Disperser
Spray tank, liquid agent, A/B 45Y-3	Herbicide	..	Spray
Spray tank, dry agent, A/B 45Y-4	BW agent	..	Disperser
Spray tank, dry agent, A/B 45 4-4	BW agent	..	Disperser
Spray tank, A/B 45 4-1	..	..	..
Spray tank, liquid agent, E29R1	VX, etc.	..	Spray
Spray tank, dry agent, E41	N, UL2, etc.	65 gallons	Disperser
Spray tank, liquid agent, E44	Herbicide	..	Spray
Spray tank, liquid agent, M10	HD, etc.	30 gallons	Spray
Spray tank, liquid agent, Mk12 Mod 0	HD, etc.	40 gallons	Spray
Spray tank, liquid agent, M33	HD, etc.	70 gallons	Spray
Spray tank, liquid agent, M40	HD, etc.	200 gallons	Spray
Spray tank, liquid agent, TMU-28B	VX	..	Spray
Spray tank, dry agent, TMU-38/A	Incap.	..	Disperser
Spray tank, liquid agent, TMU-66/A	Herbicide	50 gallons	Spray
Spray tank, liquid agent, PAU-7/A	Herbicide	..	Spray
Spray tank, liquid agent, PAU-7/B	Herbicide	..	Spray
Spray tank, dry agent, Aero X2A	TX, etc.	65 gallons	Disperser
Spray tank, liquid agent, Aero 14B	GB, VX, NU, UL1, etc.	80 gallons	Spray
Free-fall bombs			
Bomb, 100-lb, M47A2	HD	31	Bursting
Bomb, 115-lb, M70A1	HD	27	Bursting
Bomb, 125-lb, M113	HD	..	..
Bomb, 500-lb, M78	CG, *or*	93	Bursting
	CK	80	
Bomb, 500-lb, Mk94	GB	50	Bursting
Bomb, 750-lb, MC-1	GB	100	Bursting
Bomb, 750-lb, BLU-52/B	CS2	123	Impact
Bomb, 1000-lb, M79	CG, *or*	190	Bursting
	CK, *or*	160	
	AC	88	
Bomb, 4 000-lb, M56	CG	1060	Bursting
Bomb, Mk116 Mod 0 (*Weteye*)	GB	..	Bursting
Bomb, *Bigeye*	..	..	..
Bomb, entomological	..	..	..
Cluster weapons[d]			
Canister cluster, 50-lb, E158R2	CS	5	(264 XM16 canisters)
Canister-cluster, 50-lb, XM15	CS	5	(264 XM16 canisters)
Canister-cluster, 130-lb, E159	CS	10	(2 E158R2 clusters)
Canister cluster, 130-lb, XM165	CS	10	(2 XM15 clusters)
Generator cluster, 175-lb, M44	BZ	..	(3 M16 generators)
Bomb cluster, 100-lb, M12	HD	26	(14 M69 bombs)
Bomb cluster, 500-lb, M19	HD	71	(38 M69 bombs)
Bomb cluster, 500-lb, M31	HD	..	(38 M74 bombs)
Bomb cluster, 750-lb, M43 (or CBU-5/B)	BZ	39	(57 M138 bombs)
Bomb cluster, 750-lb, E108R2	BW agent	..	..
Bomb cluster, 750-lb	BW agent	..	..

Entered inventory	Remarks
..	Internal tank, external booms
..	Under development in 1967; expendable; suited to F4-C aircraft
..	A 1962 USAF requirement under development in 1965. An expendable munition about 85 cm in diameter and 400 cm long, for high-speed tactical aircraft
..	Under development in 1969; tested with rice-blast spores
..	Under development in 1966; designated TMU-28/B with nerve-gas fill
..	Under development in 1966; tested with PG toxin agent
..	Mid-1960s design; for FlOO, F105 and F4-C aircraft
..	Suited to CNU-103/E shipping container, as is the A/B 45Y-I tank
..	Used for high-altitude release trials in 1962
..	75-140 kg payload; under development in 1965 for F100, FlO5, F-4C and A-4D aircraft
	Under development in 1964 for *Mohawk,* etc., aircraft
1940	Expendable; 92 000 produced for mustard gas during WWII; 4 per A20-A plane
..	US Navy smoke-tank for A-4B, etc., aircraft; weighs about 500 kg filled. Has been used with CS in Viet-Nam
1942	Nonexpendable; contours of 2 000-lb bomb; 2 per B-25 bomb-bay; 21 000 made in WWII
1942	Contours of 4 000-lb bomb; for wing-racks of B17 and B24
1966	For Fll l-A, etc., aircraft; in-board station of F105
	Under development in 1965 for F-105, etc., aircraft
1969	For low-or-high-speed aircraft; a modular design, whereby up to 4 tanks can be mounted on a single wing station
..	Under development in 1970 for F-4, etc., aircraft
..	A modified version of the TMU-28/B
	About 5 m long; suited to F-3D, F-7U, F-2H2 and A-4D aircraft
1960s	US Marine Corps spray tank for A-4D, AD-5, AD-6, AD-7 and FJ-4B aircraft; about 5 m long
Early 1940s	Heavily used in WWII with incendiary fill; obsolete for mustard soon after war
Mid-1940s	About 1.3 m long and 20 cm in diameter; 0.06 hectare instantaneous area coverage'
Late 1940s	Became obsolete in mid-1950s
1942	About 1.5 m long and 50 cm in diameter; 33 000 were filled with CK during WWII
1950s	US Navy and Marine Corps weapon. 0.6 hectare instantaneous area coverage
1950s	Modified 750-1b demolition bomb; 16 per F1O5-D/E/F aircraft; 1.3 hectare instantaneous area coverage. Previously, El 10
1968	Converted BLU-1 napalm tank; 1700 issued in South Viet-Nam 1968-1970
1943	63 000 gas-filled during WWII; 90 per cant of them with CK; AC filling obsolete by 1961; about 175 cm long and 50 cm in diameter
	Experimental WWII weapon
1966	Replacement for Mk 94; said to be a 500-1b guided bomb
..	Under development in 1966; apparently a binary VX weapon
..	Presumably for vector-delivered BW agents
1967	Eight modules, each of 33 canisters; hand-dropped from aircraft up to 350 knots; ENSURE 30
1969	Modification of E158R2; $403 each in 1972 procurement
1967	For light aircraft fitted with bomb-shackles
1969	Modification of El59
Early 1960s	For wing-racks of light aircraft, such as Ll9, L20 or Mohawk
WWII	Obsolete for mustard-filling soon after WWII
WWII	Obsolete for mustard-filling soon after WWII
WWII	Obsolete for mustard-filling soon after WWII
Early 1960s	For subsonic delivery
..	Under development in 1954
..	Under development in 1965; ***Sadeye*** cluster of Flettner rotors

Table 1.5. Continued

Type and designation of weapon	Agent	Payload (kg)	Mechanism
Bomb cluster, 1000-1b M34A1	GB	90	(76 M12SA1 bombs)
Bomb cluster, El33	BW agent	..	(E61 R4 bombs)
Bomb cluster, M33	AB	. .	(M114 bombs)
Bomb cluster, ***Misteye II***	GB, ***or*** VX	.. ..	..
Canister dispenser system, XM27	C S	8	(72 XM54 grenades)
Canister dispenser system, CBU-l9/A	CS	. .	(BLU39/B23 canisters)
Canister dispenser system, CBU-3O/A	C S	25	(1280 XM16 canisters)
Bomblet dispenser system, CBU-15/A	GB	69	(BLUl9/B23 bomblets)
Bomblet dispenser system, CBU-16/A	BZ	31	(BLU2O/B23 bomblets)
Bomblet dispenser system, ***Padeye 1***	BZ	. .	. .
Bagged-agent dispenser system, XM28	CS2	326	(2 090 paper bags)
Bomblet dispenser system, XMC-1	UL1	180, ***or*** 950	(1944 El20 bomblets) (4608 El34 bomblets)
Dispenser system, BW submunitions	..	. .	. .
Air-to-ground rockets			
Rocket, LSFFAR, 2.75 inch, XM80	CS	. .	
Rocket, LSFFAR, 2.75 inch, submunition warhead, XM99	CS	. .	. .
Submunitions used in certain air and ground weapons			
Canister, XM 16 (previously E49)	CS	0.02	Burning
Cartridge, 35 mm, E23	CS	0.02	Burning
Grenade, XM54	CS	0.12	Burning
Canister, BLU-39/B23	CS	. .	Burning
Bomb, 6-lb, M69	HD	1.87	Tail-ejection
Bomb, 10-1b M74	HD	. .	Tail-ejection
Bomb, 10-1b E29R1	HD	1.1	Burning
Bomb, 10-1b M125A1	GB	1.18	Bursting
Bomb, 10-1b Ml38	BZ	0.68	Burning
Bomb, E61 R4	BW agent	. .	. .
Bomb, M114	AB	..	Bursting
Bomblet, E112	GB	. .	
Bomblet, spherical, E118	GB	. .	Bursting
Bomblet, spherical, 4.5 inch, E13OR2	GB	..	Bursting
Bomblet, spherical, 4.5 inch, El33	GB	. .	Bursting
Bomblet, spherical, El39	GB, GD, etc.	. .	. .
Bomblet, spherical, Ml39	GB	0.6	Bursting
Bomblet, BLU-19/B23	GB	>0.6	Bursting
Bomblet, BLU-2O/B23	BZ	..	Burning
Bomblet, BLU-2l/B45	UL2		
Bomblet, BLU-22/B45	UL1	. .	. .
Bomblet, US Navy	G-agent	1.4	. .
Bomblet, US Navy	V-agent	0.45	. .
Bomblet, spherical Ml43	BW agent	. .	Bursting
Bomblet, 4.5 inch, spherical, El20	ULl, etc.	0.1	Spraying
Bomblet, 3.4 inch, spherical, El34	UL1, etc.	0.2	Bursting

Notes:

a This list includes many experimental weapons-most, if not all, of the BW devices, for example-that failed to reach the standardization or qualification stages of the development process; others that are listed are still undergoing development.

b ENSURE is an acronym for Expedite Non-Standard Urgent Equipment. It denotes an administrative procedure developed during the Viet-Nam War for accelerating the fulfilment of urgent requests from field-commanders for new items of equipment. ENSURE development projects circumvented the normal R,D,T,Ecycle.

Entered inventory	Remarks
1954	For subsonic delivery; now obsolete; cost about $ 1200 each in mid-1950s; 3 hectares instantaneous coverage
..	Under development in 1958
..	Under development in 1957
..	Under development in 1966
1968	XM18 (SUU-14/A) 6 tube horizontal-ejection dispenser; for use up to 300 knots from UH-1 helicopters or light aircraft
1968	2400 issued in South Viet-Nam during 1968–1970
1968	SUU-13/A 40 tube downward-ejection dispenser; for high- or low-speed delivery
1968	SUU-13/A dispenser; for high- or low-speed delivery
1968	SUU-13/A dispenser; suited to high-speed, low-altitude delivery
..	Under development in 1966; for high-speed delivery
..	19 tube downward-ejection device for sling-loading under UH-1 helicopter. ENSURE 215, under development in 1970
..	24-tube downward-ejection system; one dispenser per B47 bomber or two per B-52
..	Under development in 1965; *Gladeye*-dispensed Flettner rotors
..	Under development in 1970
..	Under development in 1970
1967	Size of a flash-light cell; for E158, XM15, E159, XM165 and CBU-30/A
1967	For E8 launcher; skitters on ground, as does XM16 canister
1968	M7A3 grenade with modified fuse; for aircraft dispensers, such as XM27
1968	For CBU-19/A; skitters on ground
WWII	Obsolete soon after WWII, except with incendiary filling; for M12 and M19 clusters
WWII	Obsolete soon after WWII, except with incendiary filling; for M31 cluster
..	Experimental WWII weapon, intended for a 64-bomb cluster
1954	Now obsolete; for M34 cluster
Early 1960s	For M43 cluster (CBU-5/B)
..	For E133 clusters; under development in 1958
..	For M33 clusters; under development in 1957
..	Used in a 1957 *Corporal* warhead field test
..	Under development in 1958
..	Tested in *Little John*, *Honest John*, *Corporal* and *Sergeant* warheads by 1962
..	Under development in 1958
..	Tested with GA, GB and GD fillings during 1968–1969
Early 1960s	For *Honest John*, *Little John* and *Sergeant* warheads; previously, E130R2 (?)
1968	Larger than M139 bomblet; for CBU-15/A dispenser system
1968	Similar contours to BLU-19/B23; for CBU-16/A dispenser system
..	Under development in 1966
..	For SUU-13/A dispensers; under development in 1966
..	Tested in 1969
..	Tested in 1969
Mid-1960s	For *Sergeant* warhead; same size as E139 and M139 bomblets
..	Plastic, with pyrotechnic pressure source. Under development in 1960; primarily for XMC-1 dispenser
..	Plastic, for wet biological fills. Under development in 1962; primarily for *Sergeant* warhead

[c] By "instantaneous area coverage" is meant the area over which the payload of the weapon has spread 30 seconds after detonation.

[d] Other aircraft CW and BW cluster weapons are the CBU-2A/A and CBU-7/A munitions, which were under development in 1966. They may be carried by B-57 aircraft.

Sources:

The table is compiled from information contained in references [9–10, 42–45, 47, 69, 195, 222, 246, 254, 278, 280, 319, 420, 616, 729 ,731 ,767, 828, 1234, 1347, 1430–1449, 1599, 1613–1617].

vector delivery of BW agents seems to be much less important than aerosol delivery.

To illustrate the variety of possible CB weapons, table 1.5 lists some of the US devices that have been referred to in the open literature.

II. *Defences against CB weapons*

Defences against antipersonnel CBW

A CBW attack is more difficult to defend against than to deliver. The defence is technologically more demanding than the offence. To be effective against antipersonnel CB attack, it must embody a clear understanding of the many problems involved, a considered stratagem for dealing with them, efficient organization and training of personnel, and well deployed supplies of special protective equipments. We begin by describing the latter.

There are four basic lines of defence for the individual against antipersonnel CBW agents. First, there are the normal physiological defence mechanisms of the body. These have evolved over the generations to counter the many different toxic or infective challenges to which the body is exposed in daily life. Some can be boosted to counter the effects of CBW agents as well, as for example in the use of prophylactic vaccines. Second, there are the possibilities of physical protection. CB weapons of the bulk-dissemination type work by contaminating the environment. If people can be shielded from their environment, they will not succumb to CB attack. The air they breathe can be filtered; their skin can be protected inside special clothing; or they can remain inside air-conditioned shelters. Third, there are the chemical countermeasures that can be used to destroy environmental contaminants before they do any harm—disinfectants, for example, to destroy BW agents, and special "decontaminants" to decompose or absorb toxic chemicals. Finally, there are medical countermeasures that can be used if all else fails—antidotes to counter the effects of poisons that have entered the body, drugs to relieve their effects until the body can cope with them, antibiotics to prevent or retard the build-up of infections, and so on. To be sure, not one of these lines of defence will always be perfect or fool-proof, but together they can be expected to blunt most forms of CB attack, provided they are exploited with reasonable efficiency. And it is to be noted that 100 per cent protection is not necessarily the objective. What is needed is a level of protec-

tion that is sufficiently high to render CBW attack uneconomical or otherwise unattractive to the attacker.

This section describes briefly the main features of modern CB protective equipments and procedures, and discusses their efficacy in the context of civilian defence and combat operations. For a fuller account, the reader is referred to the many standard textbooks and manuals on the subject, for in contrast to the offensive side of CBW, there is a substantial body of open literature on the defensive side [37, 293–315]. As might be expected, however, official publications in this area tend to be reticent on any inadequacies that the protective equipments or procedures described may possess.

Detection of CBW agents

With the exception of the chemical irritants, the most potent types of antipersonnel CBW agent are not detectable by the unaided human senses when present in casualty-producing quantities. They may therefore exert their effects before defensive countermeasures can be taken. Special warning devices are therefore of great importance. Indeed, against some modes of CB attack, the defence may stand or fall according to the efficiency of its agent detection and alarm capabilities. In some situations, the warning system should ideally be automatic, but this will rarely be feasible at the present time.

In addition to their warning function in alarms, agent detectors will also be important after an attack has taken place, for purposes of "confirmation monitoring". They will be needed to guide decontamination operations, and to indicate when it is safe to relax physical protection. For decontamination duties, manually operated devices, rather than automatic ones, will be adequate: the requirement is not so much for rapidity as for specificity. For CW agents, a range of simple and ingenious detectors has been developed over the years. There are test papers and test powders which change colour in contact with liquid CW agents, and there are air samplers which can suck suspectedly contaminated air through tubes of colour-changing test reagents. Such devices are standard issue for many national armed forces and civil defence organizations. BW agents present more of a problem.

As regards automatic detectors, it is really only the nerve gases among the CW agents that call for them. Most other agents have enough odour or irritancy to warn of their presence, or are unsuited for use in situations where automatic alarms would be of any value. The nerve gases are toxic enough to suggest employment in off-target attacks which, in contrast

to on-target attacks, can be mounted without audible or visible warning from delivery vehicles. A second important function of automatic nerve-gas detectors is in the rapid reconnaissance of possibly contaminated terrain.

A need for automatic nerve-gas alarms has been felt since the nerve gases were first developed, yet it is only recently that devices suitable for field use have become standard military equipment, and even then only in a very few armies. The technical difficulties and the design problems are great. There have been two main approaches: point-source alarms and area-scanning alarms. In the first, the device analyses air sampled automatically from its immediate surroundings. Several different analytical techniques for nerve gas have been adapted for this purpose, initially colourimetric ones, but more recently enzymatic and electrochemical ones, and devices based on changes in surface potential [316]. The sensitivity of the latest alarms is not openly published information, but some of the older colourimetric devices could respond to Ct-dosages of 1 mg-min/m^3 or less [295, 375]. Equipment of this type could be valuable in reconnaissance missions, for which purpose it might be mounted on scout cars or helicopters, or carried by special patrols. To be useful against off-target attacks, several such alarms would need to be placed some hundreds of metres upwind, and linked to a central warning system [317], requirements that may be difficult to satisfy in many tactical situations. This on-site approach, as embodied in the US Army's M8 alarm standardized in 1969 [318–319], is further advanced than the second approach, which, however, seems better suited to warning against off-target attacks. Here the intention is that instead of analysing actual air samples, the alarm should monitor distant air with special beams of radiation. The underlying principle is that of infra-red spectroscopy. A number of different experimental devices have been constructed and tested [320], but without as yet fulfilling all the requirements made of them. Their power consumption, for example, can be enormous, particularly those that are intended to be used like radar to scan wide areas, employing laser beams for Raman spectroscopy [321].

Against substances as potent as the nerve gases, the requirement must be for almost instantaneous detection against a background of normal air pollutants. This combination of rapidity and selectivity seems to be possible for the nerve gases, but for BW agents it is unattainable at the present time. Various prototype BW alarms exist, but they all make a trade-off between selectivity and rapidity of response. The difficulties arise because of the minute concentrations that have to be detected, and from the problems of distinguishing pathogenic microbes from the non-patho-

genic ones that are invariably present in the air, not to mention the multitude of inanimate particles also present.[39] Moreover, the alarm may not be of much value unless it can respond to a high proportion of all the different species of pathogenic microbe that might be used in a BW attack. There are many scores of these. The swiftest acting devices work by detecting abnormally high aerosol particle counts, leaving the user to judge whether this is due to natural phenomena or to enemy action. Such particle counters may, like the nerve-gas alarms described above, either be air samplers or long-distance air monitors. Notable among the latter is the British experimental LIDAR[40] device, which can be used to scan incoming air over coastlines, for example, or to monitor and track effluents from high-speed aircraft [323–324]. The rudimentary detection capability provided by particle counters can be made more discerning only at cost of retarded reaction times. Likewise, although techniques have been developed in recent years for identifying specific airborne pathogens within a few minutes, only those for which preparations have been made can be identified. An attacker is hardly likely to advertise which agent he will employ. As is described further in chapter 4, in appendix 1 and in Volume VI, the most promising compromises between rapidity and selectivity are offered by the various fluorescing or radioactive antibody techniques.

The fact that discriminating BW alarms do not yet exist is to some extent compensated for by the delay before the effects of BW agents manifest themselves, and by the apparently greater military attractions of off-target BW attacks compared with on-target ones: relatively slow-responding devices monitoring the air upwind of a target may still give adequate warning during the time the BW agent takes to reach the target. Moreover, during the period between the arousal of suspicion and the confirmation of BW attack, it may be possible to organize damage-limiting countermeasures: there are, for example, medical treatments that can be given during the incubation period that can suppress or greatly reduce the severity of many diseases. But these are not strong grounds for optimism. It might well happen that the delivery of a BW attack arouses no suspicion whatever; and no post-attack countermeasures can compare in efficacy with the protection afforded by physical countermeasures were there advance warning of attack.

[39] The concentration of viable bacteria in outdoor air fluctuates widely, but rarely exceeds 1 000 organisms per cubic metre. The normal protein concentration of outdoor air is around 0.003 mg/m³ [322].

[40] See *SIPRI Yearbook of World Armaments and Disarmament 1968/69* (Stockholm: SIPRI, 1969), p. 133, note 30.

Physical protection: respirators, protective clothing and collective shelters

The respirator, or "gas mask", is the basic component of any CBW defence. It can also serve as a protective mask against radioactive fallout from nuclear weapons. Most of the modern designs are refinements of the pioneering developments made in the 1920s and 1930s, which themselves grew out of the trial-and-error expedients of World War I.[41] Modern respirators are expected to reduce the concentration of contaminants in the air passing through them by a factor of at least a hundred thousand [325]. Severe though this requirement may be—99.999 per cent filtration efficiency—it has nonetheless proved possible to fulfil it. Robust filter elements made of activated charcoal (for vapour adsorption) treated with catalyst impregnants (to cope with desorption problems) and of pleated glass or plastics fibre paper (for retention of finely divided particulates) that meet the specification can be mass produced. So can outlet valves for exhaled air, which at one time were a major point of weakness in respirators, especially in cold weather. In principle, then, perfect protection of the respiratory tract is possible, whether challenged by CW or by BW agents. Nor is any agent likely to be found in the future capable of penetrating existing respirators in dangerous quantities. The only noxious substances against which the protection is poor are certain small-molecule toxic gases, such as carbon monoxide; but these will rarely be practical CW agents.

The main outstanding difficulty arises from the close fitting of the mask around its wearer's face and head. A respirator is much more likely to leak because the wearer has been careless in putting it on, or has not shaved properly, than because of inadequacies in filter or valve design. The face-sealing method used must not delay the process of donning the respirator. Today, soldiers are expected to do this within 10 seconds [325], although during exercises at least twice this amount of time is common [326]. Soldiers are also expected to hold their breath while doing so (but often they fail to do so in practice [327]).

Once on, a respirator is an appreciable burden to its wearer, restricting his vision, limiting his ability to communicate, and hampering his breathing. Respirators are, of course, designed to minimize these restrictions, and modern designs are a substantial improvement on those of World War II. In the current British service respirator, the S6, the wearer is allowed 75 per cent unimpeded vision and his voice carries to at least one-third of the distance that it would normally [325]. The current US design, the

[41] For a short historical account of this work, see Volume I, pp. 52–56 and 88–90.

M17A1, has a fitting that allows the wearer to drink safely from a canteen [328]. It is said that, with sufficient training, combat soldiers can perform almost as efficiently when wearing respirators as without them; the evidence for this comes from the subjective assessments of soldiers on field exercises, and from controlled experiments. In one such experiment, it was found that the performance of an experienced smoke-generator team decreased by only about 5 per cent when its members were made to wear respirators [329]. It is to be noted, however, that this experiment was performed in daylight and under cool, pleasant weather conditions. Whether the results would have been the same under tropical conditions, for example, is not at all certain. When US forces started using irritant agents in the Viet-Nam War, a crash programme was soon initiated to develop less burdensome protection [330].[42]

It is much more difficult to provide as high a level of protection for a man's skin as for his respiratory tract, or at any rate to do so without encumbering him to the point of uselessness. Ordinary combat clothing can give a fair measure of protection, but only for short periods. Liquid nerve gas and mustard gas are remarkably penetrative substances, easily capable of soaking through most normal textiles, even through shoe leather. It is therefore necessary to have some form of special skin protection available. Ideally it should be clothing suitable as regular combat uniform, but this is not yet technically feasible, at least not with the necessary degree of protection.

When mustard gas was first encountered during World War I, overgarments made of oilcloth were sometimes used as protection. This material was certainly impermeable to the agent, but at the same time it was also impermeable to air and water vapour. Although a man wearing it was safe from liquid mustard gas, he quickly became overheated and exhausted because the clothing interfered with the cooling system of the body, namely the sweating process. It is still the case nowadays that high-level skin protection can only be provided by air-impermeable clothing, and because of the heat stress this clothing creates it cannot be worn for long periods. Complete suits of clothing made from rubberized cloth or lightweight plastics are standard equipment only for decontamination personnel.

Over the years since World War I, there has been an intensive search for clothing materials impermeable to agent, but permeable to air and

[42] This resulted in the XM28 mask, which weighed less than half a kilogram, about half that of the M17. The weight reduction was possible because only protection against particulate aerosols was needed, not against agent vapours as well.

water vapour.[43] There have been several promising approaches, but none of them has been more than partially successful. Heat loss is always impaired to some extent, and the effective lifetime of the clothing is never long. Thus, as regards heat accumulation, a field commander operating under conditions where CB weapons might be, or are being, used might have to make a trade-off between heat casualties and CB casualties [331].[44] A recent model of the British *CB suit,* a permeable protective overgarment that has been adopted by a number of other NATO countries, is made from a non-woven synthetic textile coated on the outside with a liquid repellent,[45] and having a layer of activated charcoal bonded to the inside [335]. The outer coating impedes penetration of liquid agents into the cloth, while the inner coating absorbs any agent vapour that might get through. The suit looks heavy and cumbersome, but in fact it is remarkably light, and it is reported that trials in the tropics have shown that it has little effect on a man's efficiency [323]. Its main defects seem to be its shelf-life (i.e., the length of time it can be stored without deteriorating), said to be not much more than a year [336], and its poor tear-resistance: each British soldier has to carry two CB suits and have four more held for him in reserve. Later versions of the CB suit are to be made from a promising new material known as *carbon cloth,* a woven active-carbon containing fabric that is strong and tear-resistant.[46]

Although this carbon cloth is a substantial improvement on previous permeable antigas textiles, and might even be made into regular combat clothing, it is nonetheless considered in some quarters that the most satisfactory material will eventually emerge from a rather different approach,

[43] This search is described briefly in Volume I of this study, pp. 90–92.

[44] The current edition of US Army Field Manual FM 21-40, *Chemical, Biological and Nuclear Defense,* specifies three levels of Mission Oriented Protective Posture. The minimum level consists of soldiers wearing normal duty uniform and carrying their respirators, protective hoods and gloves; the intermediate level has them in permeable protective clothing, but still only carrying their other protective items; at the maximum level, they are in full protective rig. Commanders are expected to select the level most appropriate to their mission, and it is suggested that they may reduce the hazard of heat stress by mixing the levels of protective posture among members of their units, or by rotating troops to different MOPP levels to relieve body-heat build-up.

[45] One that is both hydrophobic and oleophobic. Several such repellants are available. One type that has been closely studied for nerve-gas repellency comprises a family of highly-fluorinated hydrocarbon compounds that have a group at one end of the chain that can bond readily to the fibres of the cloth. In the case of certain synthetic textiles, repellents made from Werner-type chromi-nuclear complexes in which the acido-groups are long-chain perfluoroalkanoyl radicals have proved satisfactory [332–334].

[46] The novel feature of the British carbon cloth is the technique used to achieve a uniform distribution of carbon particles that is both stable, does not completely block up the interstices of the textile, and can be mass produced. The carbon impregnation of textiles has been closely studied since before World War II [337–338].

namely, the use of clothing impregnants that destroy rather than merely adsorb invading chemicals. The traditional impregnants for this purpose —ones that were used in the standard anti-vesicant garments of World War II—are active-chlorine-containing compounds such as CC-2 [339–342][47] and other chloroimides [343–344]. The deficiencies of these materials mostly stem from the relatively large amounts of impregnant that have to be incorporated into the cloth;[48] one approach which might remedy this would be to use impregnants capable of catalyzing the air oxidation, autoxidation or hydrolysis of invading CW agents. If such catalysts can be found—and active searches have been going on for some time [345]—relatively small quantities may suffice. Protective clothing of this type, however, would probably be once-only garments: the attraction of the carbon-cloth approach is that it permits re-use after contaminants have been desorbed by suitable laundering processes.

If adequate coated or impregnated air-permeable protective clothing proves to be unattainable, there remains a further possibility that is currently being explored, namely, the use of air-conditioned, air-impermeable suits. Existing outfits of this type completely encapsulate the wearer, his head being inside a helmet that is integral with a one-piece suit of impermeable clothing that fastens closely around the wrists and ankles. The suit is fitted with air inlet and outlet valves through which the wearer's breathing and cooling requirements can be satisfied. This sort of protection is provided for high-risk workers in some agent-manufacturing or -processing plants, each worker being linked through a hose to a central air supply line [346]. As regards combat soldiers, programmes for adapting the principle to regular combat clothing are currently under way. In a US Army design at present at the stage of exploratory development, the soldier carries a back-pack that sucks air into the suit through a filter; the complete outfit weighs about 25 kilograms [347–348].

In the absence of adequate protective suits meeting the requirements of regular combat clothing, other methods have to be used for the skin protection of combat troops. The most widely issued item today is the antigas cape. This is a lightweight impermeable overgarment that a soldier can wrap around himself when he comes under CW attack and subsequently discard if it becomes contaminated. Several varieties are in use (although in an increasing number of countries they are being superceded by air-permeable overgarments). They range from such things as large ground-sheets to fashioned garments that can also serve as raincapes or

[47] The US Army code-name for *sym*-bis(chloro-2,4,6-trichlorophenyl)urea. CC-2 does not react efficiently with G-agent nerve gases, but it does with V-agent ones.
[48] The limitations are described further in Volume I of this study, pp. 90–91.

raincoats. Alongside these are lightweight impermeable hoods, leggings, gloves and overshoes, also to be discarded after contamination. All these can be used in conjunction with existing types of impregnated battle-dress or undergarments. The skin protection they afford is certainly not perfect, offering no protection against vapours, and in warm climates they cannot be worn for very long periods. Nonetheless, they are believed capable of significantly reducing the numbers of percutaneous casualties that might otherwise occur. Soldiers are expected to be able to don their protective cape and their respirator (usually in that order) within 15 or 30 seconds.

The third important form of physical protection is the collective shelter. Most recently designed armoured fighting vehicles and personnel carriers can be hermetically sealed and supplied with filtered air. Auxiliary collective shelters range from normal rooms or air-raid shelters fitted with CB filters (and also maintained at a slight overpressure to prevent ingress of contaminated air through leaks and fissures) to special collapsible shelters for field use—inflatable ones, for example. The US Army's new 10-man XM51 Collective Protective Shelter System (CB pressurized pod) [349–351] and the 2- to 6-man XM15 Collective Protective Equipment [352] are examples of the latter. Their function is to serve as CB-protected command posts or as safe refuges on a contaminated battlefield where soldiers can relax from the fatigue of wearing protective clothing, and perform bodily functions.

Chemical countermeasures: decontamination

Provided areas of CBW-agent contamination can be located, it is no great problem to remove surface layers of agent with decontaminating chemicals or disinfectants (although liquid agents absorbed in soil, paint, masonry or asphalt may be a good deal less tractable). Such treatments need not be 100 per cent efficient in themselves; it may be sufficient if they reduce the hazard to the point where natural weathering processes can be relied upon to complete the task. The main difficulties arise where the time available for decontamination is short or has to be kept to a minimum, as on an active battlefield, or when a man's skin has become contaminated. The success of a CBW attack may be measured not only in terms of the numbers of casualties secured, but also in terms of the time delay it forces on the enemy while he cleans himself up. For the most part, it is only the involatile liquid CW agents and the spore-forming BW agents that will call for special decontamination measures. For other agents, wind, rain, sunlight or soil chemicals will generally suffice.

The most widely used decontaminants are based on hypochlorites such

as bleaching powder, as they have been since World War I. Bleaching powder, particularly superchlorinated bleach, provides a convenient source of active chlorine, an oxidizing agent that is capable of decomposing most CW agents and of destroying pathogenic microbes. It may be used in many different ways. It is common practice to issue individual soldiers with small dusting cans of the powder which they can then use on contaminated skin or weapons. It is also common practice to have large supplies of bleach on hand for dusting in bulk on contaminated terrain, and for making up into slurries that can be sprayed over contaminated vehicles and other equipments.

Against the many assets of bleach, not the least of which is its cheapness, there are certain drawbacks. It is a relatively unstable substance, tending to lose chlorine on storage. It is corrosive, and may rapidly rust metals. Its efficiency declines sharply with decreasing temperature, so that below freezing point it becomes practically useless. When sprayed as a slurry, it tends to clog up spray nozzles. For these reasons, a range of other decontaminants has been developed for use alongside bleach in situations where these drawbacks would become serious.

Some of these alternative decontaminants are described in Volume I of this study.[49] One of the most recent is the US Army formulation known as *DS-2*, which is coming into increasing use in other armies. Although expensive, it can be used effectively at temperatures as low as −25°C and, being a liquid under all climatic conditions, it is readily amenable to spraying. In contrast to bleaching powder, it is not an oxidizing agent, working instead by base-catalyzed hydrolysis. Its active ingredient is diethylenetriamine, and it can be used against all the standard CW agents and most BW agents except the spore-forming ones (which can best be disinfected with bleach slurries)[50] [294, 353]. Special BW agent decontaminants include such traditional disinfectants as formaldehyde, together with ethylene oxide, β-propiolactone and peracetic acid [294]. They may be applied directly to contaminated surfaces or fed into the air of decontamination chambers or contaminated enclosures.

Heat is also an effective decontaminant besides or in addition to the chemicals just described. It may be used in the form of fire, steam, boiling water or hot air. In very cold weather it may be the most satisfactory decontaminant available. The Swedish Army has developed a portable hot-air blower, to be used in conjunction with a tent containing the contaminated items. It works on the pulse-jet principle, burning petrol, and

[49] See Volume I, pp. 93–95.

[50] Ten kilograms of DS-2 solution suffice for about 0.2 kg of mustard gas, 0.5 kg of sarin or 1 kg of VX. Ten kg of bleach can destroy about 7 kg of sarin or 4 kg of mustard [294].

can raise the temperature inside the tent to 130°C at a ventilation rate of 500 m^3/hr. It decontaminates by volatilizing away any CW agents (meaning that the downwind side of the tent will be hazardous) and by heat-sterilizing any pathogens present [326]. It is valuable in cold weather because the running water which is essential for many decontamination procedures may not be available.

Medical countermeasures: prophylaxis and therapy

A BW attack is more likely to pass unnoticed by the target population than is a CW attack, so that warning may come too late for the population to seek the physical protection of respirators and collective shelters. For this reason, medical countermeasures play a more important rôle in BW defence than they do in CW defence.

The effects of BW agent on the human body are the result of a complex interaction of two living biological systems—the agent and the victim—each capable of modifying or being modified by the other. There are probably more possibilities for altering the outcome of the interaction in a favourable manner than there are in the case of CW attack, for this involves only one biological system. The possibilities are further enhanced by the lengthiness of the incubation period that separates the manifestation of disease from the onset of infection.

First, there are the possibilities for altering the manner in which the human body responds to infective challenge. Most important here are the possibilities for immunizing people against disease, and therefore protecting them in advance against BW attack. The immunity may be specific or nonspecific. The former requires foreknowledge of the agents likely to be used in the attack. The latter may provide barriers against a wide range of agents, but as it is short-lasting (in the forms so far encountered) it requires foreknowledge of the likely time of attack.

Nonspecific immunity is not yet well understood, and as a basis for BW defence it is more of a future possibility than a present actuality. It has been observed that when certain substances are administered to animals—bacterial lipopolysaccharides, for example, or nucleic acid preparations—the resistance to some types of infection is increased for an appreciable time thereafter. Quite why this should be so is still obscure. In the case of resistance to viral infection, it has been shown that this may be caused by provoking cells to synthesize a protein known as *interferon* which can prevent multiplication of invading viruses.

Specific immunity can be induced in two ways. *Active immunoprophylaxis,* more familiarly known as vaccination, involves inoculation with a preparation either of the dead pathogen, or of an attenuated strain

of it, or of antigenic fragments obtained from it. This leads to the production of antibodies that can destroy some or all of the pathogenic microbes that may later invade the body. Effective vaccines are available against many potential BW agents, but by no means all of them [354]. In some cases the immunity conferred is rather weak, and may be overwhelmed with large doses of the BW agent. In some cases also, the immunity is short-lived, so that vaccination may need repeating frequently, sometimes as often as every 3 months. In other cases, the immunity may last for many years.

Between 2 and 4 weeks elapse between vaccination and the development of full immunity. This may be too long for BW-defensive purposes. In that event, the other technique, *passive immunoprophylaxis*, can be considered. This requires injection of serum preparations made from the blood of animals that are immune to the disease in question. The body is thus being supplied with specific antibodies, rather than being stimulated to produce them.

Immune sera may also be used to check a disease after a man has become infected, a technique known as *immunotherapy*. Human gammaglobulin preparations offer similar possibilities, but the stocks available will rarely be sufficient for wide use. It is also conceivable that in the future, interferon may be used in the therapy of viral diseases. These matters are discussed further in appendix 1.

The other forms of therapy are based on the possibilities for altering the damaging propensities of the invading pathogen. For the most part they are antibiotic or chemotherapeutic treatments, of which there are many different types, each having varying degrees of efficacy against different pathogens. Antibiotics are complex chemicals usually obtained from micro-organisms; their effects on pathogens range from a rapid lethality to a slowing down of the microbial metabolism to a point where the body can cope with the infection. Some antibiotics are specific for particular pathogens; others, known as *broad-spectrum antibiotics*, are effective against a wide range. It is the latter—such things as chloramphenicol, the tetracyclines and, more recently, such semisynthetic penicillins as ampicillin —that are of greatest value to a BW defence. Their main drawback is that microbes become resistant to them, or at least to particular types of them. This raises the possibility of the attacker using antibiotic-resistant strains of BW agent.

With certain rare exceptions,[51] the generally available antibiotics are

[51] The *Bedsonia* group of viruses are an important exception. One member of this group is the causative agent of psittacosis (or ornithosis), often regarded as a potential BW agent.

Table 1.6. Medical countermeasures against potential BW agents[a]

Agent species	Regions where disease occurs naturally	Post-infection immunity	Prophylaxis	Therapy
Influenza virus	Worldwide	Short-lived and strain-specific	Vaccines available against particular strains; need yearly boosting	No specific therapy available
Chlamydia psittaci	Worldwide	Uncertain extent	Vaccines still experimental; antibiotics may be useful	Chloramphenicol or a tetracycline: these reduce mortality, rather than shorten the disease; penicillin-G also effective
RSSE virus	Central Europe, Scandinavia, USSR	Solid and long-lasting	Attenuated living vaccine available	No specific therapy available
Yellow fever virus	Central and southern Africa and USA (not known in Far East)	Life-long	Attenuated living vaccine available that gives several years' solid immunity	No specific therapy available
Dengue virus	Tropical and subtropical mosquito (*Aedes*)-ridden areas	Long-lasting but strain-specific	Vaccine available	No specific therapy available
Chikungunya virus	Central Africa and southern Asia	Uncertain	No vaccine yet reported but could be developed	No specific therapy available
VEE virus	Northern South America	Uncertain duration and solidity	Attenuated living vaccine available; gives solid, long-lasting protection	No specific therapy available
RVF virus	Central, eastern and southern Africa	Long-lasting	Vaccine available	No specific therapy available
Rickettsia prowazekii	Worldwide among louse-infested populations	Long-lasting, perhaps life-long	Attenuated living vaccine available that gives 5-year solid protection	Tetracyclines preferred; chloramphenicol also effective
Rickettsia rickettsii	The Americas	Long-lasting, perhaps life-long	Vaccine available; needs yearly boosting	Chloramphenicol or a tetracycline very effective
Coxiella burnetii	Worldwide	Some	Vaccine available	Chloramphenicol or a tetracycline usually effective
Pasteurella pestis	Parts of Africa, the Americas and Asia	Brief and rather weak	Moderately good vaccine available; needs 6-monthly boosting	Chloramphenicol or a tetracycline preferred against pneumonic plague; streptomycin plus sulphadiazine against bubonic plague

Bacillus anthracis	**Worldwide**	**Uncertain duration and solidity**	**Several vaccines available**	**Immunotherapy now giving way to chemotherapy; penicillin is preferred, but the tetracyclines, chloramphenicol and erythromycin are also effective; sulphadiazine may help**
Actinobacillus mallei	Rare and sporadic; equine reservoirs	Rare because of high mortality of glanders	No vaccine available	Sulphadiazine preferred; chloramphenicol or a tetracycline may also be effective
Pseudomonas pseudomallei	Far East	Rare because of high mortality of melioidosis	No vaccine available	Effectiveness of therapy depends on the strain; combination of chloramphenicol, kanamycin and novobiocin preferred; sulphadiazine may help
Vibrio comma	Endemic in several parts of Asia, cholera spreads fast along communication routes, favoured by poor sanitation	Uncertain solidity, for 1–2 years	Moderately good vaccine available; needs 6-monthly boosting	Saline; antibiotics do not help the patient; but may check the contagion
Salmonella spp.	Worldwide in areas of poor sanitation	Long-lasting, but of uncertain solidity	Trivalent vaccine available that gives good 5-year protection	Chloramphenicol preferred; tetracyclines, streptomycin, kanamycin or sulphadiazine also effective
Shigella spp.	Worldwide in areas of poor sanitation	Negligible	No effective vaccines available; antibiotics and sulpha drugs have been used	Tetracycline or chloramphenicol preferred; kanamycin may be effective; sulpha drug-resistant strains of *Shigella* are common
Francisella tularensis	North America, Japan and parts of Europe and USSR	Long-lasting, perhaps life-long	Attenuated living vaccine available that gives 2-year protection; more likely to reduce severity of disease than to prevent it	Streptomycin preferred; chloramphenicol or a tetracycline may be effective, as may kanamycin or novobiocin
Brucella spp.	Worldwide	Uncertain duration	Attenuated living vaccine available, but of limited effectiveness	Streptomycin in combination with a tetracycline preferred; alternatively, streptomycin plus sulphadiazine; immune serum has also been used
Coccidioidis immitis	Arid regions of the Americas and USSR	Fairly solid and long-lasting, perhaps life-long	No vaccine available	Amphothericin-B preferred; chloramphenicol also effective

Note:
[a] Only the pathogens listed in table 1.2 are considered; there are many others that might be used in BW.

Sources:
The table is compiled from information contained in references [64, 97, 163, 354, 397, 1450–1452, 1611].

not effective against viruses that are candidate BW agents. Most of the common chemotherapeutics, such as the sulpha drugs, have a similar failing. A number of experimental antiviral drugs have recently been discovered, however, and it is possible that eventually these may be developed into countermeasures against viral BW attack.

Table 1.6 collects together information on the types of medical countermeasure at present available against the potential antipersonnel BW agents listed in table 1.2. It will be noted that vaccines are not yet available for some of them. This, it might be supposed, would count against their candidacy as BW agents, for although the attacked population might be highly vulnerable to them, the attacker might be extremely reluctant to manufacture or handle them on a sufficiently large scale. While the table indicates that there are grounds for optimism, it also illustrates the weaknesses in the medical defences against BW attack. The specificity of many of the treatments means that for an effective defence there must be considerable skill in the difficult arts of early diagnosis, rapid identification and anticipation of the types of BW agent that an attacker might use.

Against CW attack, the possibilities for effective medical countermeasures are much more limited. In the first place, prophylaxis is now possible only against certain protein agents, such as the botulinal toxins. In the second place, very few specific antidotes are available for the multitude of different agents. For the most part, the medical treatment of CW casualties is, as it always has been, supportive and palliative.

But there is one very important exception, namely, the therapy of nerve-gas poisoning. This has now been refined to the point where the simpler forms of treatment can be administered by laymen, even by the poisoned individual himself. The self-aid treatment comprises the use of atropine (or related drugs) and an oxime-type drug. The atropine produces effects in the body that are the reverse of some of those produced by the nerve gases. Special auto-injectors are standard issue in many armies today for self-administration of the drug [37, 301, 355–358]. The oximes oppose some of the actions of some types of nerve gas (e.g., sarin and VX, but not soman) for long enough to enable the body to destroy and excrete the poison, and to repair the damage done. In the British Army, for example, oxime (P2S) pills are due to enter general issue [359]; in the Swedish Army, an oxime (obidoxime) is included in the atropine formulation contained in the general issue auto-injectors [326]. These self-aid treatments are by no means completely adequate; the atropine cannot prevent paralysis of the respiratory muscles, for example, although the oxime may do so if the dose of nerve gas has not been large (and if it is not soman). Artificial respiration of the positive-pressure type may therefore also be

essential, which the victim cannot do for himself. Special resuscitators have accordingly been developed and issued, for "buddy-aid" [360–361]. Nor is the treatment without risks of its own, for atropine is itself a powerful poison: ungassed soldiers who inject themselves with it under the impression that they have been gassed may become casualties. Nonetheless, if these treatments are used efficiently, they are thought capable of saving the lives of people who have received one or two LD50s of nerve gas, and of reducing the severity of symptoms caused by non-lethal dosages (for example, the symptoms that might be experienced by someone who had not put on his respirator correctly). Only the help of experienced and suitably equipped medical workers can save the lives of people exposed to several LD50s [362].[52]

If atropine auto-injectors, oxime pills and buddy-aid resuscitators were the only lines of defence against nerve-gas attack, they would clearly not amount to very much; but arrayed alongside the physical and chemical countermeasures described earlier, they are thought capable of significantly reducing overall casualty rates.

Oxime type drugs and certain other substances also hold out a fair measure of promise for nerve-gas prophylaxis [362, 509, 750, 966, 975, 977, 1183–1185, 1364–1391].

The CB defence of civilian populations

CB weapons seem particularly suited to surprise attack, and can probably secure mass casualties over wide areas. A civilian population is harder to protect than a combat unit. It might therefore be supposed that CB weapons are no less likely to be used against civilian targets than they are against military ones, yet in many countries the civilian CB defences seem to have received a much lower priority than the military ones. A common view is that, if counter-civilian warfare were to be practised, it would be likely to be preceded by an extended period of increasing political tension, culminating in purely military warfare between opposing armed forces; there would be enough time during the war-mobilization period, so it is argued, to instruct and equip the civilian population for their CB protection. On this reasoning, all that is needed in peacetime is a cadre of CB civil defence experts, detailed contingency plans for the organization of nationwide CB protection, and a manufacturing base held in readiness for the mass production of protective equipments. For countries where the

[52] It is thought that if oxime pills are swallowed an hour or two before a nerve-gas attack takes place, subsequent use of atropine auto-injectors may prevent death from nerve-gas dosages as high as 8 LD50s [326, 362].

latter would be beyond existing industrial capabilities, contingency arrangements might be made with richer allies for emergency supplies of CB defensive materials.

In adopting such a policy for civil defence, governments would be taking a calculated risk, and in some countries at present at peace, civilian CB-defence arrangements are considerably more advanced. However, the provision of an adequate level of civilian CB protection is an extremely costly undertaking; its absence in many countries will therefore be less of a calculated risk than an economic necessity. In the opinion of the experts that produced the UN Secretary-General's report *Chemical and Bacteriological (Biological) Weapons and the Effects of their Possible Use* [363], the costs of an up-to-date civil defence against CBW attack would exceed $15 000–20 000 million for a developed country of 100–200 million people. (If the country were to set up a nationwide system of protective shelters against nuclear attack, these could be adapted to provide CB protection at a relatively modest additional cost.)

If a counter-civilian CBW attack were to be mounted, the underlying rationale would presumably be not only that mass destruction of civilian lives was more worthwhile than destruction of factories and other fixed installations, but also that CB weapons would be more economical for this purpose (in terms of delivery vehicles) than conventional weapons. Such a calculation would be difficult to validate, but the indications are that only certain biological weapons or chemical weapons based on nerve gas [364] would be at all likely to provide the necessary economy [64]. Even this is open to doubt, as is described in appendix 3. It seems likely that the mode of attack in which the calculation favoured CB weapons would be one in which the CB hazard created over the target was relatively short-lived—not exceeding 10 or 15 minutes, say, at any particular point. The principal hazard would consist of a massive airborne cloud of CBW agent, generated from large quantities of ground-functioning weapons, that moved downwind through the city. This, it might be supposed, is the most likely type of attack that civilian CB defences would have to face. If so, the problem of providing adequate CB protection is simplified.

There would, of course, be substantial risks in adopting this line of reasoning, in view of the assumptions made. For example, an attacker might decide to use CB weapons, not because of their economy as antipersonnel weapons, but rather because they might leave the fixed installations of the target area undamaged, and therefore available for use after occupation. If so, the mode of attack would be different, and a different and more demanding defensive stratagem would be needed. It can be argued, however, that such an objective would be most unlikely to appeal to an at-

tacker and, furthermore, that its attainment with CB weapons would be a practical impossibility.

Civil defence against CW attack

In civil defence against nerve-gas attack, physical protection will be the most important component. Efficient use of collective shelters, perhaps supplemented by individual respirators, can be expected to diminish the effectiveness of nerve-gas attack very considerably. The protection will never be perfect, but it could bring the casualty level down to below that from conventional attack of equivalent weight.

The provisions for warning the population to take shelter or don their respirators will be a weak point in the defence. However, as it is more likely that a nerve-gas attack would be delivered from aircraft than from missiles (in view of the large tonnages of agent needed for effect: see appendix 3), the approach of the delivery vehicles, coupled with the presumption that they contained nerve gas, could provide sufficient warning—assuming, that is, that the country under attack had some form of air-raid alert system. Communications would need careful organization in advance, with prompt receipt and dispatch via central and regional headquarters. One of the tasks of the latter would be to announce as soon as possible the likely extent and direction of travel of the nerve-gas cloud. Local civil defence officials could then ensure that people downwind of the cloud had been evacuated or taken shelter, and medical aid teams could be despatched to the afflicted area.

Medical countermeasures are unlikely to serve a primary damage-limiting function. Nerve-gas therapy needs to be started within a minute or two of exposure if it is to be of any use, and it is unlikely under the circumstances that medical aid teams could reach more than a small fraction of the casualties in time. Nonetheless, it might be considered worth ensuring that civil defence workers knew how to use atropine auto-injectors and have stocks available at local civil defence depots. The 2 mg doses of atropine which auto-injectors usually contain could save the lives of 25 per cent or so of people receiving a lethal dosage of nerve gas under likely attack conditions [362].

Collective protection against nerve gas might be provided by specially constructed shelters. If these are not available, buildings with close fitting or sealable doors and windows can give good protection, provided all ventilation is shut off before nerve-gas clouds reach the building, and provided the building is not physically damaged during the attack. Because nerve gas will eventually seep into them, such buildings will not remain safe for long. They will, however, be very much safer than the open

streets, provided they are vacated or positive-pressure ventilated as soon as the cloud has passed downwind. It would be one of the functions of the local civil defence organization to indicate when this was so. Civil defence workers wearing heavy-duty respirators and protective clothing, and carrying residual vapour detectors could be assigned for this purpose to streets in the path of the cloud.

In the absence of special shelters or modern buildings, a general issue of civilian gas masks would become essential for the defence, and might be considered prudent even when collective shelters were available. Protective clothing for the entire population would almost certainly be considered too expensive to justify the additional protection conferred and would be unnecessary if the antigas discipline were good. Only people in the immediate vicinity of functioning nerve-gas weapons are likely to become casualties through skin exposure. They would be unavoidable casualties if high-explosive weapons were used. It is likely that some areas of the city will remain hazardous to walk through unless protective clothing is worn; in this case protection can be secured through special civil defence decontamination squads. For this purpose, it would be necessary to maintain large stocks of bleaching powder or other decontaminants, together with suitable applicators, at local civil defence depots.

It must be repeated that the protective measures envisaged above could not prevent all nerve-gas casualties. On the contrary, there would undoubtedly be very large numbers of civilian gas casualties from any counter-civilian nerve-gas attack. These would impose an enormous burden on hospitals and on burial authorities. Nonetheless, the level of protection might well be sufficient to render nerve-gas attack unattractive to the attacker when he compares it with the destruction that he might cause with a conventional attack of similar intensity.

Civil defence against BW attack

Civilian targets might be attacked with BW agents in a number of different ways. One much publicized possibility envisages the covert dissemination by saboteurs of aerosols of man-to-man transmissible agents, or the clandestine infection of food or water supplies. From a civil defence point of view, the sabotage element in this mode of attack, rather than the weapon used by the saboteur, is the important one. The prevention of sabotage comes within the day-to-day mission of police and internal security forces, and it is they who provide the first line of defence against clandestine BW attack. Furthermore, as regards water and food contamination, routine public health safeguards would greatly impede successful acts of BW sabotage.

If a saboteur succeeded in starting an epidemic in a developed country, there would be a substantial probability that public health authorities would be able to bring it quickly under control. This, at least, is the view expressed in the British Home Office civil defence manual on BW [293]. It is true that an efficient public health service could reasonably expect to distinguish an act of BW sabotage from a natural epidemic, however carefully the saboteur tried to disguise it [365]. But whether the authorities could control the disease before it got out of hand seems rather less certain. Much would depend on the training, organization and equipment of the public health service, and on local levels of hygiene and sanitation. These will differ greatly from country to country. Moreover, experience has shown that even in the developed countries there is sometimes a rather low threshold beyond which public health services cannot contain epidemics.[53] But epidemics are highly unpredictable phenomena: the chances of a public health service failing to contain one that had been initiated by a saboteur must be set against the chances of the epidemic failing to take hold in the first place.

A second manner in which civilian targets might come under BW attack is through the covert dissemination of massive aerosol clouds upwind of heavily populated areas. This mode of attack might either be effected by a group of saboteurs in possession of a large aerosol generator, or by aircraft equipped with spray tanks and disguised so that their operation resembled a *bona fide* civilian activity, or by an offshore sea vessel equipped with aerosol generators. Such an attack might well produce mass casualties by primary infection but, as is described later in this volume, there are several factors that weigh heavily against its success. Not least among these is the pall of air pollution surrounding urban areas; certain air pollutants are the most efficient disinfectants known [366]. Nonetheless, it is this mode of attack against which civil defence arrangements are likely to be the weakest.

A third possibility is the on-target attack delivered by fleets of aircraft or by missiles. Missile delivery of BW agents against large civilian targets is more likely than for CW agents because considerably fewer missiles will be required. But, as is shown in appendix 3, their number or size will still need to be substantial, and therefore, perhaps, beyond the capabilities of all but a few countries.

Civil defence against aircraft-delivered on-target BW attack will be much the same as for CW. The warning time available could be long enough for the civilian population to assume a reasonable level of physical

[53] For example, the *Salmonella* outbreaks in Sweden in the late 1940s.

protection. But against off-target attacks, or against on-target missile attacks, physical countermeasures could not be relied upon, given the present state of development of BW-agent alarms. Civil defence would then become a great deal more difficult, with the burden resting heavily on medical countermeasures.

Prophylactic vaccines are available against some potential BW agents, but not against all, as we have seen. If civil defence authorities knew what agents were going to be used in a BW attack, they might consider a mass immunization programme. This would be expensive but not impossible, as means are currently available for administering vaccines to large numbers of people within a short space of time. It is unlikely, however, that the authorities could reasonably have enough confidence for this. Although multivalent vaccines are available that would give protection against more than one BW agent, they are primarily experimental and certainly do not give across-the-board protection against all likely BW agents. Furthermore, the immunity conferred by most vaccines can often be breached by dosages of BW agent that are large but whose delivery is within military capabilities. All in all, therefore, immunoprophylaxis is not a realistic means of civilian BW defence. The best alternative lies in antibiotic therapy [367].

If antibiotics are administered early enough, they can control many fatal diseases. They can also suppress certain diseases if given during the incubation period, although this is unlikely to be feasible in civil defence [365]. But antibiotic therapy has a number of grave limitations, as has been described earlier. There are several diseases that do not respond to antibiotics, including most viral diseases, and different diseases may call for different types of antibiotic. And there is also the possibility, perhaps even the likelihood, of antibiotic-resistant strains of BW agent being used. If a city came under attack with such strains, or with a virus (such as that of yellow fever), there would be little that could be done to save people.

For therapeutic countermeasures to be valuable against bacteriological attack, stocks of more than one broad-spectrum antibiotic must be available, together with other types of chemo- or immuno-therapeutic for antibiotic-resistant diseases, and, as an essential component, laboratory facilities for the rapid identification of the agent used, and for establishing the antibiotic-resistance pattern of the agent. Such a laboratory will have the task not only of indicating the appropriate form of therapy, but also of confirming the fact of BW attack in the first place.[54] For this purpose, the time normally taken in medical practice for identifying disease agents (1 or

[54] This is discussed further in appendix 1, and in Volume VI of this study, *Technical Aspects of Early Warning and Verification.*

more days for bacteria, and 2–6 weeks for viruses and rickettsiae) would be far too long. If an adequate BW defence is to be marshalled against BW attack, a period much in excess of 6 hours will be too long. It might therefore be considered prudent to maintain on a permanent basis a special hospital-cum-laboratory, equipped with all possible agent identification and diagnostic aids, to which samples of suspected contaminants, and suspected initial victims of biological-weapon attacks, could be transferred with the minimum of delay [368–371].

A ton of antibiotic will suffice for one course of treatment for about 45 000 people, the cost working out, at 1959 US prices, at about $10 per head [367]. The cost would be about the same nowadays, for in relative terms antibiotics are now cheaper than they were. Antibiotics, like immune sera and vaccines, can be markedly unstable on storage, so that the maintenance of civilian BW defence precautions will be an expensive business. Their application, should it be necessary, will introduce further costs, for the disruption of a country's medical services entailed in operating a BW defence will be very great, and may in itself create further public health problems.

The CB defence of combat units

The problem of providing CB protection for combat units differs in one important respect from that of civilian CB defence. The equipments and procedures used must interfere as little as possible with the routine activities of their users. The defence must be good enough not merely to raise the costs of CB attack beyond that of conventional attack; it must also avoid offering the enemy an actual inducement to attack by reason of the impediments that it may impose. Military CB defence can therefore make less use of collective protection than the civilian defences; soldiers must be given good enough individual protection to compensate for this. But at the same time, the individual protection must not greatly interfere with the soldier's ability to move around, fight, defend himself and communicate with his fellows. And in addition to this, the high casualty rates that can be obtained with CB weapons and, at least in the case of the nerve gases, the rapidity with which they will appear, mean that protection must be instantly available whenever there is a likelihood of CB attack. These problems have already been referred to, together with some of the solutions that have been adopted.

It is general practice in the armies of the developed countries today to issue individual protective equipments to all combat personnel serving in areas where use of CB weapons is considered at all likely. In addition, most of these armies incorporate special CB defence units within their

organizational structure. These are entrusted with CB defensive measures that cannot be performed by regular combat units, and with augmenting those precautions that combat units can take. The details of the arrangement vary from army to army, as illustrated in chapter 3 below.

The individual soldier carries a respirator, a set of protective clothing, a kit containing decontaminants and medicaments (atropine auto-injector, anti-vesicant skin cream, etc.) and, in some armies, simple agent-detection devices. He is expected to don his respirator and protective overgarment (or fasten it up, if he is already wearing it in "open posture") within 15 seconds of the alarm being given. Automatic and/or non-automatic agent-detection devices will be carried by trained personnel within all low-echelon units. Communications with adjacent units, and with rear headquarters, will be essential to the overall defence in transmitting and receiving warnings of the presence of CBW agents. Each combat unit down to platoon level will carry with it equipment for initial decontamination of its vehicles and weapons. Areas will be established in the rear by the special CB-defence units for more rigorous decontamination, and for the servicing of protective clothing and respirators. These arrangements will be intended for the most part as precautions against nerve-gas attack. They will also provide a first line of defence against BW attack, but this will be effective only if there is adequate warning. If there is not, mass BW casualties will begin to appear after a lengthy interval; to cope with these, stocks of antibiotics, chemotherapeutics and perhaps also disease-suppressing immunotherapeutics, will be maintained in rear areas [372]. As with civilian defence, one essential component in the BW defence of combat units will be the agent identification and diagnostic field laboratory [373].

There is a limit to the amount of time for which the sort of CB protective equipment that is in general issue can withstand a continuously contaminated environment. This becomes most serious in situations where the ground is heavily contaminated with involatile nerve gases or vesicants. Few commanders will be willing to allow their units to remain in such areas unless it is absolutely essential. If it is, heavy casualties, albeit somewhat delayed ones, may be inevitable. High airborne concentrations of CBW agents cannot be maintained for more than a few minutes without excessive expenditures of weapons; but after exposure to several aerosol or vapour attacks, respirator filters may become saturated and need replacing.

Doctrines for the use of nerve gas against combat units carrying protective equipment call for surprise-dosage attacks—the setting-up of casualty dosages within 15 seconds or so. This is within the capabilities of modern chemical weapons. It is reported, for instance, that a single large nerve-

gas rocket is expected to be able to threaten 50 per cent casualties over an area of 2 or 3 square kilometres within the time it takes for a soldier to protect himself. Despite their atropine auto-injectors, half of these casualties are likely to die unless skilled medical aid can be brought to them within a few minutes [362]. Such a casualty rate might effectively destroy the combat unit's usefulness, and for this reason units operating against an enemy known, or merely thought, to possess nerve gas are likely to wear respirators or even maintain full protection in the course of their mission. Authorities differ on how their overall combat efficiency will be affected by this. Some hold that any decrement would be marginal —that, despite the fatigue caused by prolonged masking and the burdens on individual movement, adequately trained and experienced soldiers can fight almost as well in full protective rig as they can without it. Decontamination procedures, although time consuming, can be accommodated, so the view continues, without serious disadvantage, given careful forward planning. Other authorities hold that the decrement would be substantial —that the fatigue and the diminished powers of communication would seriously lower morale and group cohesion, and that the protective clothing would be too cumbersome and awkward to permit efficient use of instruments and weapons. The more optimistic view is the one commonly expressed in public by officials in countries that have decided against acquiring nerve-gas capabilities of their own. The more pessimistic view is common in the United States,[55] where, as is described in chapter 2, below, it is an essential feature of like-with-like nerve-gas deterrence reasoning.

[55] For example, the following abstract has been published of a paper entitled *Tactical Implications of the Physiological Stress Imposed by Chemical Protective Clothing Systems* that was presented at the 1970 US Army Science Conference [374]: "Chemical protective uniforms have been assessed for their effects on soldiers wearing them in the heat. A multi-disciplinary laboratory approach is used to measure material and uniform characteristics, to predict tolerance time for soldiers on operations in temperate or warmer environments and to validate these predictions in climatic chamber trials with volunteer subjects marching on treadmills. Subsequently, small-scale field studies are conducted. Tactical military operations are studied by scientific collaboration with military units in maneuvers. The predictions based upon the results of laboratory studies have been confirmed in the field. Even in a temperate environment, troops wearing chemical protective clothing have severely limited tolerance time for hard work. Conserving the soldier by transporting him (or at least as much of his load as possible) and providing extra men or rotating heavy loads or hard work tasks must receive far more attention when troops are encapsulated in chemical protective clothing than usual. Unusually long rest breaks in the shade must be provided. Even then, the effectiveness of encapsulated troops in operations requiring hard physical work (e.g., approach marches, assaults or sustained fire missions) may be limited to one hour or less at ambient environments above 75°F."

It is not clear from this abstract whether the troops were "encapsulated" in air-impermeable protective clothing, or whether the experiments described involved one of the air-permeable expedients described earlier in this chapter.

In the absence of actual combat experience, both views are no doubt equally tenable. Much will depend on climatic conditions: the warmer the weather, the heavier will be the burden of adequate protection.

Defences against anti-animal and antiplant CBW

Against anti-animal weapons

The extent of the overall damage that might be inflicted if domestic animals came under CW attack might be considered too insignificant either to warrant deployment of special defences, or to attract such attack in the first place. Antigas protective equipments for animals have, however, been developed, notably for horses, messenger dogs and carrier pigeons during World War I—a war in which these creatures made a significant contribution to military operations. Many types of animal respond to the same medical treatment that is used in human antigas therapy.

Anti-animal BW is a greater threat than anti-animal CW, particularly since transmissible pathogens might well be used to deliver an attack. Collective physical protection of domestic and draught animals might be possible if there were adequate warning. Prophylactic countermeasures might also be possible, for in the richer countries there are a number of animal vaccines that are in regular use. Some of these were originally developed during World War II in anticipation of anti-animal BW—notably those for rinderpest and Newcastle disease. The vaccines might either be used to immunize entire flocks or herds (which might be prohibitively expensive) or to create *cordons sanitaires* around foci of disease in attacked areas to prevent an epizootic from building up. Rapid mass slaughter of the infected animals might also be used for this purpose, as in the current British method of dealing with outbreaks of foot-and-mouth disease.

Against antiplant weapons

Specific countermeasures against antiplant CW—defoliation or crop destruction—are not feasible. As for anticrop BW, the only realistic possibility is the setting up of *cordons sanitaires* in a similar fashion to those that might be used to cope with anti-animal BW. Another conceivable possibility lies in the development of disease-resistant plants. It is the success of endeavours of this type that lies behind the current "green revolution", in which crop yields have been greatly increased by planting specially developed strains. (But it is also to be noted that in breeding these strains for increased crop yields and resistance to endemic disease, immunity against other diseases has often been lost: monoculture crops may thus be particularly vulnerable to BW attack.) For this to be worth-

while, however, the precise BW agent which might be used has to be known a long time in advance, perhaps several years.

A further possibility might be to spray fungicides or other disinfectants over attacked areas. But this might not be considered economical, even if it worked, particularly since the manpower needed might alternatively be used to plant a second crop.

Chapter 2. The utility of chemical and biological weapons

This chapter is concerned with the possible military applications of chemical and biological (CB) weapons, and with the merit that military authorities might see in possessing an offensive CBW capability. The United States is the only country today to acknowledge that it does so; and the rationale that its spokesmen have generally given is that of deterrence rather than first-use. We now examine the basis of this, and the manner in which other countries whose CBW capabilities remain undisclosed might value them.

Because CB weapons have rarely been used in modern warfare, conjecture can scarcely be avoided in discussing their present utility. Moreover, for those CB weapons that have been used, much of the experience gained is likely to have become considerably outmoded. In order not to overburden this chapter with speculation, we discuss the attractions and limitations not of CB warfare but of CB weapons. Our approach is therefore more technological than military, with the discussion revolving around the capabilities of CB weapons for certain types of mission as compared with those of the non-CB weapons that might otherwise be used. This we feel to be in keeping with the subject, for CB weapons have always been more of a technologists' offering than a military requirement. The principal failing of this approach, which we have tried to remedy, is that it does not immediately bring into the discussion the many nonmilitary and nontechnical factors affecting use of CB weapons. The illegality and singular unpopularity of CBW, for example, have always meant that the question of initiating or preparing for it has never been a purely military matter.

The technicalities of CBW, and the peculiar attributes of CB weapons, make for employment costs and benefits that differ importantly from those attaching to other weapons. This chapter opens with an account of these, describing the main points of difference between CB weapons and other categories of weapon on which preferences for the former might be based—differences in operation, in effects, in performance, and so on. It is shown here how CB weapons might, under certain circumstances, provide options that could not be matched by other weapons. In the second section

of the chapter, we show briefly how these might be exploited in different types of military action. In the third section, we draw conclusions about the overall value of CB weapons.

I. *Distinctive features of CB weapons*

Advocates of CB weapons have written at length about the military attractions of CBW techniques. Their writings [376–396] provide our point of departure, but, taking into account the opinions of other authorities, we have tried to set their claims against the background of priorities and countervailing limitations which they sometimes seem to ignore. We begin by describing the principal characteristics of CB weapons that set them apart from other forms of armament and which are likely to have a major influence on decisions to initiate CBW or to refrain from doing so. The discussion is divided into five sections, each dealing with a particular aspect of CB weapons: unorthodoxy; diversity, time delays; biospecificity; and area-effectiveness.

Unorthodoxy

There are military reasons why CB weapons have not been used often in the past, and why they remain unconventional nowadays. But there are other reasons as well, in particular the legal and moral proscriptions that surround CBW. These factors must clearly enter into an appraisal of CBW today, for, apart from anything else, the very fact of unconventionality has military significance.

Most weapons have presumably been considered unconventional in their time, and moral outcry has generally attended the introduction of novel ones. Moreover, the military have often been reluctant to assimilate radically new techniques of fighting.[1] But there is an equally long tradition of military expediency overcoming moral resistance or conservative reaction to new methods of warfare, and although CB weapons have existed for a long time now, it may well be asked whether these in turn might not eventually be considered conventional and acceptable. Might not CB weapons take the same path as napalm, for example, seems to be taking today? Two considerations argue against this. Military and nonmilitary reaction against CBW has long been codified into formal prohibitions

[1] J. B. S. Haldane's concept of "Bayardism" may be noted here. It is referred to in Volume I of this study. (*The Problem of Chemical and Biological Warfare, Vol. I. The Rise of CB Weapons* (Stockholm: SIPRI, 1971), p. 235).

under international law. The psychological and social attitudes from which the moral and legal proscriptions stem seem generally as hostile as ever towards CB weapons. The question is whether these factors will remain powerful enough to withstand the military attractions of present or future CB weapons.

The sectors of international law that concern CB weapons are discussed in detail in Volume III of this study.[2] The prohibitions contain no specific provisions for sanctions in the event of infringement, but an infringer would certainly risk attracting reprisals of some sort. The extent of the risk would depend in part on the importance his enemy attached to the international laws of war as a whole, for to condone one breach might imply tolerance of another. This is one of the general mechanisms whereby international law acquires force. Another such mechanism resides in the fact that a belligerent who resorts to illegal, and potentially outrageous, methods of warfare is in effect announcing that he is ready to pursue his war aims with extreme measures. He therefore risks not merely reprisals (which, in the eyes of international law, ought not to be out of proportion to the original offence), but also retaliation in an extreme form. He risks, in other words, a further escalation of the war. This might act as an especially strong constraint in a war which could become nuclear.

This particular constraint is one among many that appear to have operated in the past. These are discussed elsewhere in this study.[3] The analysis takes into account a range of technical, military, legal and political factors, but central to it is the notion of deep psychological aversion among the majority of people, including the military, who become aware of CB weapons. It is difficult, if not impossible, to validate this notion, but it seems plausible enough. Poison and disease can unnerve people to an extent which other dangers cannot; and the outbreaks of mass hysteria and the superstitions which they have provoked in the past are well recorded [e.g., 397–398]. Less obvious is the question of whether people who would normally reject the idea of CBW would continue to do so under abnormal circumstances, particularly during wartime or in the face of a deliberate attempt to modify public opinion. There is a certain amount of evidence to suggest that they might, circumstantial though it may be. For example, gas was not used during World War II, even though the stocks available greatly exceeded those used during World War I, and despite the many enormities perpetrated during the war. Likewise, the public relations campaign mounted in the late 1950s by the US Army Chemical Corps to in-

[2] See Vol. IV *CBW and the Laws of War* (Stockholm: SIPRI, 1972).
[3] See Volume I, pp. 294–335, and Volume V, pp. 22–31.

crease its popular and Congressional support[4] may have been successful in the short term, but the present level of popular and Congressional hostility towards US CBW activities suggests that it was a failure in the long term.

If there are indeed deep-rooted and widespread inhibitions about CBW, it is reasonable to attach importance to whatever constraints on using CB weapons may result or may be sustained by them. Many such constraints can be envisaged. Depending on the type of country concerned, resort to CBW may weaken domestic support for the war, may alienate influential friends and allies abroad, and may provide the enemy with valuable propaganda capital. For these reasons, authority to order use of CB weapons is likely to rest at a much higher level than their military or strategic importance would otherwise warrant. This in turn may introduce a further constraint, for the person in whom the authority is vested may be disinclined to expose himself on an issue where the possible military benefits may be slight and uncertain, and the political costs substantial.

But it must also be noted that precisely the same psychological reactions that may generate these constraints may also furnish incentives to use CB weapons. People who are horrified by CBW may behave irrationally when subjected to it. An attacker might perceive tactical or strategic advantage in this. For example, beset by odourless, invisible, intangible and deadly CBW agents, the morale of his enemy's combat units might sag drastically, however well protected they might be. A CBW attack on his enemy's homeland might spread alarm and despondency to the point of mass panic.

The possibilities of psychological effects such as these have been emphasized by advocates of CB weapons. As expounded in the military manuals [399], German CW doctrine at the time of World War II valued them at least as highly as any other attribute of CB weapons.[5] US CBW experts have also given some support to this evaluation in more recent times [e.g., 390] as is reflected in current unclassified US CBW manuals [e.g., 97].

Be that as it may, the factors that weaken morale or generate panic are notoriously difficult to predict, let alone exploit. For instance, it was reckoned by some that the British strategic bombing offensive of World War II would swiftly destroy the will-to-war of the German population. If anything, it had the opposite effect. The same might well be the case with CB weapons, even though the nature of their psychological impact would be different. It is therefore hard to imagine a belligerent deciding

[4] See below, pp. 194–95.
[5] See Volume I of this study, p. 300.

to exploit the supposed psychological effects of CB weapons on any scale except in some massive act of aggression or in a last-ditch situation—circumstances where the constraints referred to above might not be significant. But to say this is to revert to the question of whether the various non-military constraints that stem from the unorthodoxy of CB weapons would in fact weigh significantly against the purely military advantages there might be in starting CBW. If military considerations were paramount, the supposed psychological effects of CB weapons might well be valued as a supplementary asset.

Diversity

In the previous chapter we described some of the many types of CBW agent that have been developed. These differ widely in several respects, notably in the types of organism that are susceptible to them, in the time of onset, severity and duration of the effects they produce, and in their persistency in active form after they have been spread. They may be used with a wide range of delivery systems. There is therefore considerable variety in the military effects that may be sought with them. Other categories of weapon do not possess such flexibility. Explosive weapons, say, may differ from one another as regards size, fusing, and so on, but their ultimate effects on living organisms are always those of physical destruction. In contrast, the sort of damage that CB weapons may inflict can be preselected from a rather wide choice. Weapons filled with one type of agent might be used to create a mortal hazard of several hours' duration, or of only a few minutes with another: with a third, the weapons might be used merely to disable an enemy temporarily without permanently injuring him. It is this diversity that has led their advocates to compare CB weapons with surgeons' instruments, and other weapons with butchers' tools. The incapacitating agents, in particular, have been proclaimed as implements of "war without death".

Although there are obvious attractions in the diversity of CBW agents, they can be exaggerated. It is certainly true that at the outset of a CB-weapon acquisition programme there will be a wide range of choice. But the larger the number of different weapons available, the more complicated will decision-making and logistical processes become. Even the richest and most sophisticated army will have to confine its procurement to a very small proportion of the many toxic or infective agents that have combat potential. The principal criteria by which the choice might be made need describing here.

Military classification of CBW agents

Tables 1.1 and 1.2 in chapter 1 classify selected CBW agents according to their broad pathology or morphology. The class distinctions made there have some military significance, but they do not reflect the sorts of difference in CBW-agent properties that dictate the different purposes for which the agents might be used. Such a differentiation is made in table 2.1. The military significance of the classification is as follows.

The distinction between *biological* and *chemical* agents is important. To take the antipersonnel agents first, the reason is twofold. First, BW agents, with their much greater potency (see table 1.3, page 42), are suited to attacks on large targets. The area of effectiveness of even a small antipersonnel biological weapon is often expressed in square kilometres, and that of a large one, for example an aircraft BW agent spray tank, in several tens or hundreds of square kilometres. In contrast, the areas of effectiveness of individual chemical weapons range from a fraction of a hectare up to a few square kilometres at most. The second reason is that BW agents inevitably involve incubation periods of at least a day, and often a good deal longer. CW agents are valued for the relative immediacy of their effects.

Chemical antipersonnel agents have been developed for two broadly different types of effect: acquisition of enemy casualties, and harassment of enemy personnel. The *casualty agents*—a category that encompasses all biological antipersonnel agents as well—include the lung-irritants, blood gases, vesicants, nerve gases, toxins, psychochemicals and nonirritant physiochemicals described in chapter 1. The *harassing agents* comprise the sensory irritants; their function is not to cause casualties (although their use alongside other weapons may well increase overall casualties) but to lower enemy combat efficiency, thus extending their users' ability to manoeuvre. A man affected by a harassing agent such as CS becomes much less efficient at using his equipment, and may choose to abandon protective shelter or concealment rather than remain exposed to the agent.

Employment doctrine for chemical casualty agents differs substantially according to the length of time for which an agent remains effective when spread on the ground. This time period depends on environmental conditions, notably temperature, wind speed, humidity and soil chemistry, but it also depends on the volatility of the agent—on its tendency to evaporate. An agent volatile enough to persist for no longer than 10 or 20 minutes is designated *nonpersistent;* one that can contaminate ground effectively for several hours or more is called *persistent.* Nonpersistent agents permit rapid

Table 2.1. Military classification of CBW agents

Principal categories	Examples from tables 1.1 and 1.2	Features on which sub-categories are based	Militarily desirable features
Antipersonnel agents			
Chemical			
Harassing	The sensory irritants	Persistency	Instantaneous multiple irritancy
Casualty			
Incapacitating	The non-irritant physiochemicals The psychochemicals	*No satisfactory agents yet developed*	
Lethal			
Persistent	Some nerve gases, such as tabun and VX The vesicants		Percutaneous effectiveness Rapidity of action
Semipersistent	Some nerve gases, such as soman		
Nonpersistent	Some nerve gases, such as sarin The blood gases The lung irritants		
Biological			
Contagious		*Military attractions apparently small*	
Incapacitating	Influenza virus		
Lethal	*Chlamydia psittaci* *Rickettsia prowazekii*[a] *Pasteurella pestis* *Vibrio comma*[a] *Shigella* spp.[a]		
Noncontagious			
Incapacitating	Dengue fever virus[b] Chikungunya virus[b] VEE virus[b] RVF virus[b] *Coxiella burnetii* *Coccidioides immitis*	Incubation period Length of illness caused Aerobiological decay rate	Low level of immunity Antibiotic resistance Availability of vaccines
Lethal	RSSE virus[b] Yellow fever virus[b] *Rickettsia rickettsii*[b] *Bacillus anthracis* *Actinobacillus mallei*		
Antiplant agents			
Chemical			
Defoliants	2,4-D 2,4,5-T	Species specificity	Low species specificity Rapidity of action
Herbicides	Picloram Cacodylic acid		
Soil sterilants	Bromacil Monuron		
Biological	*Pyricularia oryzae* *Puccinia graminis*	Species-specificity	Contagiousness
Anti-animal agents		*Military attractions apparently slight*	

Notes:

[a] The contagiousness of these agents depends strongly on a low level of sanitation or personal hygiene among the target population.

[b] The noncontagiousness of these agents depends on the absence of disease-vector species from the fauna of the target area.

follow-up operations; persistent ones do not unless full protective clothing is worn, but they can be used to hamper or even prevent enemy operations for prolonged periods over terrain on which they have been spread.

Rapidity of action and percutaneous effectiveness greatly increase the military attractions of chemical casualty agents. The longer an agent takes for effect, the poorer it is suited to a fast-moving battlefield. Because the skin is harder to protect than the lungs, an attack with a percutaneous agent is more likely to succeed than one with a respiratory agent. But it takes longer for an effective dose of poison to penetrate the skin than the lungs. This means, first, that percutaneous agents cannot act as rapidly as respiratory ones, and, second, that nonpersistent agents may evaporate away too fast from skin or clothing to produce significant percutaneous casualties (unless they are extremely toxic: sprays of a volatile nerve gas, such as sarin, may be highly dangerous to masked personnel lacking skin protection). At the present time, therefore, percutaneous effectiveness is poorly compatible with nonpersistency: although certain nonpersistent agents may produce a large number of percutaneous casualties, the same weight would produce many more casualties by respiratory attack. And because percutaneous effectiveness is also poorly compatible with rapidity of action, persistent agents cannot produce heavy and immediate casualties unless they are aerosolized: their volatility will generally be insufficient to create a substantial vapour hazard unless their victims remain in contaminated areas for long periods. A possibility for compromise lies in the type of munition used: with some agents, persistency and percutaneous or respiratory effectiveness depend in large measure on the droplet-size spectrum of the disseminated agent. In this context, "intermediate-volatility" or *semipersistent* agents, such as soman, become important.

Since the late 1950s, military classifications of antipersonnel CBW agents have attached importance to the proportion of fatalities to be expected among casualties. Where the death rate is considered unlikely to exceed 1 or 2 per cent, the agents are classified as *incapacitating agents* [400]. It is these substances that are most frequently cited to illustrate the benefits of the diversity of CB weapons.

Outside CBW, casualty death rate is not normally a consideration that enters at all strongly into the selection of weapons, largely because there is little the designers of conventional weapons can do to reduce it. But with CB weapons, whose casualty effects depend on damage to specific physiological processes, the possibility does arise. Different agents can attack different physiological processes, damage to any of which may put a soldier out of action. But since some of the processes may be less crucial to continued life than others, different agents may have much the same casualty-

producing ability but different lethalities. A man who becomes paralysed is just as much of a casualty as one who becomes asphyxiated.

Nonetheless, the traditional military function of a weapon is to produce casualties—to put enemy personnel out of action by killing or injuring them. An ability to control the precise type of casualty is a refinement of this basic function. The circumstances under which it would fulfil military requirements would hardly be normal ones. Unless they obtained, the military attractions of incapacitating agents would depend primarily on their quantitative casualty-producing ability. As far as the chemical incapacitants are concerned, no candidate agent that has yet been described in the open literature can compete with the nerve gases in this respect. The psychochemicals and the nonirritant physiochemicals of table 1.1, for example, are either too slow to take effect, inadequately toxic or ineffective percutaneously.

The principal option for which incapacitating agents provide is the application of armed force without at the same time having greatly to endanger life or limb. Both political and military assets may reside in this. The political assets—for example, a greater freedom in the use of armed force—are discussed elsewhere in this study.[6] The potential military assets are twofold. First, incapacitating agents might be valuable in situations where there is positive military advantage in inflicting large numbers of nonfatal casualties on an enemy—in order, say, to overwhelm his medical and transportation facilities. Second, they might be valuable in situations where military operations would endanger friendly or noncombatant personnel. Examples here include the rescue of hostages and the engagement of enemy forces intermingled with friendly or neutral civilians.

The main functional divide among the *biological antipersonnel agents* lies in the contagiousness of the diseases they cause. Some agents are more likely to initiate epidemics than others. A biological weapon that can cause an epidemic is obviously much more potent than one whose effects are confined solely to the people who come into immediate contact with its payload. For this reason it might be supposed that contagious-disease agents would have greater military attractions than noncontagious-disease agents. This is not necessarily the case. The factors that promote or retard the spread of disease are only poorly understood, so that an attacker could not rely on his weapons creating an epidemic. Moreover, an epidemic, once started, may be unexpectedly persistent, and may spread in unexpected directions, so that risks of backfire would compound the uncertainties about whether the disease would actually take

[6] See Volume V, pp. 47–52 and 133–34.

hold and spread of its own accord. It is because of these factors that the two classes of BW agent fall into different military categories. The uncertainties attaching to contagious-disease agents would make their use extremely hazardous to an attacker whose positions were at all close to the target area. This would not apply so strongly to noncontagious-disease agents, which, from an operational point of view, resemble highly potent forms of delayed-action poison gas.

The contagiousness of a disease depends only in part on the properties of the disease agent. Some diseases can be transmitted directly from man to man, for example via exhaled air. Such "transmissible" pathogens, such as the influenza viruses, would invariably be classified as contagious-disease agents. Other diseases depend for their contagiousness on local conditions. Outbreaks of cholera, for example, reach epidemic proportions only when levels of hygiene and sanitation are low. Yellow fever epidemics require the presence of particular mosquitoes to transmit the disease from infected to uninfected people. This means that if yellow fever viruses were employed in a BW aerosol, they could be regarded as noncontagious-disease agent in Scandinavia, say, but as contagious-disease agent in tropical areas where *Aedes* mosquitoes are present in large numbers.

The distinction between lethal and incapacitating agents has the same military significance for BW agents as for CW agents. In contrast to the chemical ones, the biological incapacitants compare more favourably to their lethal counterparts. As far as can be judged, there is no great difference in the casualty-producing powers of the two classes. The ability to conduct human experimentation with incapacitating BW agents has certainly increased their relative military attractions, for this can go a considerable way towards removing some of the unpredictabilities of weapons based on them. Human experimentation has been performed with potentially lethal pathogens, but mostly with attenuated strains—strains which would not be used as BW agents.

Within the broad classes of contagious- and noncontagious-disease agents, and of lethal and incapacitating ones, the parameters of major military importance are length of incubation period, agent-decay rate after dissemination, and, for incapacitating agents, duration and type of illness. Ranges of agents having properties differing in each of these respects might be considered worth maintaining. For example, against small targets close to friendly units, an agent that could not survive for very long after dissemination would be preferred to one that could because the downwind hazard would be smaller. A more hardy agent would be needed if long-range, off-target attacks were being contemplated.

From a military point of view, aerosols or sprays of antipersonnel BW

agents, used without additives,[7] are unlikely to be effective through the skin. As noted in chapter 1, one possibility for securing percutaneous effectiveness from bulk-dissemination BW weapons is in the use of arthropod disease vectors, such as infected mosquitoes. But the use of vectors would introduce a third biological component into the overall weapon system, thus adding to its unpredictabilities. The limitations of the other ways of achieving percutaneous effects with biological weapons—contaminated projectiles or fragmentation weapons, infected barbed wire, and so on—have already been referred to.

Both chemical and biological *antiplant agents* have been developed. As with the antipersonnel agents, the chemical ones are suited only to the attack of relatively small targets, up to a dozen square kilometres or so at most per operation. The biological antiplant agents are suited to much larger targets. In contrast to antipersonnel BW agents, they are likely to be selected for their ability to initiate diseases that spread of their own accord among industrial or food crops, with noncontagious-disease agents being valued less highly. As each one is generally specific for a particular plant species, an arsenal of antiplant biological weapons is likely to contain more than one agent. As table 1.2 indicates, there is a wide range of viral, bacterial and fungal plant-pathogens to choose from.

Chemical antiplant agents have been used extensively in the Viet-Nam War. Three distinct operational categories have appeared: *soil sterilants,* for poisoning earth so as to retard plant growth within it; *herbicides,* for killing crops; and *defoliants,* for stripping the leaves off vegetation in order to deny natural cover to the enemy. Chemical antiplant agents are not as species-specific as the biological ones, but plant species may still differ widely in their susceptibility to them. A chemical that merely induces premature leaf-fall in one type of plant may kill another.

Anti-animal agents. So far as is known from the published literature, no country has ever given much priority to CBW agents intended solely for use against domestic or draught animals. In the US biological-weapons programme, active work on anti-animal weapons ceased in 1954. Some biological antipersonnel agents, though, have been valued for their additional anti-animal properties—anthrax, for example—and it is also to be noted that a number of the belligerents during World War II took defensive precautions against possible anti-animal BW attack. Canada and the USA, for instance, went to considerable lengths to develop vaccines against cer-

[7] No pathogen of BW interest seems capable of penetrating intact skin, but some can invade through broken skin. It is thus conceivable that the presence of a chemical skin-irritant in a biological-weapon payload might confer percutaneous effectiveness. Such a weapon would, of course, have only a small area of effectiveness.

Table 2.2. Composition of past antipersonnel CW agent stockpiles[a]

Principal operational features of stockpiled agents	Agents stockpiled during World War II[b]				Agents stockpiled in 1970
	UK	Japan	Germany	USA	USA
Harassing agents					
Nonpersistent tear gas	*CN*	*CN*	CN	CN	*CN*
Persistent tear gas	CA	—	—	—	—
Nonpersistent multiple irritant	*DC*	DC	DA Adamsite	CNS[c] Adamsite	*Adamsite* CS
Persistent multiple irritant	—	—	—	—	CS-2
Lethal casualty agents					
Nonpersistent	Phosgene	*Phosgene* *Chloropicrin*	Phosgene	Phosgene	*Botulinal toxin A*[d]
Nonpersistent and quick-acting	—	AC	*AC* *CK* *Sarin*	*AC* CK	Sarin *Shellfish poison*[d]
Persistent	Mustard HT[e] *Lewisite*	Mustard Lewisite	Mustard *HN-3* Tabun	Mustard Lewisite HT *HN-1*	Mustard[f] HT[f] VX
Incapacitating casualty agents	—	—	—	—	*PG*[d] *BZ*

Notes:

[a] Details are given only of those arsenals about which there is much available information.

[b] Italicized entries denote agents stocked in relatively small quantities only. Agents referred to by US Army symbols or trivial names are identified in table 1.1.

[c] CNS is a liquid formulation containing 23 per cent CN and 38 per cent chloropicrin, the balance being chloroform.

[d] These agents are toxins, and stocks of them are currently being destroyed alongside the US stockpile of BW agents.

[e] HT is a 3:2 mixture (usually) of mustard gas and the vesicant agent T. It has greater persistency than normal mustard.

[f] Mustard gas has recently been declared obsolete by the US Army and stocks of it are being destroyed.

tain diseases of cattle and other livestock. Among these was rinderpest, its causative virus being one of the nine BW agents to which the Western European Union Armaments Control Agency pays particular attention in its verification activities today.[8] Anti-animal BW is of course always a possibility in connection with sabotage, a possibility that is sometimes considered when outbreaks of foot-and-mouth disease are being investigated.

The foregoing account illustrates the principal categories and subcategories of CBW agent that have aroused military interest in the past. A country that was interested in exploiting the diversity of CB weapons might build up an arsenal that contained one or more agents from several or all of the categories. Tables 2.2 and 2.3 illustrate this by showing the ranges

[8] See Volume V, pp. 190–214.

Table 2.3. BW agents standardized during the US biological-weapon programme[a]

Microbial species[b]	Agent category	Characteristics of agent preparation: Symbol[c]	Production concentration[d] *org/gm*	Half-life in storage *weeks*
Antipersonnnel agents				
**Bacillus anthracis*	Lethal	N (wet)	3.10^{10}	80 at 15°C
Yellow fever virus	Lethal	OJ	..	..
		OJAP (vector)	n.a.	5[e] at 27°C
**Francisella tularensis*	Lethal	UL1 (wet)	2.10^{11}	8 at 4°C
		UL2 (dry)	4.10^{11}	5 at 4°C
Brucella suis	Incap.	AB1 (wet)	3.10^{10}	3 at 20°C 21 at 4°C
**Coxiella burnetii*	Incap.	OU2 (wet)	$1–5.10^{10}$	>12 at 4°C >170 at −50°C
*VEE virus	Incap.	NU, wet	$2–4.10^{10}$	1 at 4°C >40 at −40°C
		NU, dry	..	>34 at 4°C
Antiplant agents				
**Pyricularia oryzae*	For rice	..	..	..
**Puccinia graminis tritici*	For wheat	TX (dry)	$2–4.10^{8}$	100 at 4°C

Notes and sources:

[a] Destruction of the US stockpile of biological weapons commenced in July 1971, with completion scheduled for October 1972 [165]. The last of the antipersonnel BW agents was destroyed in March 1972 [1453]. The list given here is not complete; it makes no mention, for instance, of agent UC [1456], the identity of which (e.g., an incapacitating strain of *Francisella tularensis*) has not yet been disclosed.

[b] Strains marked with an asterisk (*) are those which, according to press reports quoting US Army spokesmen [657, 884, 1454, 1612], formed part of the US biological-weapon stockpile at the time of its destruction.

[c] For additional information on the properties of the agents represented by some of these symbols, see the 1962 edition of the manual FM3-10 [420].

[d] The production concentration for agent NU is given in units of the mouse intracerebral LD 50 (which is probably about one viral particle) per gram. For agent OU, the unit is the guinea-pig intraperitoneal ID50 (roughly one rickettsia) per gram. For agent TX, it is uredospores per gram.

[e] The standardized vector for agent OJ is the *Aedes aegypti* mosquito (symbol: AP). Infected mosquitoes, stored in lots of a hundred at 80 per cent relative humidity and 80°F, each lot occupying 3.74 litres of space, and being fed with 10 per cent sucrose at 48 hour intervals, have a 50 per cent survival time of 40 days.

[f] These decay rates were measured inside aerosol-chambers, presumably at room temperature and in the dark, except those of agent UL1, which were measured in the field.

[g] Applied at a rate of 0.01 kg of active uredospores per km^2 under suitable weather conditions, agent TX is reckoned capable of causing an 85 per cent loss of wheat yield within 45 days.

of agents that have been standardized or manufactured for inclusion in certain national CB weapon arsenals in the past.

Time delays

One feature of CB weapons which as much as, or more than, any other serves to set them apart from other categories of weapon is the time scale

Principal operational characteristics				
Aerobiological decay rate[f] *min*$^{-1}$	Incubation period *days*	Duration of incapacitation among survivors *weeks*	Mortality rate *per cent*	Other US Army symbols and preparations
insignificant	2–3	4–5	*95–100*	TR2 (dry)
..	3–6	1–2	*(30–50)*	UT
n.a.			*4–100*	..
0.05 at 85% RH 0.20 at 75% RH 0.04 at 85% RH	2–10	1–3	*30–40*	TT (wet) ZZ (dry)
0.0003 at 85% RH 0.07 at 20% RH	7–60	8–12	*1–2*	NX (wet)
0.001 at any RH	15–18	1–2	*0–1*	MN (wet) NT (dry)
0.02 at 85% RH 0.005 at 20–60% RH	3–4	1/2–1	*0–2*	TD
insignificant	1–4	n.a.	n.a.	..
insignificant	..[g]	n.a.	n.a.	..

within which they operate. With the sole exception of harassing chemicals, no CBW agent produces an immediate effect. Even the quickest-acting ones may take upwards of half a minute to produce casualties, while others may take hours, days or even weeks. Precisely how long this latency period lasts depends on the mechanism by which the agent damages the organism under attack. Biological agents, for instance, have to breed and multiply within a host before they can damage it. Over and above this time lag, CBW agents also have the property of remaining active for an appreciable, and sometimes a long, period after they have been disseminated. A CB aerosol cloud may continue to produce casualties as it travels downwind. Ground over which antipersonnel agents have been sprayed may remain hazardous until the agent has evaporated away (creating a sustained vapour hazard in the process), or has been destroyed by the natural processes that occur in soil.

With the exceptions of delay-fused weapons, radiological weapons[9] and smoke munitions, such time factors are unique features among weapons. With an explosive shell or bullet, for example, everything is over within a fraction of a second. Absence of delay makes for a certain operational simplicity. If a conventional weapon has not at once done what was expected of it, it will not do it at all, and perhaps another one had

[g] See below, p. 209, note 63.

Table 2.4. Persistency of selected liquid CW agents[a]

Agent	Weather conditions		
	Sunny, light breeze, around 15°C	Windy and rainy, around 10°C	Calm and sunny, lying snow, around −10°C
Sarin	1/4–4 hours	1/4–1 hours	1–2 days
Tabun	1–4 days	1/2–6 hours	1 day–2 weeks
Soman	2½–5 days	3–36 hours	1–6 weeks
Mustard gas [b]	2–7 days	1/2–2 days	2–8 weeks
V agent	3–21 days	1–12 hours	1–16 weeks

Notes:

[a] The length of time for which ground purposefully contaminated with the agents may present a potential contact hazard.

[b] At a contamination density in the range 18–60 g/m². At temperatures above about 25°C mustard gas may persist for 1½–4 days.

Source: [206, 302].

better be used. With CB weapons, where there is no such immediacy, there may be corresponding uncertainty about whether things are going ahead as planned. And if there is doubt, the decision about whether to use more weapons is made more difficult by the possible dangers of overdosing a target with CBW agent (e.g., the downwind hazard to one's own troops). On the one hand, this may mean considerable difficulty in operational planning and forecasting; but on the other hand, the various time-delays may be exploitable in operations that cannot be mounted as easily with other types of weapon. The latency-period, for example, makes for insidiousness, and this may be valuable in clandestine or surprise operations; and agents with long persistency-periods may be valuable for area-denial or the interdiction of supply routes.

The latency periods of prominent CBW agents are given in table 1.3 in chapter 1. Persistency periods are less easy to specify, for as noted earlier they depend closely on ambient conditions and on the form in which the agents are disseminated. Puddles of rainwater take longer to disappear than early-morning dew; and mustard gas disseminated from a thermogenerator device is less persistent than mustard gas sprayed from an exploding bomb. Table 2.4 gives figures for prominent CW agents under different weather conditions; they presuppose that the agents have been disseminated in a form and density appropriate to battlefield use as ground-contaminants.

As regards the persistency of BW agents, areas over which they have been spread will remain hazardous only if the agents can keep themselves alive there. This requires nutrients and/or favourable environmental conditions. Certain bacteria, such as those causing anthrax, can concentrate

their genetic material inside a protective coating (a spore) and then remain dormant, but still potentially virulent, for very long periods under certain conditions,[10] as can most fungi. Other agents may sustain themselves by becoming parasitic or saprophytic on the flora or fauna of the target area; disease reservoirs may then be created for indefinite periods, and susceptible species may succumb to these if they enter the area. As noted above, BW agents disseminated via arthropod or other disease vectors may be more persistent than those disseminated as aerosol.

In the aerosol or vapour state, most CW agents are stable enough to maintain their potency for at least as long as it takes for the cloud to become diluted to harmlessness by air currents. But such stability is only rarely found with BW agents, for after aerosolization they are exposed to an environment that is actively hostile to them. Solar radiation, particularly in the shorter wavelengths, may be quickly lethal. So may an atmospheric humidity that is either too high, too low or changing too swiftly. So may certain common air pollutants, and even oxygen itself. In general, it may be said [402] that agents disseminated in the spore state will remain alive for some days if the sky is heavily overcast, or for a few hours in direct sunlight. Unsporulated microbes, or ones that have not been specially protected,[11] may live for an hour or so on an overcast day, or a few minutes only in direct sunlight.[12] These survival periods are crucially important to the operational possibilities of biological weapons.

Biospecificity

CB weapons act specifically against physiological processes that support life. Unlike explosives, flame or bullets, they are biospecific weapons whose efficacy does not depend on gross physical damage. It may thus be possible

[10] For example, during 1941–42, *Bacillus anthracis* spores were disseminated over a test area on the uninhabited island of Gruinard, off the northwest coast of Scotland, in an early British experiment designed to assess the feasibility of biological warfare (see Volume I of this study, p. 118). An official survey made in 1966 showed that the island was still dangerously contaminated and, in the opinion of the scientists making the survey, was likely to remain so for a long while into the future [1587]. A similar "permament bio-contaminated area" exists on the Dugway Proving Grounds in the USA, a relic of a *Bacillus anthracis* experiment conducted during the 1950s [1588].

[11] For example, by the use of micro-encapsulants or certain payload additives. See below, pp. 285–287 and 312–313.

[12] To specify agent lifetimes as crudely as this greatly oversimplifies the likely situation, dangerously so perhaps, since similar specifications appear in biological-weapon employment manuals [43, 403]. The infectivity of a BW aerosol, or at least the viability of the organisms that it contains, generally declines exponentially, so that in theory the cloud never becomes completely dead. In order to specify a finite lifetime, a cut-off point has to be chosen on the exponential decay curve beyond which the proportion of pathogens remaining alive is considered insignificant. But for some pathogens, the infective dose may be as low as one organism.

to execute a CBW attack without much damage to the matériel, buildings or other fixed installations of a target area. Tactical or even strategic advantage may stem from this, for what remains undamaged after a successful attack may be useful to an occupying attacker.

No other category of weapon possesses such biospecificity.[13] The ability of CB weapons to assault the occupants of a target without physically destroying it is a unique characteristic. Whether it is an important one, however, is another question.

Modern armies do not generally anticipate having to capture enemy equipments or structures intact for their success in the field, and if circumstances arose where they did, they would have to place great reliance on the means available for doing so. Reliability is one thing that has not been claimed for CB weapons. Moreover, because CB weapons do not cause physical destruction, failure to produce expected casualty rates would not be compensated for by, say, damage to enemy guns, fortifications or the like. It is probably the case, then, that a commander would be attracted by the biospecificity of CB weapons only where he considered intact enemy matériel or installations to be of very much greater value to himself than to his enemy. Such situations seem unlikely to be common.

Yet they are not inconceivable. It is possible to envisage situations in which the occupation of an enemy airfield or harbour might be highly desirable, provided the facilities remained substantially intact after occupation. An undamaged dockyard, for example, might be of great value in aiding a sea-borne invasion. CB weapons might provide the only possible means for securing such objectives. The same might apply at a lower level in the case, for instance, of an assault on a defended bridge in the van of an advance. Likewise, at a strategic level, the weapons might conceivably permit the capture of factories or other industrial installations in working order. Some commentators have even gone so far as to suggest that extensive reliance on CB weapons in time of war would be desirable because it would reduce post-war recovery and rebuilding programmes.

Area-effectiveness and predictability

It was noted in the previous chapter that bulk-dissemination confers area-effectiveness on CB weapons. It is in this that the major military attractions of the weapons reside. In the first place, it may be reckoned that large targets can be engaged with a comparatively small weight of CB weapons, making for considerable economy and logistical convenience. In the second place, the weapons may be effective against point targets

[13] See also pp. 20–21.

without demanding highly accurate weapon delivery. Moreover, it is the area-effectiveness of CB weapons that permits the off-target CBW attack, a technique which may substantially increase a field commander's ability to conduct a surprise assault.

The effects of explosive or fragmentation weapons diminish rapidly with distance from the point of burst. This is much less the case with CB weapons. As a result, there is a greater probability of success with CB weapons than with conventional weapons against small targets whose precise location cannot be established. One of the most effective uses of gas during World War I, for instance, was in counter-battery fire: enemy guns could be neutralised with HE shell only by direct hits; with chemical shell, gun-crews could be disabled by gas drifting over them from upwind points of burst.

As a means of defence against the weight of firepower feasible today, modern battlefield doctrine envisages widely dispersed formations of troops. For example, combat units are nowadays likely to be deployed over much wider positions than before in order to present less attractive targets for nuclear attack. Area weapons have thus become increasingly important. Conventional weapons have been developed to increase their area-effectiveness, and modern proximity-fused fragmentation shell, multiple rocket launchers, napalm weapons, aircraft cluster-weapons, and the like, have a much greater area-capability than their World War II equivalents. CB weapons are consequently no longer unique in their area-effectiveness, but they still possess the singular advantage of being able to "seek out" their target. A cloud of CBW agent can penetrate fortifications, trenches, foxholes, and even armoured vehicles (if they are not fitted with special protective measures) to an extent that no other weapons can match.

This combination of properties means that simple cost-effectiveness calculations—cost in terms of weight of weapons needed, and effectiveness in terms of numbers of casualties—are likely markedly to favour CB weapons for use against area targets having some degree of protection against conventional weapons. Table 2.5 includes figures that are relevant here. It was on this sort of basis that an official calculation current in 1967 could judge nerve-gas weapons preferable to conventional or nuclear weapons for the attack of company-sized (200-man or 18-tank) formations of infantry or armour deployed under likely European battlefield conditions. Against smaller targets, the calculation favoured explosive or fragmentation weapons; against larger ones, nuclear weapons. Likely levels of enemy antigas protection were apparently taken into account. Another such calculation, this time to do with civilian targets, was offered to the

Table 2.5. Estimates of the relative potencies of CB and non-CB weapons

Weapon system		Mean area of effectiveness (MAE)		
Delivery vehicle	Munitions	Definition	Size, *hectares*	Basis of estimate
Urban area target				
A single aircraft having a bombload of 5–6 tons[a]	Incendiary	Area destroyed by fire	Up to 15	US attack on Tokyo, 9–10 March 1945[b]
	High explosive	Area over which 50 per cent casualties can be expected	Up to 22[c]	British World War II data on the MAEs of high-explosive bombs
	Nerve gas (VX)	Area over which 50 per cent casualties[e] can be expected	Up to 75[d]	Theoretical calculation[f]
	Nuclear fission (10–15 Kt airburst)	Area destroyed by blast and fire[g]	1 200	US attack on Hiroshima, 6 August 1945[h]
		Area over which 50 per cent casualties[e] can be expected	3 000	
	Biological	Area over which 50 per cent primary casualties can be expected	0–5 000[d]	Theoretical calculation[f]
	Nuclear fusion (10 Mt airburst)	Area over which 50 per cent *immediate* casualties can be expected	200 000	Theoretical calculation[i]
Rural area target				
Six 155 mm howitzers firing for 15 mins.[j]	High explosive[k]	Area over which 50 per cent casualties can be expected among personnel lying in the open	6	Swedish Army estimates[l]
	Nerve gas[m] (sarin)		2–22[n] 13–144[o]	US Army estimates[p]
	High explosive[k]	Area over which 50 per cent casualties can be expected among personnel in open foxholes	1.5	Swedish Army estimates[l]
	Nerve gas[m] (sarin)		2–22[n] 13–144[o]	US Army estimates[p]
	High explosive[q]	Area over which 50 per cent casualties can be expected among personnel in covered foxholes	0.2	Swedish Army estimates[l]
	Nerve gas[m] (sarin)		1–2[n] 6–72[o]	US Army estimates[p]

Notes:

[a] Such a bombload is that of the largest World War II heavy bomber; it can be carried by a modern fighter-bomber.

[b] Per weight of weapons used, this was the most destructive non-nuclear strategic bombing operation of World War II, an intense conflagration being created among highly inflammable buildings. A total of 1667 short tons of incendiary bombs were dropped from 279 aircraft,

UN group of CBW experts (see [136]) in 1969 by the military advisers of one of the group: for a large-scale operation against a civilian population, casualties might cost about $2 000 per square kilometre with conventional weapons, $800 with nuclear weapons, $600 with nerve-gas weapons, and $1 with biological weapons.[14]

CB weapons gain in area-effectiveness at the expense of predictability.

[14] Details of the scenario to which these figures relate are not available. It must be supposed that the dollar-costs referred to the payload of the weapons involved, exclusive of the delivery systems. If the latter had been taken into account, the figures would have been very different. In the estimate of a US Army authority speaking in 1959, the costs of adding a CBW capability to those aircraft and missile weapons-delivery systems that were suited to it would amount to no more than 5 per cent of their procurement costs. And as regards the costs of strategic bombing operations with conventional weapons, he quoted the US Strategic Bombing Survey estimate that about $4–14 million per square kilometre were spent during World War II on the demolition of German territory, the munitions themselves accounting for less than 3 per cent of this [274].

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destroying 41 km² of housing. There were 185 000 casualties in the devastated area, about 45 per cent of them fatal. [1458]

[c] Depends greatly on the distribution of people between houses and the open streets; if the majority are indoors, the MAE may fall by a factor of ten. Casualty death rate is likely to be about 50 per cent.

[d] Highly weather-dependent.

[e] About half the casualties are likely to be fatal.

[f] As set out in *Health Aspects of Chemical and Biological Weapons:* Report of a WHO group of consultants. Geneva: WHO, 1970. For the BW estimate, compare Brode, H. L., RAND publication P-3170. [1030].

[g] The casualty rate within the area destroyed by fire and blast during the Hiroshima attack was 73 per cent; 61 per cent of these casualties died.

[h] There were 140 000 casualties, nearly half of them fatal, including those outside the devastated area. The average population density was a quarter that of Tokyo. The yield of the Hiroshima bomb, which weighed about 4 tons, was about 12.5 kilotons TNT-equivalent. The areas of effectiveness are calculated from data given in Glasstone, S. *(ed.)*, *The Effects of Nuclear Weapons* [1459].

[i] Derived from the calculations reported in *Effects of the Possible Use of Nuclear Weapons and the Security and Economic Implications for States of the Acquisition and further Development of these Weapons:* Report of the UN Secretary-General [1460].

[j] 24 rounds per howitzer; 3 kg of sarin or 6.8 kg of high explosive per round.

[k] Shells fused for air-burst (proximity or time fuses). The estimated MAEs are halved for point-detonating fuses. They apply to shell designs of the 1960s; the latest forms of anti-personnel artillery shell have considerably greater area effectiveness against troops in the open due to new techniques for increasing fragmentation effects.

[l] In the Swedish artillery, it is calculated that if 10 shells are sufficient against an area target of troops standing in the open, 25 will be needed against the same troops lying on open ground, 50 if they are sheltering in ditches or shell craters, 100 if they are in open foxholes, and 1 000 if they are in covered foxholes.

[m] The nerve-gas MAEs are highly weather-dependent: hence the ranges of values. The lowest figures in each range relate to weather conditions that are barely suitable for chemical warfare. See table 2.6 for more information.

[n] Against personnel carrying but not wearing respirators, so that a surprise-dosage attack, delivered by time-on-target fire, is needed. Assumes that target personnel take at least 15 seconds to don their respirators after they have been warned to do so, and that within 3 minutes after the first volley the alarm will have reached everyone in the target area. Also assumes that target personnel are operating under conditions that favour the success of CW attack by increasing their breathing rate (i.e., that they are fatigued, under mental stress, very hot, very cold, or crawling, or on the assault).

[o] Against personnel not equipped with respirators, so that a total-dosage shoot can be used.

[p] Calculated from the chemical-ammunition expenditure tables given in the March 1966 editon of FM 3–10 [43] (these tables have been revised somewhat in the February 1971 edition of the manual).

[q] For shells fitted with time-delay fuses.

For greatest area-coverage, the weapons must make the most use possible of the air currents prevailing over and around the target. They must inject the CBW agent into these at the optimum distance from the target and in the physical form best suited to airborne transport. But the effects that the agent will then produce can be predicted—and therefore controlled—only to the extent that the meteorological situation can be predicted and its characteristics understood. Three quite different types of uncertainty come in here. First, will it actually be possible to measure or forecast all the meteorological parameters on which the performance of the weapons depends? This will be a question of having the right equipments and the right men on hand at the right time. Second, if the parameters can be measured (and it must be noted that they relate to conditions prevailing over enemy-held territory), how well will the measurements permit accurate predictions about agent cloud travel? This is a question of the predictiveness of the science of applied meteorology. To the best of their ability, expert meteorologists will have compiled tables, designed slide-rules, and so on, to permit the users of the weapons to relate likely performance to weather conditions [404–406]. But applied meteorology is not yet predictive enough for these aids always to have adequate precision, and the larger the scale of attack the more will the consequences of their imprecisions be magnified. Third, will the users of the weapons in fact be able to make appropriate use of all their meteorological back-up, whatever its limitations? This will be a question of training, discipline and skill.

Quite small changes in weather conditions can make enormous differences to the area traversed by a vapour or aerosol cloud before it becomes diluted to insignificance. This is illustrated in table 2.6. It is not only the direction of the wind that is important. As is described further in appendix 3, wind speed, wind profile, temperature, cloud cover, relative humidity and precipitation, all of which may vary widely and rapidly with time, may also prove critical. The vertical component of wind speed is at least as important as the horizontal components, and, in that ground winds are strongly affected by the shape and roughness of terrain, target topography may also be significant. It is quite possible that over a period of a few hours the weather may change sufficiently for the weight of weapons that was adequate for a given mission to become ten or even a hundred times too much or too little. If too little nerve gas, say, has been used, an attack may fail completely; if too much has been used, subsequent manoeuvres or friendly units adjacent downwind may be gravely endangered.

The less the performance of a CB weapon depends on prevailing weather conditions, the less will these meteorological uncertainties matter. Thus,

Table 2.6. Influence of weather on performance of nerve-gas weapons[a]

Weather conditions		Weight of sarin attack thought capable of producing 50 per cent casualties among unprotected people if small ground-functioning weapons are distributed over the target area[b] *Kg of sarin per km²*			6-weapon battery of 155 mm howitzers firing sarin shell for 15 minutes: Maximum MAE (Largest target over which 50 per cent casualties are likely among unmasked personnel)[c] *Hectares*			Downwind hazard (Distance downwind of the maximum MAE over which a severe to moderate airborne sarin hazard may occur)[d]
	Temperature:	−20° to 0°	0°–15°	>15°	−20° to 0°	0°–15°	>15°	*Km* any temp.
	Wind strength:[e]							
Early morning or late evening, or heavily overcast day	Light air	160	160	80	144	144	144	3
	Slight breeze	410	250	160	144	144	144	5
	Gentle breeze	740	490	410	72	96	144	10
Windy weather, day or night	Moderate breeze	1 600	980	740	29	48	72	25
	Fresh breeze	3 400	2 200	1 600	13	20	29	75
Sunny or slightly overcast day	Light air	740	570	490	48	57	57	1
	Slight breeze	1 100	900	740	29	36	48	1
	Gentle breeze	1 600	1 400	1 100	18	20	29	1
Calm night	Light air	80	80	80	144	144	144	45
	Slight breeze	80	80	80	144	144	144	75
	Gentle breeze	80	80	80	144	144	144	120

Notes:

[a] The weapon expenditures suggested by entries in the first three columns of figures sometimes diverge appreciably from those suggested by the corresponding entries in the second three columns of figures. This reflects the overdosage likely to be created by the rather larger 155 mm projectiles.

[b] Calculated from US Army chemical-ammunition expenditure tables [43] for M360 sarin cartridges (0.32 kg sarin payload) for 105 mm howitzers. Assumes that target personnel are in open or lightly-wooded terrain, either inside or outside foxholes or similar shelter. In urban areas, considerably heavier weights of attack would be required.

[c] Calculated from US Army chemical-ammunition expenditure tables [43] for M121 sarin projectiles (3 kg sarin payload). Rate of fire of US Army 155 mm howitzers is 24 rounds per 15 minutes. Target personnel as in note *b*.

[d] Calculated from US Army down-wind hazard tables for sarin weapons [43], assuming the target is circular, and assuming that the weather conditions do not change. A *moderate* airborne sarin hazard is created by a Ct dosage that might cause mildly incapacitated casualties (i.e., greater than 5 mg-min/m³ or so).

[e] *Light air* indicates wind speeds of about 1–2 m/sec; the direction of the wind will be shown by smoke drift but not by wind vanes. *Slight breezes*, about 2–3 m/sec, can be felt on the face and cause leaves to rustle. *Gentle breezes*, about 3–5 m/sec, extend light flags and set leaves and twigs in constant motion. *Moderate breezes*, about 5–8 m/sec, create dust clouds, sway tree branches and blow fallen leaves and paper about. *Fresh breezes*, about 8–15 m/sec, hinder walking somewhat and sway whole trees, breaking off small twigs and branches. Windier weather is rarely suited to use of chemical weapons.

while they may be highly significant to the large-scale employment of BW or nonpersistent CW agents for respiratory effects, they may be practically irrelevant to the small-scale use of persistent CW agents for percutaneous effects. And it must also be noted that one objective in

current CB weapons R&D is to diminish both meteorological dependence and meteorological uncertainty.

There are two important types of uncertainty other than the meteorological and related ones just described. The first has to do with the ability of CB weapons designers to predict the effects of CBW agents on living targets. It is necessary to know how much agent will infect or poison an organism, and to what degree, in order to calculate how many weapons are needed for a given military effect. Antiplant and anti-animal agents present no great problem, for any amount of direct experimentation can be done. This will only rarely be possible with antipersonnel agents, and for many of the currently favoured types there is no past combat experience to draw upon. Extrapolations from experiments on laboratory animals go part of the way, but this is very much an intuitive process on which expert opinions may reasonably and widely differ. The methods and difficulties of estimating human dosage responses are discussed in appendix 3. Estimates of the casualty rates likely to be suffered by groups of people exposed to conventional weapons are more dependable than those for CB weapons.

The second, and more important, uncertainty has to do with the level of enemy CB protection. Against an unprotected enemy, CB weapons may prove devastatingly potent, but, as described in the previous chapter, comparatively simple protective countermeasures may greatly diminish their effectiveness. Complete protection, although possible in theory, will rarely be feasible, but what a belligerent has to consider before deciding to use CB weapons is whether the level of enemy protection is high enough to make their use uneconomical compared with the use of some other weapon. It is almost certainly the case that any CB protective posture with which an army or civil defence organization may be willing to burden itself can be overwhelmed by a large enough expenditure of weapons. But the process of estimating how high this expenditure must be cannot fail to be uncertain, thus adding greatly to the other unpredictabilities referred to earlier. Table 2.7 collects together official estimates from France, the USA and Sweden for the vulnerability of different levels of protection. The significance of the great disparities between the weapon expenditures which these vulnerabilities imply is obvious enough.

While it is undoubtedly possible that the area-effectiveness of CB weapons may provide high casualty rates and other military benefits, the probability that it will do so in practice is governed by several significant factors that are poorly predictable. These unpredictabilities must be set against the results of cost-effectiveness calculations that appear to favour CB weapons. However effective a weapon may be, even a slight element of unpredictability will weigh heavily against it.

Casualty estimates for different weights of nerve-gas attack against different levels of antigas protection

Table 2.7a. French estimates for sarin weapons

Factors by which basic munitions-requirement must be increased:

(a) *for overcoming different levels of protection*

Enemy troops not equipped with respirators	Enemy troops carrying but not wearing respirators		Enemy troops wearing respirators[a]
	Poorly trained in antigas procedure	Well trained in antigas procedure	
1	4	10	20

(b) *for securing different casualty rates*

10 per cent	20 per cent	30 per cent	50 per cent	90 per cent
1	2	4	7	10

[a] Casualties thought likely to result because of faulty respirators, leaks around respirator face-pieces, and ill-disciplined masking.

Source:
Gye–Jacquot, *Vétérinaire Commandant.* Possibilités de toxiques de guerre. *L'Armée* June–July 1965: 38–47.

Table 2.7b. US estimates for sarin weapons

Level of protection A: Troops in the open or in open foxholes B: Troops in field fortifications with overhead cover or in ventilated vehicles		Per cent casualties among target population for different weights of attack delivered by 155 mm howitzers firing into an area of 2 hectares[a]		
		1-battery fire	2-battery fire	Battalion fire
Troops not equipped with respirators	A	*50–90*	*>90*	*>90*
	B	*50–90*	*>90*	*>90*
Troops carrying but not wearing respirators:				
Troops under stress (crawling or hot or cold or on the assault or fatigued)	A	*10–20*	*20–40*	*40–50*
	B	*5–10*	*10–20*	*20–25*
Troops mildly active	A	*5–10*	*10–15*	*15–20*
	B	*2– 5*	*5– 8*	*7–12*
Troops rested and well prepared (good antigas discipline, some already masked or in protective shelter)	A	*3*	*5*	*8*
	B	*1*	*3*	*4*

[a] Each howitzer firing one round (3 kg of sarin); 6 weapons per battery, 18 weapons per battalion; time-on-target fire. Wind speed between 1 and 5 m/sec. Overcast day above 0°C.

Source:
Figures calculated from data given in US Department of Army field manual FM 3–10, March 1966 edition [43].

Table 2.7 c. Swedish estimates for sarin and V-agent weapons

(i) *On-target V-agent attack*[a]

Level of antigas protection	Estimated per cent casualty rates	
	Fatal casualties	Severe but non-fatal casualties
Respirators donned, but only after a 2-minute delay; other countermeasures[b] also performed slowly	75	20
Respirators donned with 30 seconds;		
no other countermeasures	55	15
plus rapid personal decontamination	20	5
plus efficient use of auto-injectors	10	15
all this plus prior donning of rain capes to protect the skin	5	

Notes:

[a] A mode and weight of attack disseminating 1–10 g/m² of V-agent over 55 per cent of the target area, 0.1–1 g/m² over an additional 40 per cent, together with an aerosol Ct-dosage of 10–20 mg-min/m³ over 95 per cent.

[b] Personal decontamination (i.e., decontamination of skin, clothing and equipment); use of auto-injectors and "buddy-aid" where needed; and removal from contaminated terrain.

Sources:

Försvarets Forskningsanstalt (FOA). BC-stridsmedel. *FOA orienterar om* (2), December 1964. [Transl. BC warfare agents. FOA, 1969]; *and* BC stridsmedel. *FOA orienterar om* (2) 3rd ed. May 1970.

Jacksén, S. and Tammelin, L.-E. [Chemical weapons and chemical warfare defence in Swedish security policy: policy alternatives.] FOA 1 Report no. A 1401–30. September 1967.

(ii) *Off-target attack: 4 000 kg of sarin sprayed across wind over 6 km by eight low-flying aircraft (open or lightly-wooded terrain, overcast day, gentle breeze*[a]*)*

Level of antigas protection	Per cent casualty rates					
	5 km downwind (by which point cloud will have traversed about 30 km²)		10 km downwind (by which point cloud will have traversed a further 50 km²)		20 km downwind (by which point cloud will have traversed a further 120 km²)	
	Fatal or severe casualties	Light casualties[b]	Fatal or severe casualties	Light casualties[b]	Fatal or severe casualties	Light casualties[b]
Respirators donned before arrival of cloud	*0*	*5*	*0*	*0*	*0*	*0*
Respirators donned when first symptoms are felt						
Other countermeasures[c] efficient	*20–30*	*70–80*	*5–10*	*90–95*	*0*	*5*
Other countermeasures inefficient	*80*	*20*	*20*	*80*	*0*	*30*

Notes:

[a] About 10 km/hr.

[b] Symptoms confined to running nose, miosis, tightness in chest and slight difficulty in breathing.

[c] Use of auto-injectors and "buddy-aid" artificial respiration, where necessary.

(iii) *V-agent nerve gas used to contaminate a road and its verges: effects on troops subsequently using the road (road contaminated in dry weather to a density of 1–2 g/m²)*

Level of antigas protection	Per cent casualty rates	
	Severe or fatal	Light casualties[a]
Unmasked troops; countermeasures initiated only with onset of symptoms (after 6–10 minutes)		
Troops marching on road surface		
Efficient countermeasures[b]	*0*	*20–30*
Inefficient countermeasures	*0*	*30–50*
Troops marching on road verges[c]		
Efficient countermeasures[b]	*30*	*70*
Inefficient countermeasures	*70*	*30*
Masked troops forced to take cover on contaminated ground		
Countermeasures[d] initiated within 1–2 minutes	*0*	*5[e]*
Countermeasures initiated within 5–15 minutes	*5–15[e]*	*20–30[e]*
Inefficient countermeasures	*60[e]*	*40[e]*
Masked troops; minimum contact with contaminated ground (e.g., through soles of boots only)		
Personal decontamination within 5–30 minutes	*0*	*0*
Inefficient or delayed decontamination	*5[e]*	*20–30[e]*

Notes:

[a] Symptoms confined to miosis, running nose, chest tightness and slight difficulty in breathing.
[b] Gas alarm given quickly; rapid masking; use of auto-injectors and "buddy-aid" artificial respiration where necessary; decontamination of skin, clothing and equipment; withdrawal from contaminated area.
[c] Involving contact with contaminated roadside vegetation.
[d] Use of auto-injectors and "buddy-aid" artificial respiration where necessary; decontamination of skin, clothing and equipment; withdrawal from contaminated area.
[e] Casualties delayed for 1/4–6 hours.

Sources:

Same as (ii) above.

Sources:

These are rough estimates made by the Research Institute for National Defense. They are taken from the manual [1462] used by observers on Swedish Army field exercises for gauging the performance of troops in observing antigas procedures when subjected to simulated nerve-gas attack.

II. *Possible applications of CB weapons*

CB weapons thus have the following advantages. The range of effects attainable with them is adaptable to a wide choice of weapon-delivery systems and, provided the weapons will work as predicted, to a wide variety of military situations. They are area and search weapons that can harm an enemy whether he is widely dispersed or concentrated within fortified positions. They can be used against point targets without accurate location of the target. They do not destroy buildings, communication or transportation facilities, or power sources. They have singular area-denial possibilities. They are suited to clandestine or surprise operations on a large or small scale. Their logistic requirement may be small.

But they have several disadvantages. Their use is illegal and potentially outrageous and may thus have damaging political consequences. Their operation is complicated, requiring special training, special safety precautions and special forms of field intelligence. The weapons are subject to unpredictabilities which may sometimes amount to uncontrollability. Their effects may not be confinable to their immediate target area, either in space or in time. These uncertainties will complicate forward planning.

The assets may be considered to outweigh the liabilities, or vice versa, according to the circumstances of a particular mission or conflict. We now describe some of the more plausible applications that can be envisaged for CB weapons in different types of military action. A distinction is made between applications of CB weapons in theatre operations, on the one hand, and, on the other, their use against targets distant from any battlefield. We call the former "tactical employment", and the latter "strategic employment". In this usage "strategic" applications of CB weapons include both large-scale use against civilian targets, and small-scale localized use in sabotage and other irregular operations. In table 2.8 a French view is presented of the relative probabilities of these different forms of CBW occurring in different types of conflict.

Strategic employment of CB weapons

Strategic applications can be envisaged for CB weapons both before and after belligerents declare or openly acknowledge that they are at war. During the former period, whether it is succeeded by overt war or not, CB weapons might be considered to lend themselves to covert strategies of subversion or economic warfare. The insidious effects of many CBW agents, particularly infective ones, make them suited to sabotage, for not

only may they cause widespread damage, but their delayed effects may also enable the saboteur to escape detection. This is one of the few contexts in which contagious-disease agents seem to hold out much military attraction, for an attacker might reckon the resemblance between a natural and an unnatural epidemic to be close enough to divert suspicion. Recurrent acts of terrorism and assassination, successive crop failures, outbreaks of disease or food poisoning that overextend public health services, all or any of these may spread alarm and despondency, foster disaffection with a ruling régime, or weaken a country's industrial capacity. Small countries that depend for their economic viability on the annual harvests of certain crops—tobacco, say, or sugar cane—might be particularly vulnerable to this sort of activity.

An enemy might embark upon clandestine CBW operations of a rather different type immediately prior to an invasion. Military installations, command posts or communication centres might then become targets for CB sabotage. And in these circumstances, the attacker might no longer seek to conceal his CB operations. For example, he might see merit in a massive aircraft or off-shore sea delivery of biological antipersonnel agents timed so that the incubation period ended as the invasion began. One scenario that is sometimes quoted here concerns possible US employment of incapacitating biological weapons prior to an invasion of Cuba [407–409]. VEE virus, say, sprayed over the country by a squadron of aircraft a few days before invasion might subsequently sap the defenders' powers of resistance without at the same time alienating any pro-US elements in the population by inflicting enormous loss of life. Adverse factors in this scenario include the enormous political repercussions to be expected, and perhaps military ones as well. They also include the possibility—one that tends to negate the whole concept of incapacitating BW—that soldiers defending their homeland might in fact fight more desperately when gripped by disease than they would otherwise.

Once overt hostilities had begun, CB weapons might find both covert and overt strategic applications, although here the sanctions of retaliation and reprisals would presumably weigh even heavier than before. Covertly, they might continue to be used for sabotage, demoralization and attrition. Overtly, antiplant or anti-animal agents, particularly biological ones, might be used on a large scale against an enemy's farmlands or industrial crop cultivations. Antipersonnel agents might be exploited for mass-casualty effects among civilians; while this might not serve any constructive strategic purpose, it might nonetheless attract a failing belligerent intent on vengeance at any cost. And CB weapons have a vast, if uncertain, population-killing potential, as is demonstrated in appendix 3.

Table 2.8. Relative probabilities of the different forms of CBW: a French view

Type of conflict	Tactical employment			Strategic employment			
	Chemical weapons			Chemical weapons		Biological weapons	
	Lethal	Incapacitant[a]	Biological weapons	Lethal	Incapacitant[a]	Large-scale use	Localised (sabotage) use
Classical war[b]	1	2	1	0	2	1	1
Subversive war[c]	0	2	0	0	2	0	3
Nuclear war	2	2	0	0	0	0	0
Preliminaries to nuclear war[d]							
Surprise attack	2	2	0	2	1	0	0
Mounting political crisis	0	1	0	0	1	0	3
Escalation of a minor war	1	2	1	1	2	1	1

Probability: zero = 0, low = 1, medium = 2, high = 3

Notes:

[a] A term used both for harassing agents and incapacitating agents.
[b] The Arab-Israeli War of June 1967 is given as an example of a *guerre classique*.
[c] The present war in Indo-China is given as an example of a *guerre subversive*.
[d] In an opinion poll conducted during 1966, the Société d'Etudes et de Documentation Economiques et Sociales asked a number of politicians and scientists how they thought nuclear war might break out. Seven per cent thought surprise attack to be the most likely; 11 per cent, that it would happen accidentally; 37 per cent, that it would be precipitated by a mounting political crisis; and 45 per cent, by escalation of the level of violence during a minor war.

Source: Ganas, P. Nouveaux développements en guerre chimique et biologique. *Forces Aériennes Françaises* 24: 449–75, 1969.

Tactical employment of CB weapons

If it is considered that the main battlefield attractions of CB weapons lie in the support which they can give to conventional firepower and manoeuvre, a discussion devoted solely to their own particular tactical applications may be misleading. In the present context there is little alternative. It may be noted, however, that in the past some military authorities have not assessed the tactical applications of the weapons from this standpoint. For example, while their British counsellors on CW advised the Allied Combined Chiefs of Staff during World War II to regard gas as a supplementary weapon to be used in conjunction with explosives and flame, their US counsellors advised them to regard it as a weapon that could be decisive on its own if used in large enough quantities in the right place and at the right moment [410]. German doctrine resembled the US rather than the British doctrine on this point [399]. There is therefore some justification for our present approach.

We do not attempt an exhaustive discussion. We describe only those tactical applications of CB weapons that have received frequent attention

from military commentators, or which have historical precedent. For a more comprehensive picture, there are several military publications from a number of different countries to consult [299, 394, 399, 411–419], above all the various unclassified US military manuals on CB weapon employment [43, 403, 420]. Other countries, however, have published little in the open literature on this topic, and keep secret whatever military manuals they may have.

Antipersonnel chemical weapons

Quick-acting antipersonnel chemicals could find a variety of applications as fire support for offensive theatre operations. It is possible to conceive of several tactical situations where their area-effectiveness, search-out capacity, persistency, and even their ability to cause casualties without also causing gross physical destruction, could offer considerable advantages over conventional fire support. In this context, they are perhaps more likely to be used in conjunction with other weapons, for the effectiveness of each might thereby increase. This applies both to casualty agents, such as nerve gas, and to harassing agents. One occasion when the synergetic effects might be especially marked would be if nerve gas were used alongside nuclear weapons: the havoc created by the latter might gravely weaken an enemy's overall antigas posture. Likewise it has been demonstrated on battlefields in the past that harassing agents can substantially increase the efficacy of conventional antipersonnel fire against entrenched, but unmasked, troops.[15]

If CW is to be employed, the selection of CW agent as regards nature and duration of effects, and the particular targets chosen for CW attack, will depend on the battle aims of the attacker. The diversity of chemical weapons allows a wide range of choice in these respects. It may also permit the use of more than one agent in a particular attack, something which would add heavily to the burden of the defence.

Where the immediate aim is to neutralise relatively small enemy positions, the high casualty rates obtainable with nerve gas might be considered attractive. For greatest effect, nerve-gas weapons would be used in surprise attacks of short duration but high intensity, so that the enemy was given little opportunity to activate protective equipments or don protective clothing. This was a technique with which the British, with their 4-inch Stokes mortars and Livens Projectors, were particularly associated during World War I.[16] Nowadays it might be performed with tactical

[15] Demonstrated, for instance, by the Japanese in China, and by the Americans in Viet-Nam. See Volume I, pp. 152 and 202–203.
[16] See Volume I, pp. 33, 55–56 and 104.

rockets or missiles, multiple rocket launchers, ground-support aircraft spray tanks or cluster weapons, or time-on-target artillery fire. In offensive operations, the target area chosen for such attack would presumably lie in the area chosen for penetration, and extend throughout the depth of the battlefield. Nonpersistent agents would be used, rather than persistent ones that would impede the advance, and they would be introduced sufficiently far ahead of the attacker's advancing troops to avoid injuring them. Even so, the troops would generally have to mask themselves, particularly if the enemy were expected to respond with the same sort of weapon.

Persistent agents might be used against target areas that the attacker or friendly forces did not intend to enter for some time, for example, defended positions to be bypassed, or artillery that was not placed in the direction of attack. This was a technique first developed by the Germans with their World War I mustard-gas weapons.[17] Persistent agents might also be fired onto the ground behind enemy troops to delay their withdrawal, a technique which the Japanese used against the Chinese at Ichang in 1941, employing mustard gas and lewisite.[18] Persistent agents might be spread over flanking terrain to limit the areas from which the flanks might be attacked and provide at least temporary protection. The enemy would then be forced to waste time taking protective measures if he wanted to force the gas barrier, even if he tried to accelerate the passage by using personnel-carrying vehicles. The Italians sprayed mustard gas from aircraft to protect the flanks of their advancing columns during their invasion of Ethiopia.[19] For fullest effect, ground contaminated with persistent agents needs defending with conventional fire, for this may force the enemy to take cover on contaminated ground, thus increasing his exposure to the agent.[20]

In defensive operations, nonpersistent agents might be used against areas where the enemy had concentrated his troops for attack, against artillery positions, command posts, and so on. With persistent agents it might be possible not only to cause casualties, but also to impede or even prevent a poorly protected enemy from operating in a particular area. By such means the enemy could be channelled into avenues of approach that suited the defender, for example as regards defensive fire or counter-attack. A defence might also be strengthened by the use of chemical mines. These might be interspersed with high-explosive mines in a minefield in order to

[17] See Volume I, pp. 139–40.
[18] See Volume I, pp. 150–51.
[19] See Volume I, p. 145.
[20] See table 2.7 c(iii) for an illustration.

make the clearing of the minefield more difficult. Such a minefield could serve the same functions as a conventional one—to channel the enemy's attack, to cover gaps between positions, or to protect flanks—and, like a conventional one, it would need defending.

Chemical weapons might be used for more limited goals than inflicting high casualty rates or denying terrain. Small numbers of them, fired sporadically, could be used to harass the enemy by exposing him to unexpected gas clouds that drifted over his positions. This would force him into respirators, thus lowering his overall combat efficiency. Either casualty or harassing agents could be used for this purpose, the latter threatening acute discomfort rather than death among unprotected personnel. This was one of the original functions of chemical artillery weapons during World War I.[21]

For most, if not all, of the rôles described above, chemical casualty agents having a low fatality rate (incapacitating agents) would be as useful as ones having a high fatality rate, provided they were equally efficient at producing casualties.[22] In situations where enemy and friendly or non-combatant personnel were intermingled, they might be considered decidedly preferable, even if they were less efficient as casualty agents. A much-publicized use to which US forces have put the irritant agent CS in Viet-Nam (although by no means the most common one) has been to incapacitate a target population suspected of containing intermingled enemy personnel, and then rapidly moving in before the effects of the CS wear off.[23]

Antipersonnel biological weapons

In a tactical context, time factors may be extremely important; the advantage may go to the faster-moving, faster-reacting combatant. Biological weapons, with the delayed action that is imposed by disease incubation periods, will therefore generally be less attractive than chemical weapons for theatre operations. (This is part of the reason also for the lesser military importance nowadays of most of the World War II chemical casualty

[21] See Volume I, p. 137.

[22] Although this was something about which British CW technologists could not convince their military masters when they discovered the offensive possibilities of mustard gas in their laboratories early in World War I. J. B. S. Haldane has recorded the following incident: "In 1915 a British chemist proposed to a General who was concerned with such questions that the British should use dichlorethyl sulphide. 'Does it kill?' asked the General. 'No', he was told, 'but it will disable enormous numbers of the enemy temporarily.' 'That is no good to us', said the man of blood; 'we want something that will kill'." [421]

[23] See Volume I, pp. 188, 194–97 and 202.

agents—phosgene, mustard gas, and the like—in comparison with the much faster-acting nerve gases.) However, it is not inconceivable that under circumstances where a timetable for the development of battlefield events can be predicted with some confidence, antipersonnel biological weapons could serve as an important complement to other weapons. The shorter the incubation periods of the available agents, the more adaptable to battle planning are the weapons in which they are charged. In certain situations, biological weapons might even have tactical advantages over chemical weapons. Their suitability for surprise attack is enhanced by the fact that rapid multi-agent detection equipment, which has been developed for CW agents, is not yet available for detecting BW agents. There is also a broader range of BW agents to choose from as regards effects on a target population. The difficult and poor predictability of biological weapons would, however, be a severe drawback.

As in CW, the aim of the operation in which biological weapons are to be used will dictate the choice of agent and the manner in which it is to be employed, as well as the selection of targets. The objectives of biological operations may be much the same as chemical ones, but on a larger scale. They may be, for example, to delay or hamper an enemy's offensive preparations, to weaken or destroy enemy troops, or to disrupt support of enemy operations. While the tactical attractions of chemical weapons seem likely to be greatest in operations against company-sized formations of enemy troops, the most favourable tactical targets for biological attack would seem to be ones of division size or larger [43]. Apart from anything else, the larger the target, the less frequently will it move, so that the delayed effects of biological weapons would present less of a problem. One situation to which biological weapons seem particularly suited is during the preparatory phase of a large-scale combined-operations attack, such as in advance of airborne, airmobile or amphibious operations.[24]

[24] One of the most detailed illustrations of such a possibility (although surely not a particularly plausible one) to be found in the open literature is contained in the 1966 edition of *Employment of Chemical and Biological Agents* [43], one of the US military manuals dealing with CBW. Appendix X of this manual is an "Example of a US Marine Corps B/C fire support plan annex to an operations order". The scenario relates to an assault by airborne troops on an objective apparently near Würzburg, in West Germany (although it is not clear how the naval ordnance referred to in the plan could be brought to bear in such an operation). Both lethal and fast-acting incapacitating BW agents are to be sprayed over designated enemy command posts three days before the assault. They are to be delivered by carrier-based aircraft, fourteen Aero-14B spray-tanks (see table 1.5 on page 86 above) and "System No. 5" being allocated for the purpose. Immediately prior to the assault, enemy artillery positions and infantry-regiment command posts are to be attacked with nerve gas, sarin via *Weteye* and Mk94 bombs and *Misteye* cluster-bombs, and VX via Aero-14B

Contagious-disease agents are unlikely to be of value in theatre operations, where the dangers of backfire would surely be considered too great. Even noncontagious-disease agents seem unlikely to be used in areas at all close to friendly troops (unless they have been reliably immunized against the disease), except perhaps in defensive operations that are characterized by successive delaying actions. Targets chosen for BW attack would thus seem likely to occur in the rear parts of a battle area. Examples include high-echelon command posts, fortified areas, troops in reserve, assembly areas, communication centres, rear artillery and missile positions, logistical installations and air- or naval-bases.

Antiplant and anti-animal CB weapons

The tactical applications of antiplant and anti-animal CB weapons are confined mainly to chemical antiplant agents, although anti-animal agents might offer some attractions against an enemy that relied at all heavily on draught animals (horses, mules, camels, etc.) for theatre transportation, communications or supply.

Chemical antiplant agents have been used extensively in the Viet-Nam War by US and South Viet-Namese forces. Volume I of this study[25] contains a discussion of the aims and objectives behind their use, and of the different employment techniques and tactics.[26] Defoliants have been sprayed over natural vegetation, particularly jungle cover along communication routes and over suspected enemy bases. The purposes of this have been to facilitate target acquisition and aerial reconnaissance, and to diminish the risk of ambush. The value of these techniques is limited by the delayed action of the agents, and an adequate assessment of their overall costs and benefits to their users in Indo-China has yet to be published. The same applies to the employment of herbicides to destroy food cultivations, which is the other main use that has been made of antiplant chemicals.

spray-tanks. During the assault, a chemical barrier 500 metres deep is to be laid by 5-inch naval guns and 155 mm howitzers firing VX shell. CS dispersers are to be held in readiness for use against "guerillas, rioters, etc.", together with lethal and incapacitating biological weapons and nerve-gas weapons for use against targets of opportunity presented by enemy reserves. Allocated for the latter purpose are 16 BW-agent-filled, 72 VX-filled and 72 sarin-filled Aero-14B spray-tanks, together with 1 650 VX- and sarin-filled howitzer rounds (8-inch, 155 mm and 105 mm) and 276 sarin-filled Mk94 bombs, *Weteye* bombs and *Misteye* cluster-bombs.

[25] See Volume I, pp. 162–85.

[26] There is a sizeable body of French military literature on antiplant CBW [e.g., 422].

III. *The value of CB weapons*

On the basis of the foregoing descriptions, an appraisal begins to become possible of how different sorts of country might value possession of an offensive CBW capability.

First it is necessary to emphasise one factor which the previous accounts have not taken adequately into consideration. This has to do with the manner in which the enemy might react to initiation of CBW, and the whole character of warfare fought within a CB environment. The fact of one belligerent embarking upon CBW cannot fail to have a profound influence on the future conduct of the war (and, for that matter, on the conduct of future wars).

A battlefield where CBW agents are present would differ markedly from one where they were not. The whole process of tactical manoeuvre, of using weapons and equipments and of supplying forward units would become considerably more complicated. A CB protective regimen would have to be enforced at all times, with troops either wearing respirators and protective clothing, or having them immediately at hand. Elaborate arrangements would be needed for the servicing of these equipments, for decontamination, and for the resting of combat troops. Careful reconnaissance by CBW-agent detection patrols would be necessary before moving positions. Special medical supplies and decontaminants would have to be moved up to all forward areas, and sufficient time for their use would have to be fitted into the scheduling of operations. The latter would also have to take into account the likelihood of reserves being needed earlier than usual, for in a CB environment the length of time for which a given combat unit can operate effectively will be shortened.

The benefits to be gained by initiating tactical CBW would surely have to seem large for the costs of these complexities and uncertainties to be readily tolerable. Much would depend on the likelihood of the enemy retaliating in kind, for if he did not, the unpredictabilities facing the potential initiator might not be so great. Indeed, the level of anti-CB preparedness maintained by many modern armies, and the training given in the use of protective equipments, might well be sufficient to accommodate one-sided use of CB weapons with comparatively little departure from normal routine. But if both sides were to use CB weapons, even the most sophisticated levels of CB preparedness would not prevent an increasing amount of time and resources having to be allocated to keeping personnel and equipments free of contaminants. The mobility of both sides would diminish, and in circumstances where armour could not be used,

the conduct of operations might then decline towards a static and inconclusive stalemate.

Two things appear to follow from this. First, the incentives for using CB weapons tactically are likely to be greatest when the enemy is known to lack CB weapons of his own. Second, as a corollary of this, a case may be made for maintaining an offensive CBW capability in order to deter enemies from initiating tactical CBW.

Although these conclusions have attracted wide acceptance in some quarters, they tend towards oversimplification. Most notably they underrate the significance of defensive CBW capabilities—the importance of an imposing anti-CB protective posture in limiting the attractions of offensive CBW. While it is certainly the case that CB weapons have only been used since World War I against forces lacking their own CB weapons, it is also the case that those forces have lacked CB protection as well. As has been shown earlier in this chapter, even a modest level of protection may, provided its detection and warning capabilities are good, greatly reduce the tactical effectiveness of CB weapons. The maintenance of good defences in the field against CBW attack is a burdensome undertaking, but it is one which many armies today have reluctantly come to regard as a necessity. An enemy may be deterred from initiating CBW by the threat of retaliation in kind; but he may also be deterred by the excessive costs there might be in attempting to overwhelm the opposing CB defences. We will return to these matters after looking at the reasons why countries might wish to acquire CB weapons for first-use purposes.

The value of a first-use CBW capability

The initiation of CBW is illegal under conventional and customary international law. Nonetheless it is conceivable that a country might still consider maintaining stockpiles of CB weapons, or setting out to acquire them, on the basis of their first-use potentialities. There can be little doubt that the initiation of CBW will nowadays be an act of great political moment. CB weapons are exceptionally repulsive to many people. The legal proscriptions on their use are explicit and widely known. The political leaders of several countries, and the UN representatives of many more, have stated that they support these prohibitions. A country that initiates CBW within such a climate of opinion must anticipate sharp political and diplomatic repercussions. It might be supposed that these repercussions would countervail the military advantages to be gained from CBW. But military considerations become dominant in time of war, and the greater outrage may negate the lesser. Mitigating circumstances, whether true or fabri-

cated, may be claimed in justification. Situations can thus be visualised in which the political constraints might be considered insignificant. How strong would they be, for example, during a war in which nuclear weapons had been used? And would they deter defensive use of CB weapons against indisputable acts of aggression?

Whatever the strength of the various political constraints, the many technical, operational and military limitations of CB weapons referred to earlier in this chapter would still apply. It is useful to recapitulate them here by means of the following hypothetical illustration.

Suppose that a battlefield situation arose in which a low-echelon field commander decided that nerve gas was the preferable weapon. Suppose also that he then sought authorization from his superiors to employ nerve gas. (In most, if not all, armies today, such a request would be highly unusual, for it is doubtful whether many commanders would even think about employing nerve gas unless authorization in principle had already been delegated from governmental level to the military authorities.) His appraisal, and his subsequent request, would presumably have been based on an estimate of the likely performance of nerve gas in fulfilling his mission in comparison with the other weapons available to him. He would no doubt have taken into consideration all the various adverse features of nerve gas insofar as they affected his mission, and insofar as he knew about them—questions of controllability, level of enemy protection, level of CB training within his own unit, state of the weather, target topography, disposition of friendly troops in neighbouring areas, and so on. As his request ascended the command structure, broader considerations would be brought in. If nerve gas were used along one sector of a front, how would it affect operations along adjacent sectors? Or subsequent operations along the same sector? For example, the amount of nerve gas needed to engage effectively a target of a square kilometre or two might well, depending on the weather, expose many scores of square kilometres downwind to a highly dangerous nerve-gas cloud (see tables 2.6 and 2.7). Likewise, ground over which persistent nerve gas had fallen during an attack might, again depending on the weather, remain difficult to use for subsequent military operations for several weeks (see table 2.4).

Then there would be the critical decision about how the enemy was likely to respond to tactical nerve-gas attack. Whether it was escalatory or not—and as noted earlier, the probability of escalation would be substantial—the response could take many forms. It could conceivably be nuclear. Or it could be retaliation in kind. Once one side had employed CBW, the other would certainly feel less compunction about abstaining from it, and might well be under strong internal political pressure to re-

spond in kind. This might occur either immediately or at some particularly opportune moment in the future, on the same or on some other front. Although the commander's original request might have been perfectly reasonable from the short-term tactical point of view, to accede to it might well open the way to the enemy gaining a comparable or greater advantage some time in the future.

Finally, if the request survived as far as the governmental level, all the political considerations would come in: on the one hand, the possible military benefit, but on the other, the stance of the government at home and abroad, and the political and moral sentiments of the nation, and of its friends and allies.

Hypothetical though this illustration may be, it does provide a framework into which many of the factors likely to influence a country's evaluation of CB weapons may be set. For example, one might assess the overall value of CB weapons to a country in terms of the probability of requests like that considered in the illustration recurring often and filtering through to the uppermost command levels. In that the probability will be governed by perceptions of enemy capabilities and likely conflict situations, both of which will be specific for the country concerned, this is not something that can be generalized about here. What can be done, though, is to identify certain features of a CBW capability that might seem particularly attractive to different sorts of country. These would be the broad military assets of CB weapons that, for the country concerned, might weigh most heavily against the political liabilities. The following seem to be the most prominent features of this type.

1. The economics of conventional and nuclear warfare favour the rich countries. A capability to wage CBW, particularly BW, might be acquired for a comparatively small investment. Such a capability might be thought to have a mass-destruction potential comparable with nuclear-fission weapons. It might permit a country to believe that it could wield power out of all proportion to its wealth.

This is the concept of CB weapons as the poor man's atomic bomb. It came into prominence in connection with Egypt during the early 1960s [423] and later during the negotiation of the nuclear Non-Proliferation Treaty [390, 424].

2. The outcome of conventional warfare is likely to be determined in the long run more by manpower than by firepower. Quantity may prevail over quality. Because CB weapons may permit higher casualty rates than conventional weapons, they might be able to diminish the consequences of manpower inferiority.

This is a concept that was first elaborated by CB weapons proponents

in the United States, who often made use of a scenario in which the USA was at war with China [388, 395, 425].

3. The effectiveness of CB weapons is determined by the effectiveness of the opposing CB defences. The greater the probability of conflict with an enemy lacking CB protection, the greater may be the attractions of a CBW capability.

This is a concept that is implicit in another of the arguments advanced by CB weapons proponents in the United States, namely, the important contribution that CB weapons could make to a "flexible" military posture adaptable to the conduct of "limited warfare" [274, 386, 395, 426]. Many scenarios were presented, including the use of nerve gas to interdict infiltration routes during "counterinsurgency" warfare [387, 427–428], and the use of incapacitating biological weapons to support military action over areas inhabited by neutral or friendly civilians [407, 429].

4. The greater the number and range of conflicts in which a country envisages that it may get involved, the more value may it attach to the ability of CB weapons to complement other forms of firepower, and to extend the range of military options available.

This concept is closely related to the previous one. It differentiates the attractions of CB weapons to a country that regards military force as a viable instrument of foreign policy from their attractions to countries that do not.

5. CB weapons may bring about higher casualty rates than conventional weapons. They may therefore extend the power of limited weapons-delivery capabilities. Coupled with their adaptability to clandestine and surprise operations, this feature might be valued in guerilla or insurgency warfare.

This is a concept used by antagonists of the proposition that CB weapons are valuable for "counterinsurgency" operations [430]. Guerilla forces necessarily travel light and rely on light weapons. They are likely to know where their enemy's positions are more often than their enemy will know theirs. A nerve-gas mortar-bomb or rocket may cause considerably more destruction or demoralization than one filled with high explosive (see table 2.5).

Against each of these five incentives, it is possible to cite some or all of the technical, operational, military and political limitations described earlier. The value of CB weapons to a particular country will never be clear cut. It will generally be easier to justify a decision to maintain a pre-existing CB weapon stockpile than a decision to discard it or to acquire one from scratch.

The value of a deterrent CBW capability

A belligerent who is uncertain about the assets or liabilities of a weapon may decide to abstain from acquiring or using it. He might suppose that his enemy would also abstain, for the same reason, but there could be no certainty about this. Because there would be no certainty, and because CB weapons could conceivably be used to great effect, a policy of actively dissuading enemies from embarking on CBW might be considered prudent.

The first step in executing such a policy would clearly be to ensure that efficient CB protective equipments were available whenever an enemy might be tempted to use CB weapons. Most modern armies today do indeed pay considerable attention to maintaining a high level of anti-CB preparedness. There would be point in publicizing such preparedness and extolling its efficacy. A certain degree of secrecy might be necessary, if only to conceal deficiencies from the enemy.

Faced with an impressive CB defensive posture (which might alternatively take the form of assured access to an international pool of CB protective supplies), any incentive an enemy might otherwise have had to use CB weapons might weaken or disappear. Further aids to the policy of dissuasion might therefore be considered superfluous. But if they were not, the next stage might be to acquire an arsenal of CB weapons, or to secure access to an ally's arsenal, in order to be able, if necessary, to threaten retaliation in kind. Such a measure might be thought to possess the additional merit of providing a first-use option, even though this might not at first seem particularly useful.

In the preceding account of the limitations of using CB weapons, the possibility of damaging retaliation from the enemy has been presented as an important constraint. But while there may be some logic in a deterrent for dissuading enemy CBW, in addition to efficient CB defences, it is by no means obvious that it should consist of CB weapons. A deterrent may operate, so it is supposed, by threatening unacceptable damage. It is not the type of damage that is relevant so much as its unacceptability. It might well be the case that the damage that CB weapons could cause would be sufficiently unacceptable to deter initiation of CBW. But so might the damage caused by almost any other form of violence, which might also be a good deal more assured, given the uncertainties attaching to CB weapons.

It also has to be borne in mind that to a suspicious enemy, mere possession of an offensive CBW capability might imply intent to use it, even though deterrence rather than first-use was the justification given for its possession. The enemy might then feel obliged to build up a deterrent

CBW capability of his own, or improve an existing one, which in turn might be misconstrued as implying first-use intent. In that there is no particular reason why like-with-like CBW deterrents should not provide first-use capabilities, they may thus come to sustain the self-same threat that they are supposed to be deterring. Relevant here is the fact that once a country has built up an arsenal of CB weapons, its offensive CBW capability becomes institutionalized. It represents capital expenditure, and peoples' jobs or prestige come to depend upon it. Political and institutional pressure develops in support of its continued existence, even its expansion. Attempts to dismantle it will be resisted. During World War II, several countries built up large arsenals of chemical weapons; two or three acquired biological weapons also. These CBW capabilities remained unused during the war, and after the war, with the rise of nuclear weapons, they became a good deal less important in military and strategic terms. Some countries decided to discard them; others decided not to. It is not implausible to suppose that internal political considerations, as well as strategic ones, were prominent in this decision-making. Although rationales for the continued existence of those stockpiles that were maintained were presented in military terms, notably rationales of deterrence and of "limited war" requirements, it seems unlikely that they fully explain the situation. Once there was a decision to maintain stocks of World War II weapons, a logic came into currency for acquiring the very much more potent weapons that soon emerged from the R&D laboratories.

The notion of deterring like with like has long been a feature of CBW theorizing, and of evidence in support of budgetary requests for CB weapon funding. It has been sustained by the view that the principal reason why chemical weapons were not used during World War II was because of mutual deterrence in kind. This might be true, although, as is described in Volume I of this study, there were other, perhaps more important, factors as well.

Shortly after the war, in 1946, a US BW expert set out the following case in favour of a like-with-like BW deterrent:

> Although the future of essentially defensive measures against BW cannot be foretold, their present status is such as to emphasize their weakness, and to indicate that they constitute in themselves altogether inadequate protection. It would follow as an apparent imperative that provision must be made for defence by retaliation in kind [431].[27]

[27] The author of this statement recognized clearly the dangers of such a defence. He continued: "Yet in view of the difficulties that may attend recognition of the nature of a BW attack, the mere availability of offensive biological weapons constitutes a hair-trigger mechanism, ominous in its capacity for damage which may possibly be irretrievable. The pursuit of a policy of offensive development must foster military rivalry be-

However, 25 years later this line of argument was refuted in the following terms by the US delegate to the Geneva disarmament conference. He did so shortly after the US Government had announced its intention of discarding its offensive BW capability:

It is the considered judgement of the United States Government that retaliation in kind would not be the best military response to a biological attack. In fact, we judge that it would not be an acceptable or rational response to a biological attack. A country subjected to attack with biologic weapons might not be aware for days or weeks that the attack had taken place. If it concluded that it was the victim of a deliberate attack rather than a natural epidemic it would have to determine the source of the attack.

In deciding what action to take, the attacked country would then have to consider the unpredictable nature of biological weapons and the incubation period required before they can take effect. Few, if any, military situations can be imagined in which a State would try to redress a military imbalance by retaliating with weapons whose effects would not show up for days. Furthermore, biological weapons could not destroy the military arsenal—the tanks, planes and artillery—of an enemy, and the side that had initiated biological warfare would presumably have taken steps to protect its military forces, which would suffer far fewer casualties than would the civilian populations of both sides. Those, very briefly, are the reasons why biological weapons are not a necessary or even a useful counter to, or insurance policy against, the possible possession of biological weapons by some other State [432].

A rather stronger case can be made for a like-with-like CW deterrent, for it may serve not only to threaten unacceptable damage, but also, in the case of battlefield CW, as a means for reducing some of the advantage that the enemy might gain from chemical weapons. The advantage is unlikely to be large if good antigas defences are deployed, but it might be considered dangerous. The case is as follows.

Antigas protective equipments are fatiguing to the individual soldier and impede his ability to use his weapons or operate instruments or machines. They therefore lower the fighting efficiency of combat units. Although the initiator of CW would have to protect his own troops against gas, his enemy would be forced to adopt a more stringent protective stance. Once CW had begun he would have to assume that a CW attack might come anywhere on the battlefield and he would therefore have to wear

tween nations. Extended to the atomic bomb and other new weapons, it must tend to stimulate an international race in armaments of mass destruction. It must impose the need for secrecy in science at least in degree. Such secrecy, in the biological and physical sciences and perhaps in contributing fields, must cripple science as a whole, and must surely promote international suspicion. Thus if war is taken to be inevitable, or the prospect of its prevention remote, offensive development of its new weapons of mass destruction, and continued secrecy in the areas of fundamental science upon which such development depends, seem to provide the only available guarantee of peace. Yet such development may itself help to make war inevitable." [431]

full protective clothing outside collective shelter at all times. In contrast, the user would know for certain where and when he could relax his antigas discipline. Retaliation in kind would force the initiator to adopt an equally onerous protective stance. There would be little expectation of securing battlefield advantage by doing so, but rather the possibility of nullifying battlefield disadvantage. The combat efficiency of both sides would be lowered to a comparable extent.

All this hinges on the extent to which antigas protective measures impede combat units. As is noted on pages 113–114 above, this is an issue on which authorities are at variance with one another. CW experts from a country that possesses chemical weapons claim that the difference would have substantial military significance. Their counterparts from certain countries that do not possess chemical weapons appear to take the opposite view, and emphasize the importance, in deterring tactical CW, of deploying good antigas defences. Much may depend on the design of the available protective equipments and the skill of their users. An army that is equipped with sophisticated protective clothing, respirators, alarms and so forth, and which has been rigorously trained in their use, may expect to suffer a smaller disadvantage than a less well-endowed army.

Good defences may weaken incentives for initiating tactical CW to an extent which a retaliatory capability cannot. If an attacker were considering the large-scale use of nerve gas to spearhead a major land advance, certain scenarios can be envisaged in which the possibility of retaliation in kind might well be considered unimportant: by ensuring that his own antigas defences were poised in good order, the attacker might reckon on pressing his attack to a successful conclusion before being significantly damaged or impeded by retaliation in kind. The more complete the surprise of his nerve-gas operation, and the weaker the opposing antigas defences, the more probable would such an outcome be. The fact of the matter is that, as between opposing ground-forces that each possess good antigas defences, the offensive value of nerve gas declines very steeply after its initial employment, once the element of surprise has gone. And the foregoing rationale for a retaliatory capability is of course applicable only after nerve gas has already been used. It relates not to what might well be the major threat posed by enemy possession of nerve gas, but only to a subsidiary one.

It is worth noting that the size and composition of a nerve gas retaliatory stockpile for nullifying the mobility disadvantage can be specified rather precisely. The requirement would be for enough weapons to equalize the asymmetric protection-level situation. The weapons should be capable of threatening immediate casualties if the enemy is not masked or lacks

protective clothing. A single nerve gas of high toxicity and intermediate volatility would suffice for this. There would have to be enough of it to impose a high degree of uncertainty upon the enemy about the extent of the toxic hazard. The area over which the enemy is operating is unlikely to be enormous, and will certainly be predictable with some confidence within rather narrow limits. It need be contaminated only in random places, and with sufficient nerve gas to maintain the casualty hazard. A ton of VX, a low-volatility nerve gas, is capable of threatening severe percutaneous casualties over 10 per cent of a 100 km^2 area of ground for a period of several days, or weeks in cold weather; rather larger quantities would be needed in the case of higher-volatility nerve gases. Even if the requisite quantity of nerve gas is multiplied in several alternative weapon systems, it is evident that the stockpile need consist at most of a few hundred tons of nerve gas filled into suitable aircraft and artillery munitions. Anything more would be superfluous to this particular mission; and if it existed, an enemy might reasonably presume it to serve some other function, particularly if it were surrounded by great secrecy.

Before World War II, CB weapons were occasionally regarded as possessing more general aggression-deterring capabilities, similar to those nowadays accredited to nuclear weapons. The 1920 view of the US Army Chemical Warfare Service on this point is quoted in Volume I.[28] The notion is sometimes revived, particularly the view that CB weapons could provide non-nuclear powers with a "poor man's deterrent". This is discussed in Volume V of this study.[29] It is clearly the case that CB weapons cannot compete with nuclear weapons in this sort of role: they are deficient in both reliability and credibility. But the suggestion that they might nonetheless be of value to non-nuclear weapon powers is to imply that the tenets of nuclear-deterrence doctrines are relevant outside the realm of the nuclear weapon powers. Even if they are relevant, it is not at all clear that CB weapons could meet the necessary requirements. The number of weapon delivery systems needed to inflict massive damage with nerve gas approaches that needed with conventional weapons, as is shown in appendix 3. And as for biological weapons, although fewer delivery vehicles would be needed, the incubation period associated with them might well be long enough for damage-limiting countermeasures, or the execution of reprisals.

[28] See Volume I, p. 274.
[29] See Volume V, p. 101.

Chapter 3. National CBW policies and programmes

In this chapter we describe some of the CBW activities of different countries around the world. We review what we know of the main features of their policies, capabilities and research organizations. Our account is regrettably uneven, for on the one hand many countries are highly secretive about these matters, and, on the other, our information is confined to that which reaches North Western Europe. Moreover, in the absence of dependable official information, we have sometimes had to use source material of dubious reliability; this is indicated either in the text or in the bibliographical apparatus.

Only a small number of countries appear to possess CB weapons. While this may be due to the lack of information on the part of the authors, it is probably the case that, whereas modest CB weapon programmes might fail to attract notice, programmes of substantial military significance would not. Too many people and installations would be involved, while the weapons might lose much of their significance if potential enemies did not know that they existed. Nor does it seem particularly likely that CB weapons could be acquired at all easily through international trade or aid. Most, if not all, of the developed countries would surely consider it impolitic or excessively risky to include CB weapons within their arms trade with less developed countries (SIPRI's study of this trade [433] certainly revealed no such transactions). Likewise, enquiries made of prominent private arms dealers indicate that, apart from irritant agents such as CS, there is no commercial market for CB weapons.

The chapter begins with a section on the Soviet Union and other members of the Warsaw Pact Organisation (WPO). This is followed by a section on the United States and its NATO allies. The concluding section is devoted to countries outside these two alliances. Representative countries from each section—the USSR, the USA, West Germany and Sweden—have been given particularly close attention.

Table 3.1. The Geneva Protocol and the Biological Weapons Convention: Positions of the Warsaw Pact countries[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention:
	Accession	Reservations[b]	Signature
(Albania)	Not a party	—	Not signed
Bulgaria	May 1934	I, II and III	April 1972
Czechoslovakia	August 1938	II and III	April 1972
Germany, East	April 1929 (1959[c])	None	April 1972
Hungary	October 1952	None	April 1972
Poland	February 1929	None	April 1972
Romania	August 1929	I, II and III	April 1972
USSR	April 1928	I, II and III	April 1972

Notes:

[a] As of July 1972.

[b] Reservations made by certain countries upon becoming parties to the Protocol have been of four principal types:

I. The country reserves the right to use CB weapons against non-parties.
II. The country reserves the right to use CB weapons against violators of the Protocol.
III. The country reserves the right to use CB weapons against allies of violators of the Protocol.
IV. The country makes reservations of types II and III, but confines its reserved option to the use of chemical weapons, never bacteriological ones.

For a discussion of the significance of these reservations, see Volume III of this study.

[c] In March 1959 the Czechoslovak Embassy in Paris transmitted to the French Foreign Ministry a document stating the applicability of the Protocol to the GDR.

I. *The USSR and other Warsaw Pact countries*

Policy

The Soviet Union acceded to the Geneva Protocol in April 1928, making similar reservations to those that France had made 2 years earlier:

1. The said Protocol only binds the Government of the Union of Soviet Socialist Republics in relation to the States which have signed and ratified or which have definitely acceded to the Protocol.
2. The said Protocol shall cease to be binding on the Government of the Union of Soviet Socialist Republics in regard to any enemy State whose armed forces or whose allies *de jure* or in fact do not respect the prohibitions which are the object of this Protocol.

The position of states allied to the Soviet Union within the Warsaw Pact are set out in table 3.1.

In recent years the USSR has frequently reiterated its support both for the Geneva Protocol and for CB disarmament, and in these respects its declarations at the UN General Assembly and at the Conference of the Committee on Disarmament (CCD) in Geneva have been echoed by its principal allies.[1] The 1972 Biological Weapons Convention is based on

[1] See Volume IV of this study, pp. 228.

a CCD draft that included Bulgaria, Czechoslovakia, Hungary, Poland, Romania and the USSR among its sponsors. As is shown in table 3.1, these countries, together with East Germany (the GDR), have all signed the Convention, although none have yet ratified it.

Bulgaria, Hungary and Romania were all forbidden possession of CB weapons—defined as "asphyxiating, lethal, toxic or incapacitating substances intended for war purposes, or manufactured in excess of civilian requirements"—in their 1947 treaties of peace with the USSR, the USA and the other Allied Powers.[2]

In the years immediately prior to World War II, the Soviet Government emphasized both its right and its ability to retaliate in kind against transgressors of the Protocol.[3] In post-war years, however, its spokesmen have not drawn attention to this, and no explicit reference to the existence of Soviet CB weapons can be found in Soviet public statements. Nor can such statements be found in openly available publications from other Socialist countries.

In contrast, WPO countries have published a good deal of information on their protective measures against CBW attack—considerably more information as regards standardized equipments and procedures than is available from most NATO countries. It has repeatedly been stressed by Soviet officials that the protection of the civilian population, as well as that of combat units, is considered to be an essential part of these arrangements. In February 1956, Marshal Zhukov spoke as follows to the 20th Communist Party Congress:

> Future war, if they unleash it, will be characterized by the massive use of air forces, various rocket weapons, and various means of mass destruction such as atomic, thermonuclear, chemical and bacteriological weapons [434].

In the same year, General Pokrovskii wrote in his *Science and Technology in Contemporary War:*

> During [World War II], combat chemical substances were left unused for a variety of reasons ... Hence we have no experience in the employment of these means of mass destruction under conditions of contemporary warfare. However, there is no basis for hoping that in the future such substances will not be employed. On the contrary, chemical weapons may, in the case of mass surprise attacks on the part of an aggressor, find very wide employment. Foresight, founded both on theory and on science, can provide military specialists —and, indeed, the whole population—with a clear picture of how chemical

[2] For further details, see Volume V, p. 214.

[3] The statement to this effect by War Commissar Voroshilov in February 1938 is quoted in Volume I of this study at p. 287.

warfare can evolve and with a clear knowledge of what is the best system for defending the troops and the population from chemical and radioactive substances.

On BW he wrote:

In recent decades, bacteriological weapons ... have begun to be developed. A scientific analysis of the potential employment of bacteriological weapons and of the means of defence against these weapons is of significance in strengthening the defence capability of the country [435].

In his 1962 treatise on military strategy, Marshal Sokolovskii remarks:

In particular, in a future war one may expect the employment of chemical and bacteriological weapons to whose development great significance is accorded in the Western countries, particularly the United States [436].

Similar views have been set out in several other Soviet publications. There is, for example, the following passage at the beginning of a major Soviet civil defence publication of 1969:

... a new world war, if the imperialists should unleash it, would be waged with the widespread use of weapons of mass destruction and, above all, nuclear weapons. Such a war could encompass an enormous area and involve whole continents. Not only troops, but also centres of vital industry, transport, energy production and communications would be subject to devastating attack.

It would be possible to contaminate large areas with radioactive fallout and bacteriological agents. Distinctions between front and rear would disappear. Therefore, the defence capability of the socialist government does not consist only of high combat readiness and ability to supply the armed forces; it is also inseparably connected with a high level of economic development and the preparation of the population and national industrial centres for protection against weapons of mass destruction [437].

Countermeasures against CB attack accordingly form a prominent part of Soviet training both of military personnel and of civil defence cadres. When asked to comment on this during Congressional hearings in July 1969, the head of the US Army CBR and Nuclear Operations Directorate said:

Their defensive training is considerably greater than ours. If they accept, as we have announced, that we have a retaliation-only policy, and they did not wish to start chemical warfare, they would have to do very little training. However, their extensive efforts in defense training very probably could be based upon a concept whereby they would initiate the employment of these weapons and expect us to retaliate [438].

This statement gives some insight into the manner in which Soviet CBW policy is appraised in the USA.[4] The fact that since 1938 the USSR has never referred in public to possession of CB weapons is certainly not taken in the United States to mean that it does not possess them.[5] The well-known 1959 report from the Committee on Science and Astronautics of the US House of Representatives, *Research in CBR* [441], attached significance to the anti-CB precautions of the Soviet civil defence programme when it "drew the inescapable ... conclusion ... that the Soviet Union and other Communist countries plan to use CBR if they find it to their advantage". Support for this conclusion has also been detected in Soviet statements such as those quoted above, particularly that by Zhukov,[6] which frequently prefaces US Department of Defense briefings on Soviet CB weapon capabilities and intentions [274, 443–444]. The Chief of the US Army Chemical Corps was evidently referring to it when he told a Congressional appropriations committee in 1958 that

> Russia has stated publicly by the Minister of Defense—that was some 2 or 3 years back—that future wars would differ in size, shape and scope from previous wars. Then he lists what is going to be used: guided missiles, atomic, thermonuclear, chemical and biological weapons [443].

Writing in 1964, a US academic contrived to read still more into it:

> Marshal G. K. Zhukov, when he was Soviet Minister of Defense, informed the Twentieth Party Congress in February, 1956, that Soviet armed forces were prepared to use biological and chemical weapons in war [445].

It is widely believed in Western countries that the USSR possesses a powerful offensive CW capability. The firmness of this belief seems to rest mainly on (*a*) an absence of anything to indicate that the substantial stocks of chemical weapons which the USSR was known or presumed to have built up during World War II were discarded after the war; and (*b*) inferences drawn from Soviet military manuals that chemical weapons are available to

[4] It may be remarked that, throughout the 1950s and early 1960s, there appears to have been no explicit public statement by the US Government that its policy towards use of chemical weapons was that of retaliation only. On the contrary, there were several indications, of which Soviet authorities were presumably aware, that a first-use policy was being considered (see pp. 194–197 below).

[5] Indeed, some commentators have drawn exactly the opposite conclusion from the reticence of the USSR on its offensive CBW capabilities. Likewise, some commentators have inferred from the vehemence with which the USSR accused the USA of using biological weapons during the Korean War (see Volume I, pp. 224–5, Volume IV, pp. 196–221, and Volume V, pp. 238–58) that the USSR was engaged upon an active biological-weapon programme [439–440].

[6] Perhaps because one of its earliest widely-circulated English language translations read "Future war, should it be unleashed ..." [442] rather than "Future war, if they [i.e., the West] unleash it ...".

Soviet military commanders. Circumstantial evidence apparently also exists to complement this, and, by the traditional process of deducing intentions from capabilities, a menacing assessment of Soviet CW policy has become entrenched in the West. In 1969 this was summarized for the benefit of a US Congressional appropriations committee as follows:

> The Soviet Union is better equipped defensively, offensively, militarily, and psychologically for chemical and biological warfare than any other nation in the world. She has placed a great deal of emphasis on these systems in her military machine. Utilizing a wide spectrum of chemical munitions, the Soviets consider that chemical tactical weapons would be used in conjunction with nuclear weapons or separately, as the case may dictate. The Soviet agent stockpiles include a variety of agents and munitions capable of creating a wide range of effects on the battlefield. The Soviet soldier is well equipped defensively. He trains vigorously and for long periods of time utilizing his equipment. He looks upon chemicals as a real possibility in any future conflict, and respects his protective equipment. The research program in the Soviet Union for chemical warfare and biological agents has encompassed every facet from incapacitating to lethal effects, both offensively and defensively [446].

Some Western officials have even been quoted as having stated that the Soviet military establishment considers chemical (but not biological) warfare to be a conventional method of fighting, and that the poison gas which they say is available to Soviet field commanders is likely to be used whenever the latter see fit [447].

Mistrust can distort perception. Moreover, the credence attached to appraisals such as these must also take into account the familiar propensity of service branches for presenting alarming estimates of enemy capabilities and intentions when supporting budgetary requests. This is not to say that the appraisals are necessarily faulty, for that would be beyond our competence to judge. It is instead a caveat that has to be kept firmly in mind in discussions of any subject where the only sources of information are the disclosures, or purported disclosures, of military intelligence. Whether reliable or not, they are all that is available in the absence of information from official Soviet sources. Soviet officials have chosen to remain silent about the presence or absence of Soviet CB weapons; and they have offered no comment on the assessments that have been publicized in the West.

Research and development

There is no reliable information about the organization and size of the CB research and development (R&D) programmes of the Socialist coun-

tries. A US Department of Defense intelligence officer informed a Congressional committee in 1969 that the Soviet and US "CBW programs are quite similar" but the details of his appraisal were deleted in the published record [438]. The West German periodical *Soldat und Technik* speaks of "at least 25" institutes in WPO countries that are working on chemical weapons, five of which it says are in East Germany [463]. The Soviet proving grounds for CW matériel at Shikhani, Saratov, continue in use, according to a US Department of Defense official [45].[7] A 1956 publication of very dubious provenance, said to have been written by a Soviet émigré, states that before World War II the Shikhani facilities were designated the "Central Army Chemical Polygon" (*TsVKhP*); this publication also refers to pre-war chemical test facilities at the Kuzminki Polygon, near Moscow, and at Gorokhovetsky Camp, near Gorki [580].

Research reports that must almost certainly have originated in a CB R&D programme are sometimes to be found in the scientific and technical journals of the Socialist countries; some of them are occasionally published in Western journals [76, 448–450]. Examples include an aerosol study of botulinal toxin type A from the S.M. Kirov Military Medical Academy in Leningrad [105]; a study of a possible antidote for sarin or soman poisoning from the Higher Military Medical Institute at the Bulgarian Central Scientific-Experimental Base [451]; numerous papers relating to nerve gas toxicology from the J. E. Purkyně Military Research Institute for Postgraduate Training at Hradec Králové, Czechoslovakia [76, 448–450, 452–459, 1422]; a study of the effects on sheep of medemo, a V-agent nerve gas, from the Military Veterinary Research Institute in Prague [460]; and a study of an analytical technique for, *inter alia*, tabun, sarin, soman and medemo from the A. Zápotocky Military Academy in Brno [461]. All of these particular studies have a bearing on problems of effective protection against CBW attack.

Papers from the *Voyennaya Akademiya Khimicheskoy Zashchity* (Military Academy of Chemical Defence, USSR) have been published in the scientific literature, including papers on the preparation of organophosphorus compounds. For example, USSR patent numbers 193501 and 193502 were granted to the Academy on inventions made by K. A. Petrov; the patents disclose methods for preparing certain organophosphorus compounds, and the stated objective of one of them was "to obtain physiologi-

[7] The creation of the Shikhani establishment during the joint German–Soviet chemical-weapon programme of 1928–31—the Tomka Project—is described in Volume I, pp. 279–80 and 285. The Tomka project continued German–Soviet work that commenced in 1927 in facilities at Uchttomskaja (whence "Tomka"), located 20 km from Moscow [462].

cally active compounds". K. A. Petrov is the author of several dozen other Soviet scientific publications in this field, none of which identifies his place of work, and many of which relate to, *inter alia*, the preparation of nerve gases [e.g., 464–467]. The same applies to several other publications of unidentified origin in the Soviet scientific and technical literature [e.g., 468–477], including a 1961 patent specification describing a novel technique for the manufacture of pinacolone [478].

One can also find a substantial number of other publications in the literature of the Socialist countries that have a direct bearing on technical problems that might be encountered during CB R&D programmes, but which are also relevant to developments in basic scientific theory or to civilian requirements. For example, the many publications on the adsorption of gases and vapours, and the filtration of aerosols, from the Institute of Physical Chemistry of the USSR Academy of Sciences are well known. So also are the publications on organophosphorus chemistry from the Academy's Institute of Organometallic Compounds [479] and from the various research institutes in Kazan that grew up around the work of the Arbuzov family [480]. There have been many publications of interest to students of nerve-gas preparative chemistry, and of organophosphate cholinesterase-inhibition, from the Institute of Organometallic Compounds and from the I. M. Sechenov Institute of Evolutionary Physiology and Biochemistry in Leningrad [e.g., 481–493], from the A. M. Butlerov Chemical Research Institute at Kazan State University [e.g., 494], from the A. Ye. Arbuzov Chemical Institute in Kazan [e.g., 495–496], from the S. M. Kirov Chemico-Technical Institute in Kazan [e.g., 497–499], from the Leningrad Institute of Toxicology [e.g., 500], from the I. P. Pavlov First Leningrad Medical Institute [e.g., 501], and from groups at Tartu State University [e.g., 502] and Dnepropetrovsk State University [e.g., 503]. Pharmacological and toxicological studies of organophosphorus anticholinesterase agents have also been published from the Kazan State Medical Institute [e.g., 504–505], from the Kiev Scientific Research Institute of Pharmacology and Toxicology [e.g., 506–507], from the Minsk State Medical Institute [e.g., 508] and from the Leningrad Pediatric Medical Institute [e.g., 509], including studies on certain alkylphosphonofluoridates [507]. Publications from the S. Ordzhonikidze All-Union Chemico-Pharmaceutical Research Institute in Moscow have included papers on such anticholinergic glycollates as 3-quinuclidinyl benzilate [510–512] and on the possible applications of these and related compounds as antidotes for anticholinesterase poisoning.

Examples from laboratories outside the USSR include a study of the combined effects in mice of type C botulinal toxin and sarin from Pulawy

in Poland [513]; a study of the reactivation of cholinesterases inhibited by tabun, sarin or soman from the Institute of Organic Industry in Warsaw [514]; studies of neuromuscular blockade by anticholinesterase agents including sarin from the Warsaw Medical Academy [515]; the monumental series of papers on organophosphorus chemistry from the Institute of Organic Chemistry of the Polish Academy of Sciences (the 154th paper of the series was published in 1971 [516]); and the many studies of organophosphorus chemistry and toxicology performed within the laboratories of the Academy of Sciences[8] of the GDR, in particular the work of the *Forschungsstelle für chemische Toxikologie* in Leipzig, whose director is the author of several authoritative texts on chemical defence problems [517–519].

Capabilities in CBW defence

CB defence of the civilian population

The basis of civil defence in the Soviet Union is the evacuation of urban populations and their dispersal into rural areas. Shelters are provided in the major cities, but they are intended mainly for on-shift workers in essential industries. Protection against nuclear attack is, of course, the main objective. As a recent Soviet civil defence publication has put it,

> the simultaneous dispersal of workers and evacuation of the plants and institutions will greatly reduce the number of people in the cities; this in turn will sharply reduce population losses in case of a nuclear attack by the enemy ... a nuclear attack of an unprotected large city may result in the loss of life of as much as 90 per cent of the population. An early dispersal and evacuation could reduce these losses considerably, to a level between 5 per cent and 8 per cent [437].

Detailed plans apparently exist both for swift evacuation during times of escalating political crisis, and for the billetting and subsequent employment of dispersed personnel. The present chief of the Soviet Civil Defence Agency is a Deputy Minister of Defence [1592]; the civil defence programme comes under the jurisdiction of the Council of Ministers. In 1961 the US Office of Civil and Defense Mobilization estimated that the USSR was spending $500–1 500 million annually on civil defence [444].

While the dispersed population may be less vulnerable to nuclear attack, area weapons constituted by CBW agents or radioactive fallout could still have a catastrophic effect upon it, and upon its means of subsistence.

[8] For bibliographies, see the Yearbooks of the Academy of Science of the GDR [e.g., 520.]

These possibilities also have been given detailed attention in Soviet civil defence planning. Training programmes have been instituted that reach deep into the rural areas, disseminating expertise on the essentials of defence against antipersonnel, antiplant and anti-animal CBW [437].

Soviet civil defence is a unified, nation-wide system with planning formulated at the national level, but the individual economic units—the counties, industrial plants, collective farms, state farms, etc—are responsible for the specifically localized planning, and for the actual execution of the programme [437]. The basic element is the nation-wide network of Local Air-Defence Groups (MPVO). A primary MPVO unit is assigned to each "national-economic installation" in the country, with lesser installations, schools, apartment buildings and so on, organizing their own MPVO "self-defence groups". Expertise and personnel for MPVO are drawn from many organizations, notably from the All-Union Voluntary Society for Cooperation with Army, Air Force and Navy (DOSAAF) and from the Union of Red Cross and Red Crescent Societies. DOSAAF provides basic civil defence training for the civilian population: it came into being in 1951, and within 10 years had more than 30 million members. Instruction in chemical, biological and radiological defence is the responsibility of the Anti-Chemical Defence Group (PVKhO), and one of the objectives of DOSAAF is that all its members should achieve the basic PVKhO qualification. This necessitates 20 hours of classroom instruction, field exercises in CBR decontamination, first-aid, the use of respirators, protective clothing and so forth, together with refresher courses every 2 years. DOSAAF has a prolific publishing house which has put out many pamphlets, manuals and textbooks dealing with CBW. DOSAAF also has, according to a Western source, a network of shops around the country which offer civilian respirators for sale. These are rather expensive—about 10 per cent of the average Soviet monthly wage—but stocks of them, and of other CB protective equipments, are maintained by all primary MPVO units. It was said in the USA in 1964 that an estimated 25 million respirators, 12 million protective suits, and "some millions" of decontaminating kits had been issued to the Soviet civil defence organization. [444, 522–524]

CB defence of military units

Organization. Soviet Chemical Troops (BKhV) constitute a separate arm of the Ground Forces. Their present Chief is Lt-Gen V. K. Pikalov [521]. In a short history of the BKhV published in 1968 [525] his predecessor, Lt-Gen F. Manets, stated that during World War II, the principal functions of the chemical troops were

to prevent the possibility of surprise use of gas by the enemy, speedily to nullify the results of such attack, provide reliable protection for our own forces and assist them by all possible means to secure their objectives. [They were] also responsible for flame-throwing and incendiary weapons and smokescreen support.

He goes on to say that since World War II the mission of the Chemical Troops has been expanded to include biological and radiological reconnaissance and the decontamination of personnel and matériel. He notes that

In the event of rockets with nuclear warheads being used, conditions in the combat area will become extremely uncertain and difficult. There may be fires, floods, landslides, areas of mass destruction, zones of radioactive and chemical contamination. In these circumstances, only thoroughly well-trained troops, possessing the very latest and best equipment, with high morale and staunch in their political indoctrination, can possibly hope successfully to keep their fighting spirit and fulfil the tasks allotted to them. Experience in exercises has shown that our forces are indeed adequately equipped and capable of operating successfully in such conditions.

More detailed information about Soviet chemical troops was provided by the US Department of Defense for a Congressional appropriations committee in 1969:

The chemical branch of the Soviet Army is a separate troop directorate under the Ministry of Defense. It is considered to be a combat arms branch. Most significant of the chemical organizations of the Soviets is the chemical defense organization. Unlike our organization, where identification, decontamination, and CBR reconnaissance are dependent on individuals within the unit, the Soviet organization has special chemical defense units to accomplish these actions. Each Soviet front in time of war is supported by a chemical brigade, each combined army and tank army is supported by a chemical battalion, each motorized rifle and tank division is supported by a chemical company, and each motorized rifle and tank regiment is supported by a chemical platoon. These chemical troop units have special responsibilities for reconnaissance, decontamination and medical treatment (first aid, primarily) during chemical warfare. They also provide training in offensive chemical operations and supervise CB detection, reconnaissance, and decontamination training in peacetime. This organization provides an excellent chemical defense posture spread out through all echelons of command. It also has the advantage of being able to mass chemical defense organization where the need exists [45].

WPO member countries appear to cooperate closely in CB defence matters. As in NATO, there are regular meetings of CB experts from the different countries [526]. Soviet-made protective equipments have also been supplied to countries outside the WPO. A Soviet publication refers, for example, to VPKhR CW-agent detection kits supplied to China [527]; Soviet-made respirators are in use in North Viet-Namese Army units in

Indo-China;[9] and Soviet-made decontamination equipment was reportedly abandoned by the Egyptian Army in the Sinai desert after the 1967 Arab–Israeli War [528].

Training. According to the Chief of the US Army Chemical Corps, writing in 1962, the CB training programme of the Soviet armed forces was expanded around 1953 [383]. The following account of it was provided for a US Congressional appropriations committee in 1969:

> The Soviet training program is characteristic of any well-planned training program. The Military Academy of Chemical Defense located in Moscow and the Higher Officers Chemical School located on the testing grounds of Shikany provide schooling for senior chemical officers. The Chemical Officers School at Yaraslavl gives instruction in offensive and defensive procedures that could be compared to our basic officers' course, and the School for Chemical Troops at Saratov provides specialist training for the chemical enlisted men assigned to the various chemical units.
>
> The individual soldier is also well trained in CBR defensive procedures. The use of diluted toxic chemical agents to provide realism in field training for CBR personnel has been confirmed. The Soviets believe that these realistic measures stimulate a psychological awareness in the soldier that will improve his combat efficiency, and demonstrate the adequacy of protective equipment. The Soviet soldier is well trained in the use of his protective mask and is required to use it often and over extended periods. Field exercises and manoeuvres are usually based on the theme of nuclear and chemical warfare. The Soviet Army training follows the concept that chemical and nuclear warfare are a normal part of war and any future war will be characterized by the use of these weapons [45].

Equipments. Although they say little about production levels, stockages or disposition, Soviet publications [304–307, 314, 437, 529–544] do contain technical information about the various types of CB protective equipment that are available to the Soviet armed forces and civilian population. The individual Soviet soldier is issued with items of this equipment similar to those of his counterparts in Western armies, although there are certain basic differences in design. The general service respirator, for example, differs from those of most Western armies in that the canister containing the filtration elements is not built into the face-piece but is instead carried separately and linked to the face-piece by a long air-tube. The face-piece is part of a rubber helmet, the ShM-1, that envelops most of the head; in most Western respirators the face-piece is secured with straps, a method also used in the Soviet GP-40 civilian respirator. For skin protection, Soviet soldiers have a thin hooded coat—the OP-1 cloak—leggings and gloves made of a lightweight rubberized fabric. This protects against droplets

[9] See Volume I, pp. 194–95.

of CW agents; for skin protection against vapours as well, the uniform over which this clothing is worn must be specially impregnated. Certain civil defence units are issued with ZFO-58 clothing, which is made from impregnated cotton paper. The air-impermeable L-I light protective suit, made of heavy-duty rubber cloth, is available to chemical troops for full protection, although it cannot be worn for long periods (a maximum of 20 minutes above 30°C, or for 4 hours below 15°C), unless continually dampened to lower heat stress. The Soviet Army does not yet appear to have air-permeable protective clothing similar, for example, to the CB suits of the British armed forces. In the personal decontamination kits, liquid agents are used, rather than the bleaching powder common in Western armies. The IPP-51 kit, in general issue throughout the Soviet Army, contains a dichloramine concentrate and swabs, while the I-DP weapon decontamination kit contains an ampoule each of the two standard decontaminating solutions.[10] First aid kits for self or mutual help against nerve-gas poisoning are also available. These contain "special tablets ... to prevent contamination" by nerve gases such as "sarin, soman, V-gases" and for booster doses five or six hours later.[11] They also contain an atropine-filled syringe for use immediately after exposure to nerve gas [437]. Bleach, notably the DTS-HC composition for use as a water slurry, is relied upon extensively for the decontamination of large matériel. The gas-detector kits, such as the Combat Chemical Survey Meter (VPKhR) using a manual pump and tubes of colour reagents, are broadly similar to those of Western armies. The automatic nerve-gas alarms, GSP-1 and GSP-IM, are photoelectrically triggered colourimetric devices resembling the now obsolete US E-41 and M6A1 models [537]; it is not known whether Soviet chemical troops are yet equipped with second-generation alarms like the new M8 of the US Army. A variety of air-filtration units are available for the construction of collective CB shelters.

The provision of CB protection for Soviet armoured personnel carriers and fighting vehicles is apparently not as advanced as in NATO armies. However, according to the US Department of Defense, all models of the

[10] Degassing solution no. 1, comprising hexachloromelamine (DT-6) or a dichloramine (DT-2) dissolved in dichloroethane; and degassing solution no. 2, made up of 2 per cent caustic soda, 5 per cent monoethanolamine and 20 per cent ammonia.

[11] Detailed information about Soviet medicaments for the treatment of nerve-gas poisoning is not available in the open literature. A certain amount of Soviet research in this area has been published, however, and this reveals close attention to possible therapies using atropine or atropinemimetics and oximes such as TMB-4 [540, 550–551]. A 1966 Bulgarian publication describes the antidotal efficacy of a preparation known as Nemikol-5, said to be effective even against the oxime-resistant nerve gas soman [451]. Nowhere is the composition of Nemikol-5 described.

T-55 tank are fitted with mechanical filtration and an automatic control unit for defence against radioactive challenge [545].

The protective equipments of other WPO armies include both domestically produced and imported Soviet items. The GDR in particular appears to have developed a range of sophisticated equipments, including automatic nerve-gas alarms and efficient cold weather decontamination procedures [312, 517, 546–549].

Tactics and techniques. Soviet military journals regularly carry articles dealing with the tactics and techniques of CB defence up to and including battalion level procedures [527, 531, 543, 552–569]. Corresponding information from other WPO countries is also readily available, although it will not be discussed here.

Capabilities in CBW offence

Neither the Soviet Union nor any of its WPO allies have confirmed or denied possession of an offensive CBW capability. Published information about WPO CB weapons derives entirely from Western sources. What follows must therefore be read with caution. Each item of published source material drawn upon could have had one of two ultimate origins: Western intelligence services, or the imagination of publicists. Its provenance as between these two possibilities is rarely obvious. Its reliability in the latter case is zero. In the former, the reliability must be less than that of the original intelligence, for it cannot be assumed that the intelligence received by Western officials is reflected without distortion in disclosures made to the public. (While the disclosures may not in fact be distorted, the public has no means of judging this and must therefore admit the possibility.) The available source material ranges in credibility from zero (in patently obvious instances of "disinformation") to somewhere short of 100 per cent. Towards the more credible end of this spectrum are the acknowledged disclosures of official assessments; towards the other are the passages dealing with WPO CBW activities in such books as *The Penkovsky Papers* [570].[12] In cases where secret intelligence sources are cited, as in US Congressional testimony, assessments of the reliability of the sources, and of the probability of their information being correct, are invariably omitted from the published record. The public is never told whether the disclosed estimates of WPO CBW capabilities are merely ones that are technically *possible*, or whether they are ones that are thought *probable* by virtue of circumstantial evidence, or whether they are *con-*

[12] A counterpart is the purported description of British BW activities given in *Spy: Memoirs of Gordon Lonsdale* [571]. Both these publications have been disregarded here.

firmed by, say, actual observation or access to inventory records. In a climate of suspicion, where worst case analyses prevail, there is likely to be a substantial difference between a "possible" or a "probable" estimate and a "confirmed" one.

It is said that from the mid-1960s until 1969 the consensus of the US intelligence community had been that the current US estimate of the Soviet chemical weapons capability was confirmed. But during the 1969 review of the US CBW programme by the National Security Council, the estimate is said to have been closely scrutinized, and then downgraded from "confirmed" status. For biological weapons, it appears that the estimates are only "possible" ones, and there are now growing indications that more and more US officials do not believe the Soviet Union to possess, or have possessed, an offensive BW capability of much, or even any, military significance [572]. This situation, it may be presumed, contributed to the US Government's decision in 1969 to discard the US biological weapon arsenal.

Whatever the reliability of their information, Western officials concerned with CB defence firmly believe the USSR to possess a militarily significant stockpile of chemical weapons; and they consider that, even if their information were insufficient, they would nonetheless have to assume that the stockpile existed and might be used. They also believe that certain other WPO countries are capable of waging CW. A member of the US Army Chemical Corps Intelligence Agency expressed this as follows to a Congressional appropriations committee in 1961:

> The USSR has had sufficient quantities of very good material to equip some of their satellites with a good bit of this material giving them the capability to wage CBR warfare. ... Some of these satellites have attained a certain capability on their own, such as agent production and the manufacturing of devices; but it has been assisted forthrightly by the USSR in many, many cases [429].

On the face of it, however, it seems rather improbable that the Soviet Union would surrender control of any CB weapons it might possess—any more than the United States has done to its NATO and other allies. This consideration increases the implausibility, for example, of the allegations that the Egyptian Air Force used Soviet-made gas bombs during the recent Yemeni Civil War.[13]

Western information on Soviet chemical weapons

Size and nature of stockpile

Details of official Western estimates of Soviet chemical-weapon capabilities did not begin to appear in the open literature until the late 1950s, at

[13] Some of these allegations are referred to in Volume I, pp. 161 and 336–41.

the time when the US Army Chemical Corps was trying to secure increased support from Congress. In March 1960, the head of US Army Research and Development, General Trudeau, told a Congressional committee that:

> We know that the Soviets are putting a high priority on development of lethal and nonlethal weapons, and that their stockpile consists of about one-sixth chemical munitions [573].

This figure of one-sixth, which was apparently developed early in the 1950s, was to recur often in subsequent years.[14] Speaking in December 1962, Admiral Coggins, ex-Chief of ABC Warfare in the US Navy and then in SHAPE, said that "a few years ago" the Soviet Union

> had 106 chemical plants in operation, of which one half were either producing, or were capable of producing, the latest war gases. His stocks greatly exceed the combined stocks of the free world, being quite sufficient for 3 or 4 major offensives on a wide front. His present stockpile is reported as enormous, comprising fully 15 per cent of the total of the Russian military munitions [575].

In this stockpile, according to Admiral Coggins, were at least 50 000 tons of the nerve gas tabun, whose acquisition had been facilitated by the capture of the German tabun factory near Wrocław (Breslau) at the close of World War II.[15] The major part of the stockpile comprised mustard

[14] Western estimates of the Soviet CW capability seem generally to be expressed as a percentage of the total ammunition of all kinds which is available to the weapon-delivery systems that could be used to disseminate CW agents. General Trudeau's figure of one-sixth is apparently no longer given to US Congressional committees, although it is still used in other quarters. Commenting on it in a June 1969 issue of the *Washington Post*, a US journalist wrote as follows: "A responsible Government official who has provided reliable information in the past told me how the Trudeau statistic, which is cited by the Army even today, came to be. In 1963 or 1964, the source said, the Army issued a request to send a large shipment of nerve gas to West Germany under US control. 'Their argument was that the Russians have it in Russia; therefore we need it in Germany', the source recalled. The request was turned down. To back up its plea, the Army presented evidence supporting Trudeau's statement. This consisted of analysis made from aerial photos of Russia that showed large storage sheds similar to those used for storing warfare gases at the Army's depot in Tooele, Utah. 'The Army computed the roof size of the Russian sheds, figured out how many gallons of nerve gas could be stored in a comparably sized shed in Utah, added a 20 percent 'fudge' factor and came up with the estimate', the source said." [574]

[15] The Soviet Army captured 12 000 tons of German tabun, according to a British authority [578]; they are reported to have obtained small quantities both of tabun and of sarin as early as 1944 [579]. (It is said that one of the first indications in the UK during World War II that Germany had developed the nerve gases came from a Soviet military manual describing German CW agents.) A published report states that the tabun factory resumed production in Poland in September 1946 [580], but very little credence can be attached to it. Reference has also been made to the removal of the factory from Poland to a new site on the Volga river, 20 km north of Stalingrad. In their post-war plans for the factory, the Germans had envisaged it as the principal European chlorine factory [581].

gas, according to an anonymous article in a 1960 issue of *Armed Forces Chemical Journal* [576].

It is interesting to note that, in their Congressional testimony of this period, Chemical Corps representatives often spoke of insurmountable difficulties that would be involved in CB disarmament verification, yet at the same time purported to give rather precise details of Soviet CBW stocks [e.g., 1]. In these sorts of matters, however, it is easier to be certain of a presence than of an absence.

A recent reiteration of the one-sixth figure was made by the Director of the British Chemical Defence Establishment, speaking in November 1968 at the Royal United Services Institute in London. He said it was believed that between 15 and 20 per cent of the Soviet munitions stockpile, including rockets and missiles, comprised chemical weapons [577]. By this time, a number of other figures were being published, with attributions to West German officials. In February 1968, an article in *Soldat und Technik* stated that the USSR possessed 350 000 tons of CW agents, and that about 35 per cent of the Soviet stockpile of bombs, rockets and artillery weapons was chemical (25 per cent of the stockage of artillery shell, and 45 per cent of the rockets). The article also stated that the Polish, Czechoslovakian and East German armies "had access to a growing amount of CW agents" [463]. These figures were repeated in a West German radio broadcast in October 1968, again with attribution to West German officials, but with the added information that one-third of the Soviet PMD-6 land mines stocked in the GDR were gas-filled [582]. In August 1969 *Die Welt* stated that, according to a NATO estimate, the Soviet Union had 350 000 tons of chemical munitions ready for immediate use [583]. Four months later, an article in *Der Spiegel* stated that the current Bundeswehr estimate was that the USSR possessed around 700 000 tons of CW agents. The article also stated that 15 per cent of the Soviet weapon stocks in the GDR comprised nerve gas [447]. In August 1970, the Swiss journal *Allgemeine Schweizerische Militärzeitschrift* reported that the Soviet Union had been increasing its stocks of chemical weapons over the past months, and that more than one-third of the available artillery and air force weapons were chemical. In June 1971 *Soldat und Technik* also reported an increase in Soviet chemical weapon stocks, quoting "Western observers", and said that "nearly one-third of all ammunition, rocket-launchers, rockets and bombs" were to be gas-filled, with the authority to initiate their use delegated to divisional commanders [584]. In September 1970 the same journal had listed some of the CW agents "available in the USSR and in all Warsaw Pact countries", namely, phosgene, diphosgene, chloropicrin, hydrogen cyanide, mustard gas, chloro-

acetophenone, tabun, sarin, soman and something called "VR-55" [585]. Those who believe it exists understand VR-55 to be a nerve gas of greater potency than VX.[16]

In contrast to these Western European publications, purported details of such specificity about Soviet weapons have not been publicly disclosed by US officials, at least not since the early 1960s. Indeed, in this connection, the head of US Army Research and Development told Congressional committees in 1969 that "we do not know precisely what agents they have developed and deployed" [587] and that "[we are] not positive in terms of precise quantities" [588]. Shortly afterwards, however, another US Defense official told one of the committees that "the best intelligence estimates we have indicate the Russian stockpile is 7–10 times ours" [45], and from what little remains of his published testimony after censorship, it seems that he also told the committee that the Soviet stockpile included soman and a "new agent" which was not in the US stockpile [45].[17] Later on, another committee was told that the USSR was investigating the production of botulinal toxin [592].

As regards the types of chemical weapon said to be available to Soviet forces, the Chief of the US Army Chemical Corps stated, in an article published in May 1959, that

> Soviet chemical weapons are modern and effective and probably include all types of chemical munitions known in the West, in addition to several dissemination devices peculiar to the Russians ... Much of their hardware is relatively simple in design and operations are often multipurpose. For example, flamethrowers may be used for the dissemination of either incendiary materials or persistent agents. Converted artillery shells, incendiary bombs, and rotational scattering aircraft bombs are used for chemical warfare purposes [593].

Ten years later, a French CB R&D official stated that Soviet chemical weapons included land mines based on mustard gas and lewisite; shells, rockets or missiles charged with hydrogen cyanide or nerve gas; massive aircraft bombs charged with hydrogen cyanide or soman; fragmentation bombs charged with mustard gas and "K-agents"; and other aircraft weapon systems disseminating aerosolized incapacitants [589]. Apart from these, there are few open publications that purport to give details of Soviet chemical weapons.[18] When asked by a Congressional committee in

[16] It is perhaps relevant to note that the first public disclosure of quantitative information on the percutaneous toxicity of the V-agents was made by Academician M.M. Dubinin at the 1959 Pugwash Conference [586].

[17] In 1969, a French CB R&D official also wrote of a novel Soviet CW agent, which he said was an organophosphorus compound [589]. These are presumably allusions to the reputed agent VR-55, referred to above.

[18] The US Army handbook on the Soviet Army [590] is said to contain information of this kind [591], but it was unobtainable by the present authors. Publications

July 1969 to comment on certain differences between Soviet and US chemical weapon capabilities, the head of the US Army CBR and Nuclear Operations Directorate said "we envision military use predominantly against targets [*sic*]. They may be talking about large populations of civilians" [592]. Details of the difference in question were deleted from the text of the committee hearings before publication (see page 275 below).

According to a 1965 issue of *Soldat und Technik*, chemical warheads are available for the Soviet T-7A guided artillery missile (designated "SCUD-A" by NATO).[19] In addition to the T-7 series of missiles, chemical warheads are also available for some or all of the T-5 series of unguided artillery rockets[20]—what NATO calls the "FROG" series—according to *The Military Balance 1967–1968* (and subsequent issues) published by the International Institute for Strategic Studies in London [596]. The brochure issued by the British Chemical Defence Establishment to visitors at the Porton open-day in June 1969 contained a photograph of a T-5 rocket captioned "a guided missile, capable of firing a chemical warhead to a range of 30 miles". The brochure's only other illustration of a modern chemical weapon was a photograph of a truck-mounted, 40-tube 122 mm multiple rocket launcher (carrying GDR army insignia) of a type[21] that entered Soviet Army service in the mid-1960s alongside several different models of multiple rocket launcher. A 1967 issue of the Swedish Army journal *Armé Nytt* remarks that these weapons are especially well suited to the dissemination of CW agents [597]. An article in the November 1970 issue of the US journal *Army*, having noted that multiple rocket

purporting to describe Soviet chemical weapons of World War II are cited in Volume I, pp. 61–63, 79, 81, 106, 286 and 309.

[19] The T-7A entered service around 1957. It weighs about 4.5 tons and has a range of around 100 or 150 km. The latest member of the T-7 series, the T-7C, is heavier (about 6 tons) and has a longer range (about 220 km); it was introduced around 1965 [594–595]. The T-7 missiles are comparable to the US Army's MGM-29A *Sergeant*, which entered service in the early 1960s. *Sergeant* has a launch weight of about 5 tons, and a range of 139 km; the M212 chemical warhead designed for it holds about 200 kg of nerve gas [43].

[20] The T-5 series of rockets began to enter Soviet Army service during the 1950s (the T-5B or "FROG-1", around 1957). They are all about ten metres long, with launch weights of between two and three tons, and ranges of about 50 km [594–595]. The comparable US weapon, now obsolescent, is the *Honest John* rocket; equipped with an M190 warhead, it can fire about 220 kg of nerve gas to a distance of 38 km [43].

[21] This weapon, which is believed to bear the Soviet designation BM-21, is replacing the earlier BM-14 series of 140 mm rocket launchers. The rocket has a length of 2.74 m, a range of about 15 km, and weighs about 46 kg. The equivalent US weapon is the 115 mm M55 *Bolt* rocket, which is rather shorter (1.98 m) and lighter (about 25 kg), and has a maximum range of 12 km. It became operational in 1960, and is fired from the 45-tube M91 launcher. This system, which was designed specifically as a chemical weapon, can disseminate rather more than 200 kg of nerve gas per loading [43].

launchers exist in every Soviet division, remarks that "one reason for this is that they use them for firing both high explosive rounds and chemical warheads" [598]. A 1962 issue of another US military journal, *Military Review,* quotes a Western European view that the 6-tube 280 mm rocket system can fire nuclear or chemical warheads [599]. A few months later, the same journal quoted a Dutch source on the chemical and nuclear capability of the 310 mm mechanized rocket-gun, believed, however, to be an obsolete or obsolescent weapon [679].

Tactics and techniques

In themselves, none of the various Western statements quoted above can be taken as a true representation of the facts—nor, for that matter, as an untrue one. A former US Department of Defense official has offered this rationale for the supposed offensive CW capability:

> [The Soviet nerve-gas capability] came into existence in the early or mid-1950s because it wasn't until then that the Russians could afford anything ... The Russians when they started spending money and getting a conventional land force capability in the early 1950s, were faced with American nuclear weapons, and they figured that a chemical capability was a second best thing. When they got a little richer in the early 1960s they went ahead and bought the tactical nuclear capability. Once you have it, it doesn't cost you much to maintain those stockpiles, and they had all the doctrine and training programmes set up anyway [600].

A similar suggestion has also been made by a British authority [578].

The view taken by *Soldat und Technik* in 1971, quoted above, that authority to initiate CW has already been delegated to Soviet divisional commanders (and not, as seems more plausible, that it would only be delegated after a high-level political decision had been made) was repeated two months later by *Allgemeine Schweizerische Militärzeitschrift;* this journal stated that a Soviet military manual contained the following passage (translated from the purported German translation):

> Chemical weapons are used for the mass destruction of the enemy as well as to complicate the operations of his troops in rear areas. They must be employed concentratedly and with surprise. The division commander must give the order for deploying chemical weapons [601].

Much significance appears to be attached to Soviet CW manuals in the West, where they are said to enter prominently into assessments of Soviet CW capabilities and intentions. The manuals themselves are not available in the open literature for comment here.[22] It would be interesting to know

[22] Most military manuals are designed to instruct military personnel in the execution of particular orders, and are issued against the contingency of the orders being issued. Only by implication do they touch on the underlying policy considerations that might result in the orders.

whether corresponding significance is attached in WPO countries to such US manuals as FM 3–10, *Employment of Chemical and Biological Agents* [43], and its classified supplements FM 3-10A and FM 3-10B.

A recent study of the Soviet armed forces by Professor John Erickson of Edinburgh University [521] includes some discussion of Soviet offensive CW doctrine. Erickson states that in the Soviet Ground Forces, chemical weapons are "organic down to division". Commenting on the assumptions governing tactical performance and requirement made by the Soviet command, he remarks that

> they remain the insistence upon the primacy of offensive action, the use of initial mass nuclear strikes (or with chemical weapons, or a combination of both) in great depth designed to destroy the enemy's capacity for effective resistance, together with rapid day and night movement by mobile striking forces, bringing heavy concentrations of armour into the enemy rear . . .

His perception of Soviet CW doctrine for the execution of these initial tactical strikes, and his comment upon it, are as follows:

> The fire-plan for the use of these weapons [i.e., "nerve agents . . . delivered by missile, aircraft or conventional artillery"] would probably follow the main outlines of the nuclear plan, though a smaller number of warheads would be needed. (The chemical weapon appears to be ideally fitted in a number of instances to achieve the degree of surprise which is a cardinal point of Soviet doctrine: they could be used close to the FEBA, where, because of their own tactical requirements, the Soviet command would not wish to employ a nuclear weapon and, in particular, in connection with the planned use of airborne assaults.)

In a discussion of the recently expanded Soviet Naval Infantry (marines), he offers this speculation:

> [A]n amphibious assault [by the marines] on a limited scale may well be accompanied (or preceded) by an airborne or helicopter-borne assault on the area of the beach-head, with helicopters also being used in a ferry role and, as in the airborne assault proper, with nuclear or chemical weapon strikes being directed before the landing against enemy positions and weapons.

He notes that during the Spring 1970 manoeuvres of the Soviet Ground Forces (the DVINA exercise), a full division of airborne troops was used in a mock assault, and that their prospective drop-zones had been subject to a simulated "nuclear or chemical weapons attack not long before the actual drop". He does not say whether the latter attack was delivered by enemy or by Soviet forces.[23]

[23] Erickson describes DVINA as "a full-scale test of the mobilizational and operational performance of the Ground Forces, played against a nuclear scenario". The principal Soviet source which he cites for his account is *DVINA Voiskovye manovry . . . v*

A wire-story from Geneva in March 1971 printed in several Western newspapers quoted "Western military observers" as saying that the USSR has large stocks of chemical weapons along its border with China [602]. Professor Erickson states that the tactical missile units of the Siberian and Far Eastern Military Districts have recently been reinforced, for example by the addition of a fourth company to "FROG" battalions; he suggests that "this could be a precautionary move for reinforcing in the field of chemical weapons, which would have several advantages in the Far East". He goes on to remark that "the Ussuri fighting in 1969 seems to have been the occasion when a type of Soviet chemical weapon was employed ..." [521].[24]

Professor Erickson's study is increasingly being quoted by Western officials (to say nothing of Western journalists [e.g. 604]) as evidence of Soviet CW planning. It has to be remarked, however, that when he touches on CW, he does not cite his sources, even though the study as a whole is closely documented. Thus, as regards any of the quotations from the study given above, a reader cannot tell where the original Soviet source left off and where Professor Erickson's inference from it began. As they stand, the CW passages in the study can be taken only as speculation on the manner in which the general precepts of Soviet military doctrine, as perceived by the author, might apply to chemical weapons. They offer no firm information on whether the Soviet armed forces in fact possess the chemical weapons to which these precepts might apply.

Western information on Soviet biological weapons

During the 1950s and early 1960s, reports appeared in Western publications of an enormous research, development and production programme for biological weapons being conducted by the Soviet Union. They are no longer to be found in the more recent publications on the subject. An example of what used to be published is the following passage from a 1952 article attributed to Admiral E. M. Zacharias, former Deputy-Chief of the US Office of Naval Intelligence:

marte 1970, Moscow: Voenizdat (1970). The present authors have not been able to consult this publication, but if the other accounts of troop exercises which they have seen in the Soviet military literature are any guide, this one would not have specified whether the DVINA drop-zones had been contaminated by Soviet or by enemy forces. It is also to be noted that in the Soviet Ground Forces, radiological and chemical decontamination and reconnaissance duties are performed by the same units; therefore, the fact that such units participated in the exercise does not necessarily mean that CW operations (rather than nuclear ones) were being simulated.

[24] The sources of information from which Professor Erickson made the latter inference were local newspaper reports which at one point during the fighting had indicated a marked change in qualitative and quantitative casualty patterns [603].

In eight 'military bacterial stations', one of them on a ghost ship in the Arctic Ocean, the Soviet Union is mass-producing enormous quantities of 'disease agents' for aggressive use against the soldiers and civilians of the free world. In particular, the Red Army is stockpiling two specific 'biological weapons' with which it expects to strike a strategic blow and win any future war decisively even before it gets started officially [439].

Likewise, a French CB R&D official writing in 1968 stated that a 1960 French study showed that "the Soviets had acquired, in the domain of biological armaments, a serious advance on the Western world. The Soviet potential, in the sector of research as in that of production, is growing constantly and in recent years has benefitted from numerous discoveries." He noted, however, that as of 1968 information about Soviet offensive BW capabilities "lacked precision" [609].

It is reported that the initial US intelligence estimates of the Soviet BW programme were based primarily on the statements of émigrés from the USSR [608, 610]. Admiral Zacharias quoted several of them.[25] It seems that the credence attached to them did not begin to decline until around 1960, at which time the effort to find corroborating evidence was being increased. Many of the previously accepted "facts" were found to be the merest rumour or hearsay; the experimental and manufacturing facilities either could not be located or turned out to be such things as public health laboratories working on endemic contagious disease. It is instructive to compare the appreciations of the Soviet BW programme given in 1958 and in 1962 by the Chief of the US Army Chemical Corps to Congressional committees:

[25] Admiral Zacharias quoted a Bulgarian botanist, for example, who had "succeeded in escaping" from an island off the Dagestan coast of the Caspian Sea where the "central military bacterial station" was situated. This installation, he said, was "undoubtedly the world's largest experimental and production centre in BW"; among its "thousands" of military and scientific personnel was a "group of German BW specialists imported after the last war". Zacharias also spoke of a huge Soviet BW station on the Black Sea, not more than 250 miles from the Turkish frontier, and of others in Korea and China that were directed from a "special bacterial warfare station" at the Khabarovsk State Medical Institute. There was yet another BW facility, he said, located "120 miles north of the Iranian border" [439, 605–606]. A Reuters wire-story from Bonn in October 1954 quoted "underground reports from the Soviet Union" which claimed that the construction of six BW laboratories had begun in Azerbaijan during 1949; four of these were "along the Kura River not far from Saljany", while the other two were "in the malarial swamps of Jeflach" [607]. A 1969 *Washington Post* article spoke of a long-standing US Army belief in the existence of a BW station on an island in the Aral Sea [574], a belief apparently derived from German intelligence documents captured during World War II. The author of the *Washington Post* article alludes to these elsewhere [608], and Admiral Zacharias purports to quote from them. The Aral Sea installation was reportedly on Vozrozhdeniya Island and was said to have 10 000 km^2 of test area available to it.

[1958] I may say that the information I have received adds up to a total Communist effort in biological warfare greater than ours, although it is difficult to judge how much of it has related public health aspects. We have learnt, however, of an extensive field test program and test sites that can only be concerned with offensive employment of such agents [274].

[1962] It is believed that the Soviets now have a strong capability to wage warfare with chemical weapons. Also, the Soviet potential for biological operations is believed to be strong and could be developed into a major threat [611].

By June 1969, the appreciations being given to Congressional committees were still less confident:

As far as the Russians' BW R&D is concerned, we don't know too much about that, but we know from the scientific literature that the Russians have published openly on most of the biological agents that we have ever considered. So, we have to believe they are probably working in the same area [45].

The fact that two months earlier another Congressional committee had been told, "we are fully aware of the massive effort that the Soviets have applied to lethal chemical and biological weapons" [588] suggests a lack of consensus in official quarters,[26] particularly since in July a third Defense official was to say:

There is no clear evidence that any foreign country is presently testing biological weapons, in the sense that an operational delivery means is being used to disseminate either live pathogens or simulants [612].

The Soviet scientific and technical literature certainly contains many publications that could have originated in a biological-weapon programme; but they could equally well have come from public health work or from purely defensive BW activities.[27] Technologically, the Soviet Union is presumably as capable of making biological weapons as any other industrialized country; and, at a stretch, interpretations can be placed on such official Soviet statements as those quoted earlier to suggest the existence

[26] In the *Washington Post* of 29 June 1969, a journalist wrote that there was indeed a lack of consensus: "Another complication for the military is the growing dispute among US intelligence agencies over Russia's biological warfare capabilities ... The fact is that the State Department's intelligence agencies have reported for a number of years that there is no evidence whatsoever of any significant Russian activity in biological warfare ... 'We've been asking them [the Army] for years to find the Russian biological test facility', one source told me, 'and they can't'." [574]

[27] In connection with the Soviet BW R&D potential, a French CB R&D official has noted the immunological researches of the Mechnikov and Gamaleya Institutes in Moscow and the Kirov Institute in Leningrad; the virological studies at the Ivanovskiy Institute in Moscow; and the Soviet immunization studies using aerosolized vaccines (see appendix 1 below). He also notes that "numerous military centres are supposedly included in a biological-weapons R&D programme, such as the Kirov Military Medical Academy in Leningrad and the centres situated at Minsk, Omsk and Kazan" [609].

of a Soviet military doctrine for biological weapon employment.[28] It is thus conceivable that the USSR might possess a biological weapon capability, as US Department of Defense officials have pointed out to Congressional committees:

The USSR has a capability in biological warfare, they have the technological capability to produce, store, and deliver BW agents [592].
For the biological [warfare], their doctrine calls for its use in combination with a nuclear attack—to follow a nuclear attack with a biological attack. The nuclear attack will take care of our defenses and installations and the biological weapon will take care of people ... If that is part of their doctrine we must infer that they feel they have the capability [45].

It is harder, clearly, to ascertain whether something does not exist than whether it does; but if there were any sort of confirmation of the existence of the possible capability, the testimony of these officials would surely have indicated it.

More detailed information may possibly follow from Soviet action after the 1972 Biological Weapons Convention comes into force. On 28 September 1971, the head of the Soviet delegation to the CCD spoke as follows:

During the discussion on the draft convention suggestions were made that States parties to the convention should give appropriate notification of the destruction or diversion to peaceful purposes of stockpiles of bacteriological and toxin weapons in accordance with Article II. The Soviet Union is prepared to give such notification on the understanding that other States parties to the convention will do likewise [613].

A *New York Times* article commented upon this as follows:

This was interpreted by some delegates as an indirect admission that Moscow also possesses such weapons. A Soviet spokesman, however, did not make clear whether the notification would merely say that the Soviet Union had no such weapons, or would disclose the destruction of stockpiles [614].

[28] Thus, in the section on Soviet BW activities in his book *Tomorrow's Weapons* [444], General Rothschild, ex-Chief of the US Army Chemical Corps R&D Command, begins by quoting his version of the 1956 Zhukov statement ("... a future war, should it be unleashed ..."), and then goes on to quote as follows from an unidentified Soviet CB publication of 1959 by military writers (it was in fact a civil defence textbook): "The combined use of pathogenic micro-organisms and radioactive substances increases the effectiveness of both types of agent ... Radioactive radiation facilitates the infection of humans, increases the severity of the disease course, and negates the efficacy of specific prophylaxis of infections. The pathogenic biological agent complicates the course of radiation sickness, and thus augments the effectiveness of the radioactive weapon."

Ending with a quotation describing the potency of biological weapons and the frailty of international treaties taken from what he says is "a Russian publication" but is in fact a Yugoslav one, he concludes: "In view of these indications, and others of the same type, there can be little doubt that the Soviet Union and various satellites are prepared to use ... biological warfare."

Table 3.2. The Geneva Protocol and the Biological Weapons Convention: Positions of the NATO countries[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention:
	Accession	Reservations[b]	Signature
Belgium	December 1928	I, II and III	April 1972
Canada	May 1930	I, II and III	April 1972
Denmark	May 1930	None	April 1972
France	May 1926	I, II and III	Not signed
Germany, West	April 1929	None	April 1972
Greece	May 1931	None	April 1972
Iceland	November 1967	None	April 1972
Italy	April 1928	None	April 1972
Luxembourg	September 1936	None	April 1972
Netherlands	October 1930	IV	April 1972
Norway	July 1932	None	April 1972
Portugal	July 1930	I, II and III	Not signed
Turkey	October 1929	None	April 1972
United Kingdom	April 1930	I, II and III	April 1972
United States	Not a party	—	April 1972

Notes:
[a] As of July 1972.
[b] See table 3.1, note *b*, for the key.

II. *The United States and other NATO countries*

Policy

With the exception of the United States, all fifteen NATO countries are parties to the Geneva Protocol. The details of their ratifications or accessions are set out in table 3.2. The USA was one of the original signatories, but has not yet ratified the treaty. President Nixon resubmitted the Protocol to the Senate in August 1970, but ratification is at present blocked by the issue of chemical irritant and antiplant agents.

In the past few years, the governments of the major NATO countries parties to the Protocol have reaffirmed their adherence to the treaty, either at the UN General Assembly, or at the CCD, or to their respective parliaments. Until the late 1960s, however, there was considerable uncertainty about US policy concerning CB weapon employment, but in November 1969 President Nixon issued a statement which contained the following passages:

As to our chemical warfare program, the United States
- Reaffirms its oft-repeated renunciation of the first use of lethal chemical weapons.
- Extends this renunciation to the first use of incapacitating chemicals. . . .

I have decided that:

- The U.S. shall renounce the use of lethal biological agents and weapons, and all other methods of biological warfare.
- The U.S. will confine its biological research to defensive measures such as immunization and safety measures.
- The DOD has been asked to make recommendations as to the disposal of existing stocks of bacteriological weapons.

In February 1970, he extended the BW renunciation to "toxins, whether produced by bacteriological or any other biological method or by chemical synthesis".[29]

President Nixon's announcements came at a time when the CBW programmes of his own and several other Western countries were receiving strong domestic criticism, and when negotiations for international CB disarmament were gathering momentum. Under such circumstances, the governments of a number of other NATO countries felt it necessary to clarify their CBW policies in public statements that went beyond expressions of support for the Geneva Protocol or for CB disarmament. Some of these are quoted below.

Attitudes towards CB weapon stockpiling

With the exception of the United States, no NATO country has announced possession of an offensive CBW capability; indeed, some have declared that they do not possess one, and on the biological side some have followed the US example in renouncing any intention of doing so. The indications are that, within NATO, only the United States, and perhaps also France, possess militarily significant stocks of CB weapons, and that these stocks will soon be confined to chemical weapons only. All the NATO countries participating in the CCD discussions were included among the sponsors of the draft that became the 1972 Biological Weapons Convention. As is shown in table 3.2, all NATO countries except for France and Portugal signed the Convention as soon as it was opened for signature; none have yet ratified it.

The Netherlands. In March 1970, the Netherlands representative at the CCD recalled the fact that, on ratifying the Geneva Protocol in 1930, the Netherlands had reserved the right to retaliate only with chemical weapons, not with biological ones, in the event of CBW attack. He said that "[i]n doing this the Netherlands was among the first countries to renounce unconditionally the use of bacteriological or biological weapons" [432].

[29] For complete texts of President Nixon's policy statements of November 1969 and February 1970, see Volume V, pp. 275–77.

Canada. Also in March 1970, the Canadian Government issued the following statement:

> [T]he Government of Canada wishes to make known its attitude towards chemical and biological warfare.
> (1) Canada never has had and does not now possess any biological weapons (or toxins) and does not intend to develop, produce, acquire, stockpile or use such weapons at any time in the future.
> (2) Canada does not possess any chemical weapons[30] and does not intend to develop, produce, acquire, stockpile or use such weapons at any time in the future unless these weapons should be used against the military forces or the civil population of Canada or its allies. . . .[618][31]

Italy. Under its 1947 Treaty of Peace with the Allied Powers, Italy undertook not to "manufacture or possess, neither publicly or privately, any war material different in type from, or exceeding in quantity, that required for the force permitted". War material was defined to include "asphyxiating, lethal, toxic or incapacitating substances intended for war purposes, or manufactured in excess of civilian requirements".[32] It seems most improbable that any stocks of CB weapons were included within the "force permitted"; thus, if this treaty is not now regarded as a dead letter, Italy is debarred from possessing CB weapons, whether for deterrent or for any other purpose.[33]

France. On 9 March 1972, a government bill was passed by the National Assembly that outlaws any French work on the development, manufacture or stockpiling of biological or toxin weapons [619]. This move, which is intended to compensate for France's decision not to join the 1972 Biological Weapons Convention [620],[34] originated in a joint Foreign

[30] Canada manufactured about 1 500 tons of mustard gas and phosgene during World War II [615]. It also purchased 3 500 tons of mustard gas, and smaller quantities of lewisite and phosgene, from the US Army [616]. It destroyed its chemical-weapon stockpile in 1946 [617].

[31] The next part of the statement, which referred to irritant agents, is quoted on page 200 below.

[32] For further details of the treaty, see Volume V, p. 214.

[33] On the pre-World War II Italian CW programme, see Volume I, pp. 291–92.

[34] Explaining this decision to the UN General Assembly in November 1971, the French representative spoke as follows: "What we fear is that on the international level this would be the first step towards a policy of disarmament without control. Such a policy would limit itself to prohibiting the manufacture of weapons, the use of which is unlikely in any case. It would have the serious shortcoming of giving credence to the idea that disarmament is forging ahead, whilst the true dangers will not have been allayed, and in the field of verification it will be based on the use of national means of observation and will therefore be discriminatory, since not all states have sufficient means. International control as a principle is the indispensable corollary to any disarmament measure of a contractual nature, albeit partial. If this element is ignored, the

Ministry/Defence Ministry proposal, and was approved in principle by the Council of Ministers in October 1971 [621–622]. It is not publicly known whether France has in fact been conducting a biological weapon programme to which the legislation applies.[35]

To judge from the French military literature,[36] chemical weapons are more highly regarded by the French military than are biological weapons; and certainly up to the time of World War II, the reservations which France had made on ratifying the Geneva Protocol were given substance in the form of a strong retaliatory CW capability. Like the Soviet Union, however, France has not emphasized its reservations since World War II, and has not publicly confirmed or denied possession of chemical weapons. But there is circumstantial evidence to suggest that retaliatory stocks continued to be maintained after the war. During the late 1960s, there were newspaper reports of obsolete French chemical weapons being dumped in the Bay of Biscay [623] and the Mediterranean [624]. Chemical weapon tests continued at the Algerian-Sahara proving grounds until well after Algerian independence (continued French access being specified in the independence agreement, along with access to the Saharan nuclear and rocket test sites). US Department of Defense testimony was deleted in the published record of a set of 1969 Congressional hearings when it touched on the French CW programme, even though testimony that the United Kingdom did not manufacture chemical weapons remained uncensored [69]. Published reference to a French chemical weapon factory was made by a French defence official in 1970 [625]. The existence of a French nerve-gas stockpile does not seem out of keeping with a military strategy that is substantially independent of NATO, and which values an independent nuclear deterrent. It has not lacked advocates among French military writers [e.g., 626].

draft convention on the prohibition of the manufacture of biological weapons is an extremely dangerous precedent, the existence of which will weigh heavily upon all disarmament work. A State cannot merely have faith in the goodwill of other Powers in a field where its security is at stake." [620]

[35] For the text of the legislation, see Volume III, appendix 5.

[36] French military journals do not give as much discussion to CW problems as do, say, US or Soviet ones. But the more professional of them, particularly those intended for reserve officers, regularly carry programmes of forthcoming lectures or training-courses, and accounts of past ones, organised by the staffs of the different military regions, and which sometimes encompass CBW matters. Especially noteworthy in this connection are *Le Pharmacien de Réserve, L'Officier de Réserve* and *Le Médecin de Réserve.* Other French military journals that have published information about French CBW activities, or general articles on different aspects of CBW, include *Revue du Service biologique et vétérinaire des Armées, Revue du Corps de Santé des Armées, Revue militaire d'Information, Revue de Défense Nationale, Mémorial des Poudres, L'Armée* and *Forces Aériennes Françaises.*

The United Kingdom. In May 1968, the British Defence Secretary answered a parliamentary question as follows: "We neither develop nor produce bacteriological weapons, and no question of a role for them in our deterrent strategy arises" [627]. Five days later, a parliamentary Select Committee was told by the Director of the British BW defence R&D establishment that the UK would have to do "a good deal of development work" before it could retaliate in kind against BW attack [628]. In December 1969 the UN General Assembly was told by the British representative that "as successive British governments have made very clear, we have never had any biological weapons, we do not have any now and we have no intention of acquiring any" [629]. As regards chemical weapons, the Ministry of Defence informed the House of Commons in June 1968 that the "only stocks of nerve gases currently held are small quantities necessary for the development and testing of defensive measures" [630].[37] In May 1970, the Defence Secretary spoke as follows to the Commons:

> NATO as a whole has chemical weapons available to it because the United States maintains an offensive chemical capability. However, I believe that both the former and the present Government in Britain were right not to stockpile offensive chemical weapons in the United Kingdom. If the House really considers the situation, I believe that it will recognise that it is almost inconceivable that enemy forces would use chemical weapons against NATO forces except in the circumstances of a mass invasion—in which event more terrible weapons would surely come into play. [632]

This was a view which he had presented in rather more detail to a parliamentary Select Committee in July 1968:

> One may have one's own views as to whether a country that has them for retaliatory purposes might use them first. One has to accept there is a potential threat to this country from both chemical and biological weapons. The view we have taken is that we must maintain ... an adequate defence capability in both fields. In the field of chemical weapons we have a very good defence capability indeed so far as our services are concerned. It is not so easy to conceive of the use of chemical weapons against a civil population in these islands. Their use against soldiers in Europe is something which one must almost expect if there were a war in Europe. We have not felt it necessary, nor indeed did the previous Government, to develop retaliatory capability here, because we have nuclear weapons, and obviously we might choose to retaliate in that way if that were the requirement. But this is something one has to keep under continuing review. ... [I]n the biological field it is very difficult to form

[37] The Director of the Chemical Defence Establishment indicated what was meant by "small quantities" at a press conference in October 1970. He stated that the current stocks of nerve gases in Britain amounted to about 50 kg, comprising samples of VX and four different G-agents, namely sarin, soman, GF and something called T-2715 [631].

a fully satisfactory estimate of the nature of the threat in this theatre, but the possibility is there, and we are therefore doing research on defence against these weapons, for a very small cost indeed, which I think is well worth continuing. [633]

Like the Defence Secretary, British officials have repeatedly stressed the importance attached by the government to maintaining an imposing defensive stance against possible CBW attack [e.g., 634]. The British CB protection R&D programme appears to be one of the largest in the world, and according to the NATO Information Service, "it is the British who make the most effective contribution to NATO's studies" in the field of CB defence [635].

The United Kingdom maintained a substantial stockpile of chemical weapons until around 1957 when the last of it was dumped into the Atlantic Ocean [636].[38] Up to about this time, an active chemical weapon R&D programme had been in progress, including preparatory work for the possible construction of a large automated nerve-gas factory at Nancekuke, in a remote part of Cornwall. In the mid-1950s, however, a policy decision was taken that ended the programme and confined the Nancekuke establishment to pilot plant and process research operations. The following account of this has been published by the Ministry of Defence:

In the years immediately following [1945], Europe was far from settled and it was considered possible that this country might become involved in another major war. Against this background and bearing in mind the time it takes to design and, if necessary, erect a complex chemical plant, it was decided to undertake a design exercise against the event of the UK requiring a retaliatory capability as a deterrent. It was also necessary to produce sufficient quantities of ... newly discovered agents (now known as G agents) to enable them to be properly evaluated and to support research and development of protective measures. To meet these needs a pilot plant was required and, since Sutton Oak[39] was not a suitable site for this purpose, the Establishment was transferred to Nancekuke in 1951. The pilot plant was built and from 1953 to 1955 it produced sufficient GB to prove the process and to meet the requirements for assessment trials and the testing of defensive equipment under development at Porton.[40] Subsequently international tension relaxed to the point where it

[38] At a site beyond the 1 000-fathom line, 12°W 56°30 N, about 250 miles west of Colonsay [637]. During 1955–57, this particular site received around 25 000 tons of German tabun bombs, British mustard gas and phosgene bombs and shells [638]. For earlier dumping operations, see Volume I, pp. 153 and 305.

[39] The Chemical Defence Research Establishment, Sutton Oak, Lancashire, is referred to in Volume I, pp. 271–72. See also page 214 below.

[40] Details of past and present production activities at Nancekuke were disclosed at an open-day for the press on 29 October 1970, which was attended by one of the authors of the present study. At full capacity, the Nancekuke pilot plant could turn out about 6 kg of sarin per hour, and when it ceased operations there were about 15 tons of sarin in store. It is now derelict. Existing nerve-gas production facilities

was not judged necessary to proceed with the erection of a production plant [640].

The new policy did not extend to irritant-agent weapons, and in 1956 a major programme was initiated to improve existing chemical riot-control equipments, culminating in the development of CS [15]. This has been extended to the development of a variety of CS devices that are used to simulate different nerve-gas weapons on training exercises. It is not known how the relevant War Office or Ministry of Supply directives defined the difference between the weapons R&D that was to stop (e.g., nerve gas) and that which was to continue (e.g., CS). As regards incapacitating weapons, uncertainty regarding current policy has arisen from the government's decision in 1970, referred to below, to reinterpret the Geneva Protocol to exclude chemical agents that are "not significantly harmful in other than wholly exceptional circumstances" [642]; in recent years, the British Chemical Defence Establishment has been studying the effects in volunteers of agents such as LSD [52] and BZ [641].

West Germany. At the time of World War II, Germany built up a powerful CW capability, both offensive and defensive; it also instituted a BW research programme, but this seems to have been both small and unproductive.[41] After the war, its CW capability was dismantled, and its CBW research activities outlawed, in accordance with the broad disarmament principles laid down in the UK–USA–USSR Potsdam Agreement of August 1945. In October 1954, shortly before sovereignty was restored to the western zones of Occupied Germany, Chancellor Adenauer made a declaration whereby the future Federal Republic of Germany (FRG) undertook "not to manufacture on its territory any atomic weapons, chemical weapons or biological weapons, as detailed in ... the attached list". This declaration was formally incorporated into the revised Brussels Treaty of 1954 setting up the Western European Union (WEU), and since then the WEU Armaments Control Agency has been applying inspection

at Nancekuke, which are essentially little more than rather large laboratory-bench set-ups, can produce about 1.5 kg per day of different G-agents. There is also a laboratory-bench apparatus for V-agents, which can be operated on continuous flow. At the time of the open-day, it had last been used in February 1968 to make about 10 kg of VX. A photograph of it appeared in a British newspaper [639].

Nancekuke is also the site of a CS production facility. This uses a batch process that can yield about 30 kg of CS per day. In all, about 33 tons of CS have been made at Nancekuke since 1960, according to the director of the establishment. Some CB protective items are also made at Nancekuke. There is a 40 kg/day production unit for the oxime-type nerve-gas therapeutic, P2S. A pilot plant is also under construction for production of carbon cloth (see p. 96).

[41] See Volume I of this study, pp. 116–17 and 278–284, for details of German CBW activities prior to World War II.

procedures for verifying that the FRG is continuing to observe it.[42] No infractions have been reported by the Agency.

The *White Paper 1970 on the Security of the Federal Republic of Germany and on the State of the German Federal Armed Forces,* published by the Federal Minister of Defence on behalf of the FRG Government, [643] states:

> The Federal Republic neither possesses nor does she store any biological and chemical weapons; she does not seek possession of, or control over, weapons of that kind, she has made no preparation for using them, does not train military personnel for that purpose, and will abstain from doing so in the future.

Stores of chemical weapons do, however, exist in the FRG, but they belong to the US forces stationed there.[43] The quotation from the *White Paper 1970* given above indicates that the FRG has no control over them; it also appears to rule out the possibility of the weapons being released to FRG forces in the event of a European war.

While official policy on CBW appears to contain no provisions for offensive CBW activities on the part of the FRG, it follows that of most other NATO countries in providing for the maintenance of up-to-date defences against possible CBW attack. In the words of the *White Paper 1970:*

> As long as the efforts to ban biological and chemical weapons prove fruitless, the Federal Government is under obligation to protect German civilians and soldiers from the dangers inherent in these weapons. Apart from the personal equipment of each individual soldier the forces maintain a number of special NBC defence units.
>
> The research effort necessary to stave off these dangers and to treat afflicted personnel is confined to known agents.

However, allegations have often been made, particularly from the GDR, that the FRG has in fact been conducting an offensive CBW R&D programme [e.g., 645–646]. Such allegations have generally received official denials, particularly in recent years [647–648], and some of them have been investigated on an informal basis by the WEU Armaments Control

[42] See Volume V of this study, pp. 190–219. The list of chemical and biological weapons referred to in the Adenauer declaration is reproduced in Volume V, p. 197.

[43] According to a press report, chemical detachments of the US Seventh Army have depots at Hanau, Viernheim, Mannheim and Massweiler [447]. The site at Hanau, about ten miles east of Frankfurt, was taken over by the Chemical Division, US Army European Command, in 1947, and was extensively refurbished to provide warehouses, offices, barracks, laboratory and training-school facilities [644]. There is no published information about the size of the US chemical-weapons stockpile in the FRG, or about the chronology of its build-up.

Agency.[44] Allegations have also been made that West German industrial concerns have been manufacturing CW agents both at home and on foreign soil [312, 646, 649–650]. The majority of these have been directed against Farbenfabriken Bayer AG, which, however, has repeatedly denied them [651–653].

The United States. President Nixon's policy statement of November 1969, quoted above, referred by implication to the US retaliatory CW capability. For many years, the existence of the US chemical weapons stockpile has been no secret; on the contrary, since the late 1950s the US Department of Defense has repeatedly stressed its importance during Congressional hearings, in the military journals, and at press and other briefings. One of the most explicit statements of the Defense Department's attitude towards CB weapons prior to President Nixon's policy redefinition was issued by the Office of the Secretary of Defense in April 1969:

> It is the policy of the United States to develop and maintain a defensive chemical-biological (CB) capability so that US military forces could operate for some period of time in a toxic environment if necessary; to develop and maintain a limited offensive capability in order to deter all use of CB weapons by the threat of retaliation in kind; and to continue a program of research and development in this area to minimize the possibility of technological surprise. This policy on CB weapons is part of a broader strategy designed to provide the United States with several options for response against various forms of attack. Should their employment ever be necessary, the President would have to authorize their use. The United States does not have a policy that requires a single and invariable response to any particular threat. In the field of CB warfare, deterrence is the primary objective of the United States.
>
> CB weapons, in many situations, may be more effective than conventional (high explosive and projectile) weapons. Accordingly it is believed wise to deter their use. . . . [654]

In a similar vein, suitably modified to accomodate President Nixon's new policy, Ambassador Leonard spoke as follows to the CCD in March 1970:

> At the present time, some states believe that a chemical warfare capability is important for their national security. States maintain chemical warfare programs and stockpiles to deter the use of these weapons by others and to provide a retaliatory capability if deterrence were to fail. Unlike biological weapons, whose very doubtful retaliatory value we have already discussed,[45] the inability of an attacked nation to retaliate with chemicals could give a significant military advantage to any government which might decide to violate the prohibi-

[44] See Volume V of this study, p. 213.

[45] Ambassador Leonard's remarks on the retaliatory value of biological weapons are quoted on page 157 above. A commentary on his remarks about chemical weapons occurs on page 158 above.

tion on the use of chemical weapons. If only one side were using chemical weapons, the mobility and fighting capacity of the other side would be greatly restricted in the entire area of combat by the need for protective clothing and other defensive measures, while the attacker would not be thus hampered in the areas he desires to leave free of contamination [432].

By the end of World War II, around 135 000 tons of CW agents had been manufactured in the USA.[46] Part of this output was discarded in the postwar years, but at the same time a large nerve-gas manufacturing programme was under way, with full-scale production commencing in 1954 [655]. Production of novel biological and toxin weapons apparently also commenced around this time [656–657]. A further increase in procurement occurred around 1960 [658]. In the early stages of this manufacturing programme, and indeed throughout most of the period preceding President Nixon's statement, the underlying official policy remained obscure, as can be seen from the compilations of official statements on US CBW activities published by the Disarmament Subcommittee of the Senate Foreign Relations Committee [591] and by the Library of Congress Legislative Reference Service [659–661]. It was not until the mid-1960s that declared US policy towards employment of CB weapons became explicitly one of no-first-use, and even then there were doubts about the categories of weapon to which this referred. There are indications that during the interim period actual policy had shifted away from no-first-use, just as it had done during the mid-1930s.[47]

In 1947, the Truman Administration withdrew the Geneva Protocol from the Senate along with a number of other pending treaties regarded as "obsolete" [662]. This was done despite the fact that in 1943, President Roosevelt, concerned about possible German or Japanese use of chemical weapons, had announced that:

> The use of such weapons has been outlawed by the general opinion of civilized mankind. This country has not used them, and I hope that we will never be compelled to use them. I state categorically that we shall in no circumstances resort to the use of such weapons unless the first use of them is by our enemies.[48]

For the next decade and a half there was neither confirmation nor denial that this was to remain official US policy. In fact, such public policy-statements as there were—for example, in the Congressional testimony of the US Army Chemical Corps during the late 1950s [274, 443]—con-

[46] See Volume I, pp. 277 and 304–05 for further details.
[47] For an account of US CBW policy prior to World War II, see Volume I, pp. 273–78.
[48] For a full text of President Roosevelt's statement, and an account of its background, see Volume I, p. 319.

spicuously refrained from mentioning the Roosevelt statement. Moreover, the Roosevelt statement referred only to chemical weapons. Since before World War I and through World War II, the relevant US Army manual, *Rules of Land Warfare,* had contained a passage interpreting article 23 of the 1907 Hague Regulations as prohibiting biological warfare [277, 664]; but in the 1956 edition of the manual, the passage was replaced by a statement that the USA was not bound by any treaty restricting the use of bacteriological weapons [665].

In 1955, the Miller Report [666], produced by a civilian advisory committee and approved by the Secretary of the Army, advised the Chemical Corps to seek "a more candid recognition of the proper place of chemical and biological warfare". It also advised that the Corps "must have an opportunity to be heard and its recommendations weighed early and frequently at critical points within the military, in order that maximum consideration may be given in over-all Department of Defense thinking to meshing chemical, biological and radiological warfare into plans of warfare and plans of defense as they are being developed". Subsequently, the public was told of substantial changes in the Army's CBW organization and R&D programmes following adoption and implementation of the Miller Report [667–668], but still nothing was said of the underlying CB weapon policy. The Chief of the Chemical Corps described it to a Congressional appropriations committee in 1958 [443], but all that remained uncensored in the published committee hearings was the information that the policy had been in effect since 1956.

By 1959 the Chemical Corps' publicity effort recommended in the Miller Report was fully under way. The Corps went to considerable lengths to impress upon Congress and the press its view of the value of CB weapons in a flexible military posture adaptable both to global and to "limited" warfare [274, 443, 669],[49] for by this time the "massive retaliation" strategy that had dominated the US military stance was beginning to give way to the concept of "flexible response". It was against this background that Congressman Robert Kastenmeier introduced a concurrent resolution into

[49] Chemical Corps publicists involved in this effort (for bibliographies, see [670–671]) were in fact among the first postwar CBW commentators to draw attention to the 1943 Roosevelt statement, although their attitude was one of hostility rather than support. For example, an article by General Rothschild (see p. 184, note 28) in the June 1959 issue of *Harper's Magazine* has the following as its penultimate paragraph: "If this very brief analysis of chemical and biological warfare is correct, it follows, I suggest, that we must take two new steps in our military policy. First, we must reject once and for all the position stated by President Roosevelt that an enemy can have the first chemical or biological blow wherever and whenever he wishes. That blow could be disastrous. We must make it clear that we consider these weapons among the normal, usable means of war." [380]

the House of Representatives in September 1959 that called for a reaffirmation of "the long-standing policy of the United States that in the event of war the United States shall under no circumstances resort to the use of biological weapons or the use of poisonous or obnoxious gases unless they are first used by our enemies" [672]. He explained that he had inferred from public statements and articles that the Department of Defense was trying to bring about a relaxation of the existing policy strictures applying to CB warfare [673]. His resolution, which was never adopted, came at a time when the Executive Branch had just completed a major review of US CBW policy [674] (the results of which have never been published). Both the Department of Defense and the Department of State expressed strong opposition to the resolution. The former argued:

> Similar declarations might apply with equal pertinency across the entire weapons spectrum, and no reason is perceived why biological and chemical weapons should be singled out for this special declaration. ... Moreover, as research continues, there is increasing evidence that some forms of these weapons, differing from previous forms, could be effectively used for defensive purposes with the minimum collateral consequences [675].

The State Department argued in a similar vein; it spoke of US responsibilities towards "our own and the free world's security", and said that this required the "maintenance of an adequate defensive posture across the entire weapons spectrum, which will allow us to defend against acts of aggression in such a manner as the President may dictate". It made no reference to the 1943 Roosevelt declaration, but observed that the United States "is committed to refrain from the use, not only of biological and chemical weapons, but the use of force of any kind in a manner contrary to the [UN] Charter" [676].

The terms of the Administration's opposition to the Kastenmeier resolution strongly suggests that US policy had moved, or was moving towards one that permitted use of CB weapons in response to enemy attack, whether or not the enemy had used them first. When President Einsenhower was asked at a press conference in January 1960 whether US CBW policy had shifted from one of no-first-use, he responded in notably vague terms: "I will say this: No such official suggestion has been made to me, and so far as my own instinct is concerned, [it] is not to start such a thing as that first" [677].

During the mid-1960s, when the United States began to employ certain forms of CBW in the Viet-Nam War, it also began to articulate a no-first-use policy on other forms of CBW. In March 1965, Deputy-Secretary of Defense Cyrus Vance stated that "[w]hile national policy does proscribe

the first use of lethal gas by American forces, there is not, and never has been, a national policy against the use of riot-control agent" [678]. In December 1966 the United States voted in favour of a UN General Assembly resolution calling on all countries to observe the principles and objectives of the Geneva Protocol.[50] Three months later, Cyrus Vance told a subcommittee of the Senate Foreign Relations Committee that "it is clearly our policy not to initiate the use of lethal chemical or lethal biologicals" [424]. Policy on incapacitating CB weapons, whose advent was in large measure responsible for the high-level support given to the CB-weapon programme, was left obscure, and was to remain so until President Nixon's action in 1969.

Lack of attention to the US CBW programme at senior government levels may account for past obscurities and ambiguities in US CBW policy. It is a commonplace that the military of any country usually sees it as its duty to conserve or expand its various options in the absence of specific directives to the contrary. It seems that before the 1969 National Security Council review that led to President Nixon's CBW policy statement, the only other major ones were those of the Joint Chiefs of Staff in 1967 (which was never completed) and of the National Security Council in 1958–59 [674]. This situation is now changing, for President Nixon has called for an annual Executive Branch review of all facets of US chemical-weapon policies [681]. Moreover, in accordance with Public Law 91–121 of 19 November 1969, the Secretary of Defense must report twice a year to Congress on what has been spent on CBW preparations, and for what purpose [682].[51]

Attitudes towards use of irritant and antiplant CW agents

As noted earlier, the present obstacle to US ratification of the Geneva Protocol is the issue of whether or not the Protocol proscribes use of chemical antiplant and/or irritant agents in war. Because these agents have been used in the Viet-Nam War, the issue is an inflamed one. The US Government has claimed, and continues to claim [683], that their military employment is not illegal, but in doing so it is becoming increasingly isolated from most of the world, including some of its NATO

[50] For details, see Volume IV, pp. 238–243.

[51] Section 409 (a) of PL 91–121 is as follows: "The Secretary of Defense shall submit semiannual reports to the Congress on or before January 31 and on or before July 31 of each year setting forth the amounts spent during the preceding six-month period for research, development, test and evaluation and procurement of all lethal and nonlethal chemical and biological agents. The Secretary shall include in each report a full explanation of each expenditure, including the purpose and the necessity therefore." [682]

The law also requires that Congress receive 30 days' notice of any open-air testing of lethal agents.

allies. In December 1969, at the instigation of Sweden, the UN General Assembly voted on a resolution that declared, *inter alia,* that the use of "any chemical agents of warfare" was "contrary to the generally recognised rules of international law, as embodied in the Protocol".[52] The resolution was adopted with 80 votes in favour, 3 in opposition and 36 abstentions. The three countries to oppose were Australia (which at that time was employing irritant agents alongside US forces in Viet-Nam), Portugal (which has been accused of using CB weapons in its African territories[53]) and the USA. With the exception of the latter two countries, all members of NATO abstained. They either took no position on the substance of the resolution, or, as in the case of France, expressed support but abstained on procedural grounds. Since then, some polarization of NATO-country attitudes has become apparent.

France. The French abstention on the 1969 resolution was explained as follows:

> [T]he French delegation confirms that it is true that through Mr Paul Boncour in Geneva in 1925 ... France made it clear that the Protocol of 1925, in our view, was of very general scope. That is still our position. However, we have constantly maintained that the text of 1925 left no doubts on that point. For that precise reason, we do not think it is up to the General Assembly ... to give an interpretation of an international convention. Now, while favouring in substance that draft resolution ... my delegation will have to abstain in the vote on it [629].

A French military directive, *Instruction française sur les Armes spéciales* (11 May 1959), notes that use of all "gaz de combat", including irritant agents, is forbidden by virtue of "engagements internationaux" [687].

[52] For further details, see Volume IV, pp. 285–89.

[53] See Volume I, pp. 210–11. According to a spokesman for the Peoples Liberation Movement of Angola (the MPLA), two-thirds of the food cultivations in the MPLA-dominated territories of Angola were destroyed by aircraft herbicide (and napalm) operations during 1970–71 [684]. After visiting Angola, several foreign journalists have published reports of extensive combat herbicide employment; these have been collected together and publicized by the MPLA and its supporters [e.g., 685]. Most noteworthy among them are articles in the Swiss *Gazette de Lausanne* for 15 April 1971 and the West German *Frankfurter Rundschau* for 4 June 1971: both report interviews with (different) Portuguese field commanders in which the latter are said to have confirmed Portuguese employment of antiplant CW agents. Some degree of South African cooperation has also been alleged.

South African mercenaries are reported to have flown herbicide missions for the Portuguese during April and May 1972 over areas of Mozambique controlled by FRELIMO. One of the herbicides said to have been used was a South African manufactured formulation of 2,4-D. Details of these operations were disclosed to a British newspaper, purportedly by one of the mercenaries involved [686].

The Netherlands. In a speech to the UN General Assembly on 1 October 1970, the Netherlands Foreign Minister (now Secretary-General of NATO) spoke as follows:

My Government shares the concern that destruction of crops by chemical means for military purposes usually means great suffering of the civilian population. Moreover we are seriously concerned that large-scale use of herbicides and defoliants for military purposes might have ecological long-term effects of an unpredictable nature in man's environment. Therefore, in our opinion we should strive to establish a clear rule for the future which would exclude the use of those agents for warlike purposes.

He went on to speak of chemical irritants, but at that time his government's policy was still in a state of flux. A fortnight later, however, he included the following passage in a letter to Parliament:

The Government recognizes that the use of tear gases in warfare can in certain cases serve humanitarian purposes. Nevertheless, in the framework of international negotiations the Government is ready to take account of a majority opinion in the United Nations that considers the use for purposes of warfare of all biological and chemical agents—including tear gases—prohibited.

The Government will try to promote a consensus along these lines in order to ensure maximal effectiveness of the ban on the use of biological and chemical agents of warfare. Moreover, this pursuit of a consensus aims at enlarging the probability of achieving ultimately a worldwide agreement on a total ban on biological and chemical warfare agents. Against this, the possibility will be given up of using tear gases (which are not indispensable as military weapons) in armed conflicts with a view to saving lives.

In the Government's opinion, a comprehensive ban on the use of biological and chemical agents of warfare should apply to all armed conflicts in which armed forces are engaged in hostilities. On the other hand, such a ban should not apply to the use of tear gases for policing purposes as, for instance, the maintenance of law and order, where the saving of lives is imperative, regardless of whether such use for policing purposes takes place by the police, by military personnel or by forces of the United Nations [688].

Some of the substance of this statement was repeated by the Netherlands representative at the UN General Assembly on 5 November 1970 [689].

Norway. The Norwegian representative to the UN General Assembly spoke as follows in November 1970:

With regard to the question of chemical and biological weapons, our basic position is very clear: current international negotiations should aim at achieving an effective ban on the use of biological and chemical weapons and on their development, production and stockpiling, including a ban on the use in warfare of tear gases and herbicides [690].

In the following year, this position was stated more forcefully:

> My Government ... is of the opinion that a comprehensive ban on chemical weapons should establish beyond question that the use in warfare of tear gases and herbicides is strictly prohibited [619].

Canada. The Canadian Government statement of March 1970 quoted on page 187 above went on to say:

> Tear gas and other crowd and riot control agents are not included in this present commitment because their use or the prohibition of their use in war presents practical problems in relation to the use of the same agents by police and armed forces for law enforcement purposes which require detailed study and resolution [618].

Since then, however, the government has resolved its attitude. In November 1971 the Canadian representative to the UN General Assembly, stated that "tear gas and other riot- and crowd-control agents" had in the meantime "been given the most careful study by the Canadian authorities, and they have concluded that, as a contribution towards international agreement on the elimination of chemical warfare, Canada's reservations with regard to the use of these agents in war should be waived". He went on to read a communiqué from his government which reiterated Canada's no-first-use policy with regard to chemical weapons, and he stated that this applied "to all chemical ... agents whether intended for use against persons, animals or plants" [692].

West Germany. In the formulation of the 1954 Adenauer declaration that was incorporated into the revised Brussels Treaty, the CW agents whose manufacture the FRG thereby renounced were defined to include "irritant" and "growth-regulating" chemicals in excess of civilian requirements.[54] "Growth-regulating" was a term that had recently come into currency to describe the mode of action of herbicides such as 2,4-D and 2,4,5-T. As noted above, the West German Government continues to affirm its support for the Adenauer declaration.

The relevant West German military manuals draw attention to the illegality of using chemical weapons of any type in war, including (it must be assumed, in view of the Adenauer declaration), chemical irritant and antiplant agents. Thus, the Defence Ministry directive ZDv 15/10 of 1961, *Kriegsvölkerrecht Leitfaden für den Unterricht* (Teil 7), has this comment on the Geneva Protocol: "dadurch ist die Anwendung aller chemischen Kampfmittel verboten" [687].

[54] See Volume V, pp. 196–97 for further details of the definition.

The United Kingdom. Since 1930, the United Kingdom had taken the position that irritant agents came within the scope of the Geneva Protocol. However, in February 1970 the Foreign Secretary spoke as follows to Parliament:

> In 1930, the Under-Secretary of State for Foreign Affairs, Mr Dalton, in reply to a Parliamentary Question on the scope of the Protocol said: Smoke screens are not considered as poisonous and do not, therefore come within the terms of the Geneva Gas Protocol. Tear gases and shells producing poisonous fumes are, however, prohibited under the Protocol. That is still the Government's position. However, modern technology has developed CS smoke which, unlike the tear gases available in 1930, is considered to be not significantly harmful to man in other than wholly exceptional circumstances; and we regard CS and other such gases accordingly as being outside the scope of the Geneva Protocol.[55] [642]

Although the government adduced certain legal arguments in support of this interpretation (see Volume III, chapter 3), the ensuing parliamentary debate indicated that they were opportunistic ones designed to maintain freedom of action in the use of CS weapons in Northern Ireland [693–702], even though the Protocol did not apply there. An ex-Minister involved in the decision has since published his account of the events surrounding its elaboration and announcement [703]. The new British Administration has announced that it is reviewing its predecessor's interpretation of the Protocol [704].

On the question of antiplant CW agents, Parliament was told in March 1970 that "Her Majesty's Government have never regarded herbicides and defoliants as being covered by the terms of the Geneva Protocol" [705].

The United States. When the US Government submitted the Geneva Protocol to the Senate in August 1970, it also submitted a statement which contained the following passage: "It is the United States' understanding of the protocol that it does not prohibit the use in war of riot-control agents and chemical herbicides" [706–707]. This understanding met with opposition from the Senate Foreign Relations Committee, whose Chairman, after hearings had been held, referred the matter back to President Nixon in April 1971 in the following terms:

> The Committee asks therefore that the question of the Protocol be reexamined considering whether the need to hold open the option to use tear gas and herbicides is indeed so great that it outweighs the long-term advantages to

[55] Mr Dalton's and other government statements of the time on the scope of the Protocol are reviewed in Volume I, pp. 269–70. The discovery of the irritant properties of CS in 1928 is referred to in Volume I, p. 69. The physiological effects of CS are described above, on pp. 45–46.

the United States of strengthening existing barriers against chemical warfare by means of ratification of the Protocol without restrictive interpretations [708].

At the time of writing, the President has not yet responded.

Research and Development

Some degree of coordination between the CB R&D programmes of NATO countries is effected through the NBC-Defence Panel that is part of the NATO Armaments Group. This meets regularly, its members including CB R&D personnel from all NATO countries except Greece, Iceland, Luxembourg, Portugal and Turkey. France participates actively in it. One of its achievements has been to secure agreement on specifications for different classes of CB-defence equipment. For each class, one country is assigned the task of evaluating test methods for all newly developed items from Panel countries: CB protective clothing is the responsibility of the UK, for example, and respirators the responsibility of the Netherlands. There is also an NBC-Defence Panel (Long Term) that was set up in 1967 as part of the NATO Defence Research Group [709], but for the time being it is in abeyance.

Outside this particular framework, several bilateral and multilateral arrangements exist between NATO countries. For example, since 1958, the United States, the United Kingdom and Canada, together with Australia, have joined in a quadripartite Technical Cooperation Programme. This ranges over almost all non-nuclear areas of military technology, its main functions being to provide a channel for the exchange of technical information, and to identify possible subjects for joint R&D projects. Of its many sub-groups, Sub-Group E is concerned with CBW [709–711].[56] Another quadripartite venture between these same four countries, dealing less with research and more with actual hardware, is the ABCA Armies Standardization Programme. This was set up in 1964 to identify common military requirements and to promote standardization of equipments and procedures. Among its several committees is a Quadripartite Matériel Committee, which includes a CB Warfare Equipment Working Group [710–711].

Canada, the United Kingdom and the United States have long main-

[56] The 1971 meeting of the TCP Working Panel E-1 (chemical defence) was convened at Edgewood Arsenal in the USA to discuss R&D progress since the 1970 meeting (held in Canada). On the agenda were: a review of toxic, training, flame and smoke agents; field assessment and dissemination of chemical agents; prophylaxis and therapy of CW casualties; physical protection; detection; and decontamination [714]. The 1967 meeting was in Australia [709].

tained close liaison in CBW matters.[57] This has taken the form both of series of tripartite conferences [712] and some division of work between the R&D facilities of the three countries. The UK, for example, has relied heavily on Canada's CB test area [713]. Other forms of intra-NATO CB R&D cooperation include the letting of CB-related research contracts by the US Army to foreign laboratories,[58] and close liaison within the FINABEL countries.

The United States. The USA has spent nearly $1 500 million on CB R&D over the 27 years since the end of World War II. Table 3.3 sets out the year-by-year expenditures. Immediately after the war, the programme was funded at less than 5 per cent of the 1964 expenditure ($6 mn for fiscal year 1947 [715]), but it expanded substantially during the Korean War, a number of World War II R&D facilities being reactivated. The 1955 Miller Report (referred to on page 195 above) recommended a further expansion of the programme; so did a 1959 report from the Defense Science Board [1]. After initiating a series of service and inter-service studies on the matter, the Director of Defense Research and Engineering, Dr Herbert York, endorsed a large increase in CB R&D spending [1, 274].[59] Starting with the allocation of an extra $8 million from emergency defence funds in fiscal year 1960, and continuing with increased authorizations from Congress [274], a five-year graduated expansion plan was put into practice that more than quadrupled the size of the programme [429, 591]. The greater part of this was handled by the Army; as the Chief Chemical Officer described it during 1961 Congressional testimony:

> The Army has primary R.D.T.&E. responsibility within the DOD for CBR programs. It investigates CB agents, their possible use as weapons, their employment, defenses, and countermeasures. The Army Chemical Corps has been assigned the responsibility for detailed coordination of the CB R&D programs of the three services.
>
> The Army is responsible for developing, producing and servicing CB materiel and equipment for its own requirements and, as assigned, for the Navy, Air Force, Marine Corps and military assistance programs. It has also been assigned the responsibility to procure, store and issue CB munitions within the DOD. [429]

[57] See Volume I, pp. 118–20 and 293, for information on this cooperation during World War II.

[58] Thus, in 1969, both the Norwegian and the Netherlands National Defence Research Organisations had $0.15 mn US Army contracts for "gas and aerosol cloud diffusion studies" [717].

[59] In a newspaper interview in 1960, Dr York explained his reasons for supporting the Chemical Corps expansion plans. He had been particularly impressed by the possibilities of CB weapons, particularly incapacitating weapons, in "limited" warfare [718]. Recently he has described this as his biggest mistake during office as DDRE [719].

Table 3.3. Annual CB research, development, test and evaluation funding for the US Department of Defense, 1946–1973

Fiscal year[a]:	1946–57	1958	1959	1960	1961
Funding ($ mn)[b]	ave. 19[c]	37	38[d]	49	59
Service breakdown (percentages)[f]					
Army					
Navy and Marine Corps[g]					
Air Force[h]					
Activity breakdown (percentages)[f]					
Offensive studies					
Defensive studies					
Either[i]					
Category breakdown (percentages)[j]					
Basic research					
Exploratory development					
Advanced development					
Engineering development					
Test and evaluation					
Field breakdown (percentages)[k]					
Chemical warfare and defence[l]					
Biological warfare and defence[m]					
Either[n]					
Smoke, flame, incendiaries, etc.					

Notes and sources:

[a] 'Fiscal year' 1970 (for example) runs from 1 July 1969 to 30 June 1970.

[b] Actual or programmed expenditures. The 1963–69 figures were published by the General Accounting Office of the Comptroller-General of the United States [1471]; the others are taken from Department of Defense releases (1946–62 [1465], 1970–73 [1600]). Defense Department figures for FY 1963–69 are as follows: FY 63, $115 mn; FY 64, $126 mn; FY 65, $117 mn; FY 66, $115 mn; FY 67, $109 mn; FY 68, $89 mn; FY 69, $94 mn [1465]. There are often considerable variations in the published figures for CB RDT&E funding, due, no doubt, to different accounting methods, or to the inclusion or exclusion of certain programme elements (e.g., meteorological studies, or projects financed from emergency funds available to the Secretary of Defense [1463] or from the Southeast Asia support budget [1464]). Invariably excluded are the salaries of military personnel and the maintenance or construction of RDT&E facilities. The figures given here do not include the CB RDT&E expenditures by US government agencies other than the Defense Department.

[c] This is the annual average. The total expenditure for 1946–57 was $223 mn. The figures for FY 1945, FY 1947 and FY 1950 were $8 mn, $6 mn and $6.5 mn, respectively.

[d] $38.3 mn was in the President's FY 1959 budget for CB RDT&E; of this, it is reported that $17.4 mn was sought for CW R&D and $18.9 mn for BW R&D [669].

[e] The FY 1963 appropriation was substantially higher than the actual expenditure, namely $146 mn, of which the Army's share was 73 per cent [1468–1469]. Likewise, $158 mn was in the President's FY 1964 budget for CB RDT&E, the Army's share again being 73 per cent [1470].

[f] Calculated from actual or programmed expenditures, according to General Accounting Office figures, for 1963–69 [1471], and Defense Department figures for 1970–73 [1600].

But in the following year the new Director of Defense Research and Engineering, Dr Harold Brown, spoke of the deficiences of this arrangement:

The area of biological and chemical warfare has suffered many years from a lack of coordination between the Chemical Corps, doing the development, and the other parts of the Army, which would do the delivery, and still more lack of connection with the Air Force and the Navy which have until the

1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
79	122[e]	129[e]	119	114	101	87	90	68	64	60	53
	76	73	74	79	87	91	91	..	95	95	94
	9	13	13	8	1	4	4	..	3	3	4
	15	14	13	13	12	5	5	..	2	2	2
	48	44	43	44	44	41	34	23	19	27	27
	17	22	24	23	22	26	33	38	43	37	41
	35	34	33	33	34	33	33	39	38	36	32
							4	5	7	7	8
							43	50	58	55	52
							22	12	10	13	14
							11	11	5	7	7
							20	22	20	18	19
								55	59	63	67
								33	28	26	22
								9	10	7	7
								3	3	4	4

[g] The Navy had maintained a small CB RDT&E programme since World War II; in its FY 1962 budget this element doubled over the previous year to a level of about $6 mn [1475].
[h] FY 1962 was apparently the first year in which the Air Force sought CB RDT&E funds—$0.9 mn [1474–1475].
[i] Expenditures on basic research, on the exploratory-development 'general investigations', and on test and evaluation.
[j] Calculated from Defense Department figures for Army funding (appropriations for FY 1969 [1476], actual or programmed expenditures for 1970 [1476] and 1971–73 [1598]).
[k] Calculated from Defense Department figures for actual or programmed expenditure by all the service departments [1600]. See also note *d* above.
[l] Including RDT&E on irritant agents and herbicides. These accounted for 5, 6, 7 and 5 per cent of the total CB RDT&E funding for 1970, 1971, 1972 and 1973, respectively [1600].
[m] Since President Nixon's CBW policy statements in FY 1970, Defense Department spokesmen have stated that the "biological research" programme—as it is now called—is consistent with the new policy, no offensive BW RDT&E being performed. Originally, $3.96 mn had been programmed for biological-weapon R&D during FY 1970 [1479]; this was subsequently reprogrammed to a level of $3.5 mn (of which 17 per cent went towards antiplant weapons, 54 per cent towards incapacitating weapons and 29 per cent towards lethal weapons [1600]). The FY 1969 appropriations contained $3.2 mn for biological-weapon R&D [1472].
[n] Test-range safety and instrumentation. Not included are projects which are contained in either chemical or biological programme elements, but which are in fact relevant to both.

past year or so been unwilling to spend any money to do either development or procurement of delivery systems, munitions, bombs and so on, which could deliver the chemical and biological warfare agents [716].

Subsequently, both the Air Force and the Navy substantially increased their development (and procurement) programmes for advanced CB weapon systems.

The status of the Chemical Corps was altered during the 1962 Army re-

organization. Along with the other Technical Services of the Army, the Corps' RDT&E and procurement missions became fragmented within the new Army Materiel Command; and the Office of Director of CBR Operations was upgraded from Army Special Staff status to Army General Staff status [611, 658, 720], thereby accomodating another of the principal recommendations of the Miller Report. At present, the Director of CBR and Nuclear Operations is included within the Office of the Assistant Chief of Staff for Force Development [720]. The Chemical Corps did not entirely lose its identity during the process: in Congressional testimony, for example, and elsewhere, it continues to be referred to as though it remained a self-contained entity. The special schooling and personnel management of Army chemical officers contribute to this [658], and they themselves sustain a distinctive *esprit de corps* [721].

The CB R&D programme has shrunk somewhat since the 1960–64 expansion. During 1964–67, a major study of CB matériel requirements was performed for the US Secretary of Defense by the Army Combat Developments Command,[60] and this was followed in 1968 by an extensive reorientation of the R&D programme. In 1969, shortly before President Nixon's curtailment of the biological-weapon programme, Congress declined to authorize further funding for offensive CB R&D [722]. This stricture was subsequently relaxed.

At least 90 per cent of the CB R&D programme is conducted by the Army. The Navy's contribution was described as follows during 1969 Congressional testimony:

> The Department of the Army has the principal DOD responsibility for chemical and biological weapons and defense. The Department of the Navy utilizes information derived from the Army's program and maintains a relatively small technological effort of its own to explore those problems which are of unique Navy and Marine Corps interest. The [budget] element of chem/bio weapons and defense supports the development of air-launched, surface-launched and subsurface-launched BW/CW weapons and associated equipment with respect to safety, logistics, handling, stowage, delivery, new weapon concepts, and target analysis and effectiveness; and the development of detection devices and means to protect personnel, both collectively and individually, from environments both afloat and ashore contaminated by BW/CW agents. [723]

Some or all of the BW/CW weapons programme was terminated in 1969, however (after $11.7 mn had been spent since 1965 [1446]), and during 1972 Congressional testimony it was stated that the Navy was no longer doing any CB agent or weapon R&D [1594]. Much of the Navy's CW work had been conducted at the Naval Applied Science Laboratory at

[60] Project *Mandrake Root*. See pp. 326–327 below for further details.

Brooklyn, New York, but in 1970 this facility was scheduled for closure, the CW activity to be transferred to the Naval Weapons Laboratory at Dahlgren, Virginia [724–725]. Navy BW research has been performed for the most part at the Naval Biological Laboratory, which forms part of the Naval Supply Center at Oakland, California,[61] and by the Naval Unit at the Army's Fort Detrick facilities. The principal Navy facility for the test and evaluation of CB matériel is at the Naval Ordnance Test Station, China Lake, California. The Navy appears to be less concerned than the Army about full-scale field testing of CB weapons. As an Assistant Secretary stated to a Congressional committee in 1971:

> In most of the cases there are harmless organisms or chemicals that are sufficiently analogous that you can do field testing with the harmless organisms, having done laboratory testing with the real organisms [726].

The Air Force performs most of its CB R&D at the Air Force Armament Laboratory and the Air Proving Ground at Eglin Air Force Base, Florida [680, 1033]. It is reported that the Air Force also manages the CBW test area at Eniwetok Atoll in the Marshall Islands of the Pacific [727].

The principal Army CB R&D facilities are Fort Detrick and Edgewood Arsenal, both in Maryland, and the Dugway Proving Grounds in Utah. Fort Detrick used to comprise the commodity centre for biological agents, munitions and protective equipments of the Army Materiel Command. It conducted the greater part of the BW R&D programme (employing about 400 degree-holding scientists for this purpose, as of 1969) and was responsible for procurement of BW matériel from industry, from Pine Bluff Arsenal and from Rocky Mountain Arsenal. It also housed an Army Medical Unit, responsible to the Army Medical Research and Development Command and working specifically on medical countermeasures against biological weapons, a small Naval Unit, and Public Health Service and Department of Agriculture liaison offices [728]. In October 1971, following the closing down of the US biological weapon programme, President Nixon announced that part of Fort Detrick was to be turned over to the National Cancer Institute as a centre for contract work. The Detrick antiplant-warfare facilities[62] were to be turned over to the Department

[61] See Volume I, p. 121, note 45, for the early history of this establishment.

[62] Fort Detrick was the centre of the R&D programme supporting US armed services capabilities for antiplant CBW. During 1943–45, about 1 100 chemical herbicides were examined there as potential CW agents. After World War II, the development both of anticrop CBW agents and of chemical "vegetation control" agents (for use as

of Agriculture and the US Park Service. The Army medical unit, now called the Army Medical Research Institute of Infectious Diseases (AMRIID), was to be the only restricted access area to remain [738]. By July 1972, the National Cancer Institute had let $8.3 mn worth of contracts for work at Detrick [1596], and in the following month the laboratories received a visit from the Soviet Minister of Health [1597]. By this time the staff and budget of AMRIID had trebled over their 1970 levels [1598].

With the closing down of the biological commodity centre, nine of the Detrick civilian workers were transferred to the Dugway Proving Grounds [740], with nine military personnel to continue "a small classified effort on [BW] threat analysis" [1599]. Another 52, and 21 military personnel, together forming the staff of the Warning, Detection and Protection Laboratory, were transferred to Edgewood Arsenal [740]. This is the Army's Chemical Commodity Management Center, performing chemical RDT&E (as of 1969, using nearly 1 200 qualified scientists), organizing procurement of CW, flame and smoke matériel from industry and from the various Army plants, and preparing mobilization plans [741]. It also provides an army-wide radioactive waste disposal service [1599]. It is responsible to the

defoliants) continued at Detrick. By 1950, certain esters of 2,4-D and 2,4,5-T had been selected as the most promising military defoliants. The agent R&D programme ceased in that year, but during the Korean War both the Air Force and the Navy cooperated in tri-service R&D work on delivery technologies, the former developing and procuring a large-capacity aircraft spray-system (without actually using it during the conflict). In 1955 the stockpile of vegetation control agents was disposed of, and in 1960 the Air Force's large spray-system of the Korean War (the MC-1 *Hourglass* system) was declared obsolete. Agent R&D commenced again in 1954, a further 11 000 chemicals being screened between then and 1957, when work again ceased. Large-scale delivery and effectiveness trials were conducted at Camp Drum, near New York, in 1959. In May 1961, the newly created Advanced Projects Research Agency of the Department of Defense, commissioned Detrick to examine the technical feasibility of jungle defoliation and chemical crop destruction in Viet-Nam as part of *Project Agile*. As noted in Volume I, pp. 162–64, combat employment of these techniques began shortly afterwards. H-34 helicopters equipped with HIDAL spray tanks (see table 1.5) were used initially, together with C-123 cargo aircraft equipped with renovated MC-1 spray-systems. Agent *Purple* was used for defoliation (following its success during the Camp Drum trials), and agent *Blue* for crop destruction. Also procured for crop destruction (up to 1964) were the 2,4,5-T formulations code-named agents *Pink*, *Green* and *White* (*White* was subsequently used to designate a widely used picloram 2,4-D formulation). In 1962, a large R&D programme was again instituted at Detrick (and at the Air Force Armament Laboratory), with field trials being conducted at several sites in the continental USA, in Hawaii, in Puerto Rico and in Thailand, and with R&D contracts worth about $2 mn being let for agent research to 10 industrial concerns (in 1965, more than 80 per cent of the industry-performed R&D was being done by Monsanto Research Corporation, Pennsalt Chemical Corporation and Ethyl Corporation). By the end of 1969, Detrick had tested and evaluated 26 000 chemicals as potential vegetation control agents. Also being sought, from about 1967 onwards, were chemical soil sterilants that could also serve as defoliants [9, 729–737].

Army Munitions Command (MUCOM) which, together with the Test and Evaluation Command (TECOM) and the Supply and Maintenance Command, is part of the Army Materiel Command. Until 1966 Edgewood Arsenal had administrative control over Fort Detrick. It houses the US Army Environmental Hygiene Agency, the MUCOM Operations Research Group, and the Army Nuclear Defense Laboratory [742]. The latter is apparently a vestige of the old Chemical Corps radiological-warfare programme.[63] In July 1971 the Arsenal merged with Aberdeen Proving Ground, an adjacent TECOM installation (open-air testing of CB matériel has been performed there as well as at Edgewood Arsenal [195, 1602]), becoming one of the latter's tenant activities, and coming under the jurisdiction of its commanding officer. Its own commanding officer still retains command jurisdiction over Pine Bluff and Rocky Mountain Arsenals. [743, 1601]

Dugway Proving Ground was a mushroom growth of World War II,[64] created as a chemical- and flame-weapon test site in the Great Salt Lake Desert close by the Deseret Chemical Warfare Depot and the Tooele Ordnance Depot (as they were then called) [744–745]. It was reactivated in 1950, together with the adjacent Granite Peak Installation, a BW test site.[65] Together they formed the principal Army CBW test and evaluation facilities. In 1953 a major study of the "meteorological aspects of CB operations" was launched there [746]. After the 1962 Army reorganization, part of the test complex, all of which came under the overall supervision of the Army Materiel Command, was assigned to TECOM. The TECOM sector, which retained the designation Dugway Proving Ground, performed relatively small-scale testing of Army CBR weapons and protective matériel. It also ran a CBR Weapons Orientation Course for the Continental Army Command. The other sector was designated Deseret Test Center, with headquarters at Fort Douglas, and coordinated the CB testing of all three services. [658] In 1968, Dugway was merged into the Deseret Test Center [747], and in 1970 the headquarters of the expanded Deseret Test Center were transferred to Dugway Proving Ground [748].

US Army CB testing has been performed at several other locations both

[63] According to its 1959 Congressional testimony, the Chemical Corps "had determined the military feasibility of offensive radiological warfare, that is the deliberate use of radioactive pellets to contaminate an area" [274]. A year later the head of the Chemical Corps testified that "We feel the use of radioactive materials as a weapon has a very definite application. We feel we have proven the feasibility of the delivery of these materials" [443]. The RW defence R&D programme included fall-out studies and the design of dosimeters; a facility was established at Dugway to simulate the fall-out fields that might occur in nuclear war [274]. The fiscal year 1969 budget for the Nuclear Defense Laboratory was $5.7 mn [741].

[64] See Volume I, p. 276, note 9.

[65] See Volume I, p. 120.

inside and outside the USA. In some cases, different environmental conditions have been sought; in others, a larger test area has been needed, particularly in the case of BW trials. During the expanded BW programme of the 1960s, much of the testing of developmental biological weapons was done in the Pacific [749]. (When these tests were first mooted, they were opposed on the grounds, particularly, that migratory birds might carry pathogenic material away from the test zones and into populated areas. The Army then conducted much experimentation at Fort Detrick with many species of bird to demonstrate that this was improbable.) Aircraft spraytank delivery trials of BW agents, including toxins, and of simulants, have been conducted over Eniwetok Atoll [574] and Johnston Island. Entomological warfare (i.e., the employment of insect vectors to spread BW agents) problems have been studied in the field at Baker Island [292] and in the Hudson Bay area of Canada [611]. The TECOM Arctic Test Center at Fort Greely, Alaska, has been used for both chemical and biological weapon trials.[66] Other environmental test sites that have been used in the CB R&D programme include the TECOM Tropic Test Center at Fort Clayton in the Panama Canal Zone, Fort Huachucha in Arizona, and a forest site on the island of Hawaii [292, 1197]. In addition to these, several other sites have been used specifically to study the effects of different chemical or biological antiplant weapons. These include Department of Agriculture facilities in Texas and Puerto Rico [735], several Hawaiian sites used by the Department of Soil Science and Agronomy of the University of Hawaii under contract with Fort Detrick [730], the Pran Buri Defoliation Test Area[67] in Thailand [752], and the Fort Detrick sub-facility at Avon Park, Florida.

Other US Government and military agencies that have contributed to the CB R&D programme include the Office of Civil Defense [45]; the Agricultural Research Service of the Department of Agriculture (which has certain CB civil-defence assignments [753] in addition to its role in the herbicide-warfare programme [735]); the US Army Natick Laboratory [754], which continues the long-standing involvement of the old Army Quartermaster Corps in the development of protective clothing

[66] Fort Greely, which was established as an environmental test centre in 1949, has five test divisions, one of which is "Nuclear, Biological, Chemical and Special Projects" [751]. Its CW test activities sprang into prominence in January 1971 when it was disclosed that 200 weapons charged with VX had been mislaid there in 1966 at its Gerstle Testing Area [763]. Open-air tularemia studies were conducted at the Delta Creek area 30 miles west of Fort Greely during 1966–67.

[67] Fort Detrick's herbicide test programme in Thailand commenced in April 1963, in cooperation with the Military Research and Development Center of Thailand. The Pran Buri site was located on the Replacement Training Center of the Royal Thai Army [732].

[274]; the Army Atmospheric Sciences Laboratory, performing agent cloud-travel studies [1599]; the Army Surgeon-General, sponsoring work on CB casualty treatments [274]; and the various Army and Navy medical research units studying bird migrations and local infectious diseases in the Middle and Far East [755–761]. The Department of Agriculture's Animal Disease and Parasite Research Laboratory, set up in 1955 on Plum Island off Long Island, has long been rumoured to include BW work within its purview [764], but this has been officially denied [765]. (Since 1954, the Department of Agriculture has had "responsibility for research and development on defective aspects in the anticrop and antianimal [CBW] areas" [1603].) About a quarter of the total R&D programme is contracted out to universities and to industry.[68]

Table 3.4 collects together information on the major US CBW installations.

The United Kingdom. The British CB R&D effort is organized on a triservice basis by the Ministry of Defence. Within the Ministry, the Director of Research (Chemical and Biological)[69] is responsible to the Chief Executive, Procurement Executive (via a Deputy Controller to the Controller of R&D Establishments and Research) for research in aid of procurement for the armed services. He acts as the headquarters director for the Ministry CB R&D stations, which are located on Porton Down, near Salisbury in Wiltshire. Several specialised advisory committees, made up of people from industry, the armed services and the universities, are available for consultation and to make recommendations.[70] The greater part of the R&D is done at the Porton establishments but a certain amount of contract work is

[68] For further details, see below, p. 283. Involvement of US industry and the universities in the CBW programme has been reviewed in detail elsewhere [762, 766–767]. Some of the major contractees maintain substantial CB R&D facilities, including open-air test areas. One example is the Ashford Experimental Site of Cornell Aeronautical Laboratory, Inc., 35 miles from Buffalo, New York. According to a 1966 brochure from CAL, this was established "to provide a remote complex for conducting experimental research both in an Ordnance Laboratory and on the outdoor ranges ... Typical programs include ... development of instrumentation for cloud assessment ... [and] evaluation of defoliants ..." CB contract work has apparently been performed both within its indoor ordnance test chambers and on its 2.4 km² test area [768]. Contractees have also conducted large-scale meteorological studies using harmless CBW agent simulants; examples include the field trials of 1965 by Meteorology Research Inc., over Victoria, Texas, and of 1960 by Travelers Research Center Inc. over Fort Wayne, Indiana, both firms having Dugway Proving Ground contracts [769–770].

[69] Prior to the 1971–72 reorganization of the Ministry of Defence, the DR(CB) was called Director of Biological and Chemical Defence.

[70] Among these committees are the Chemical Defence Advisory Board and the Biological Research Advisory Board, which advise the two Porton establishments, and are part of the Advisory Council on Scientific Research and Technical Development (DSAC) of the Army Department of the Ministry of Defence [772].

Table 3.4. The principal US CB RDT&E, production and training centres

Establishment	Year established	Total fixed investment $ mn	Area *km2*	Total number of staff (during the year given in parenthesis)
RDT&E facilities[a]				
US Army Chemical Commodity Center, Edgewood, Maryland	1918	123	42	1 900 (1972)
US Army Biological Defense Research Center, Fort Detrick, Frederick, Maryland	1943	94		18 *(1972)*[b]
US Army Medical Research Institute of Infectious Diseases, Fort Detrick, Frederick, Maryland	(1953)	..	..	1 300 (1972)
Deseret Test Center, Salt Lake City, Utah	1942	> 33[c]	3 300	1 200 (1972)
Manufacturing facilities[d]				
Phosphate Development Works, Sheffield, Alabama	1950	>50	..	..
US Army Rocky Mountain Arsenal, Denver, Colorado	1942	105	74	800 (1964)
Newport Army Chemical Plant, Newport, Indiana	1958	14	..	300 (1962)
US Army Pine Bluff Arsenal, Pine Bluff, Arkansas	1941	136	60	1 800 (1966)
Training facilities				
US Army Chemical Center and School, Fort McClellan, Anniston, Alabama	1951	..	184	700 *(1966)*[e]

Notes:

[a] Some US Army CB RDT&E has been conducted at other locations. These include US Army Natick Laboratory, Massachusetts [754]; the Pitman-Dunn Laboratory at US Army Frankford Arsenal [1493]; the Army Medical Laboratory at Fort Meade, Maryland [1474]; the US Army Picatinny Arsenal, Dover, New Jersey [1599]; and US Army Aberdeen Proving Ground [195] (into which Edgewood Arsenal has now been incorporated). Much has also been performed in the facilities of industrial and university contractees. Other field-test sites for CB materiel, for example those in the Pacific and the various environmental test centres, are noted in the text.

The Navy and Air Force CB RDT&E centres are also noted in the text. These are smaller than the Army ones. The Naval Biological Laboratory at Oakland, California, had a total staff of 125 in 1961 [1494]. That of the Air Force Armamenta Laboratory at Eglin Air Force Base was 535 in 1969 [1495]; it is not known how many of these were involved in CBW work. The Air Proving Ground at Eglin AFB

Assignments	Literature consulted
Now a tenant activity of Aberdeen Proving Ground, but formerly the principal mission of a separate command, Edgewood Arsenal. Organizes RDT&E and procurement of toxic, smoke, flame and incendiary weapons and defences. Most of the Army's CW R&D is done here. Has two associated open-air ***testareas:Carroll*** Island (3.4 km^2) and Grace's Quarters (1.9 km^2). The BW Warning Detection & Protection Laboratory was transferred to Edgewood from Fort Detrick in 1971.	196, 740, 742, 1480-1481, 1598, 1601
Previously, the biological commodity management centre of the Army, organizing RDT&E and procurement of all types of BW agent, weapon and defence, together with RDT&E on chemical antiplant agents. Had a 1.6 km^2 open-air test area. These activities were closed down or scheduled for transfer to other establishments after President Nixon's actions in 1969-70 (see text for details).	728, 1480-1482,1598
"To develop workable medical defensive measures against biological agents," It will eventually be the only military research element at Detrick. USAMRIID is funded by the Army Materiel Command, with the Army Medical R&D Command responsible for its technical direction; it has another laboratory at Forest Glen, Washington DC. The Medical R&D Command had maintained a unit-the basis of USAMRIID-at Fort Detrick since 1953 as an element of the Walter Reed Army Medical Center.	728, 1483-1484,1598
Deseret Test Center is staffed by members of all the US armed services, under the direction of the Army Materiel Command, and performs all types of CB testing and evaluation for them at its Dugway Proving Ground. It houses the BW vulnerability-analysis team transferred froni Detrick in 1972. The US Army CBR Weapons Orientation Course is conducted at Dugway.	45, 744, 746, 1481, 1598
Otherwise known as Muscle Shoals Army Chemical Plant, it is a government-owned, contractor-operated factory for the nerve-gas precursor "di-di", situated in the TVA Wilson Dam Reservation. Now in lay-away status.	874, 876, 1485
Process R&D, production and storage of rocket fuels and toxic, smoke, and incendiary agents and weapons (and, formerly, of antiplant BW agents). Demilitarization of chemical munitions. Location of principal US sarin factory, in lay-away status since 1956.	876, 1481, 1486
Govamment-owned, contractor-operated factory for VX, in lay-away status since 1969. It also has facilities for loading VX into certain munitions. It is a part of the Newport Army Ammunition Plant.	876, 1487-1489
Prior to 1970, Its missions were process R&D for antipersonnel BW agents, and production and storage of antipersonnel biological, ***toxic,*** smoke and incendiary agents and munitions. Since then, the BW sector of the Arsenal has ceased operations, and is scheduled for conversion into a National Center for Toxicological Research, supervised by the Food and Drug Administration. The BW sector represented about $100 mn of fixed assets.	879, 887, 1490-1492
The headquarters of the Chemical Corps, and principal service school where CBR training is provided (for all services and for foreign personnel). Takes 4 000 to 5 000 students a year. Open-air facilities are available for weapon demonstrations and for the exercise of defensive procedures against toxic agents.	867-868

has a total area of I 870 km [1033]; the area available at the Naval Ordnance Test Station, China Lake, California, is not known.

[b] This is the figure for mid-July 1972. In 1969, Fort Detrick had a total staff of about 1 800 people, including approximately 400 in the unit that is now designated USAMRIID. In 1964, there were more than 3 000 workers.

[c] As of 1950. There has been more construction since then, and more equipment installed.

[d] In 1962, the US Army Chemical Corps controlled a number of other manufacturing facilities, all of which were government-owned, contractor-operated. These included the Niagara Falls Plant, for decontaminating chemicals; the New Cumberland Plant, for clothing treatment; the Marshall Plant at Natrium, West Virginia, for smoke chemicals; and the Seattle Plant, for filter material [886]. Absent from this 1962 liit were the following factories that had been included in a 1952 Chemical Corps organization chart: the Owl Plant, Azusa, California (a World War II cyanogen chloride factory); the St. Louis Plant; and the Vigo Plant, Terre Haute, Indiana (a World War II BW agent factory) **[885].**

performed by universities and by industry.[71] The total staff in the R&D establishments and at the headquarters directorate is about 1 250. The annual net funding for the CB R&D programme is at present between £3 mn and £3.5 mn [771]. CB civil defence work for the Home Office has been performed in the Defence Ministry's R&D establishments [628].

The R&D establishment now known as the Chemical Defence Establishment (CDE) Porton Down, was created in 1916, and has functioned continuously since then. In 1968 its staff included 70 scientific-degree-holding civil servants and 13 serving officers providing liaison with their respective services. Its operating budget was about £1.6 mn per year [628]. In 1921, following the 1919 report of the Holland Committee on the future of British CW organization, a second chemical R&D establishment was opened at Sutton Oak, near St Helens in Lancashire; its main task was chemical agent process R&D, and included the operation of pilot plants and the design of large-scale production plants. As noted above (page 190) it was removed to Nancekuke in Cornwall in 1951; in 1962 it was placed under the administrative control of the Porton establishment, and is now known as CDE Process Research Division, Nancekuke [640]. Its budget for 1970 was about £0.33 mn; its staff of 175 personnel included 25 qualified scientists [631].

Experimental work in the field of BW commenced in 1940 when a small team of workers was built up within the CW establishment at Porton.[72] In 1947, after a decision had been taken to supplement the *ad hoc* wartime approach to BW defence with more fundamental microbiological studies, an autonomous Microbiological Research Department was set up, and in the following year the construction of a large microbiological laboratory was begun on Porton Down. These facilities, which were completed in 1951, were designated the Microbiological Research Establishment (MRE) Porton Down [778]. The MRE budget for 1968 was about £0.9 mn, and the MRE staff included 48 scientific-degree-holding civil servants [628].

[71] In 1968, 23 CDE-related and 5 MRE-related contracts had been placed by the Ministry of Defence with 20 British universities and other places of higher education [773–775]. These contracts do not appear to have been at all large: the five MRE ones together totalled about £10 000 [628]. During an interview for a 1968 television programme, the director of CDE noted that his establishment "has close liaison with many firms who are doing their own research for pharmaceutical purposes, insecticides, and so on—we have very close liaison with them so that even the things that they reject for their commercial purposes, they probably tell us about" [776]. The V-agents, for example, first came to light by this means when VE was encountered at Jealott's Hill Research Station (the laboratories of the ICI subsidiary Plant Protection Ltd) around 1954 (see Volume I, pp. 74–75). The British LIDAR device seems to have been developed in cooperation with Laser Associates of Rugby [777].

[72] See Volume I, pp. 117–18, for further details.

Adjacent to the CDE and the MRE is the Ministry of Defence's Allington Farm, which provides laboratory animals, eggs and so forth for the two establishments and for the Army Vaccine Laboratory at Everleigh, Wiltshire (the David Bruce Laboratories). The farm also cultivates about 1 300 acres of the Porton range [779].

Field studies involving the open-air release of CBW agents or simulants are conducted at Porton, but only on a small scale in view of the limited area available (around 25 km² in all). When more space or other environmental conditions have been needed, foreign proving grounds have been used, for example those in Canada and Australia. Large-scale releases of inanimate BW-agent simulants have also been made off the north-west coast of Scotland in 1952 [780], in the Bahamas area of the Caribbean during 1954 [781–784], and over the west coast of the United Kingdom during 1957–58 [785]. It is reported that it was not until after the latter series of tests that Britain's vulnerability to BW attack became a matter of high-level concern [785].

Within the British CB R&D organization considerable importance is attached to liaison with its counterparts in allied countries. Commenting in 1968 on the information exchange arrangements with the US organization, the British Defence Secretary was reported to have said that they had provided "a great deal of knowledge of immense importance to our own defence against [CB] attack, which otherwise would cost us enormous sums to acquire for ourselves" [786]. It is not known how the US authorities view their side of the arrangement; neither is it known how much British CB R&D has contributed to the US offensive CBW capability.[73] There is a US liaison officer at Porton [628] and, until recently, there used to be corresponding British ones at the US establishments [e.g., 789]. In addition to the quadripartite arrangements with the USA, Canada and Australia, and the arrangement with NATO, the United Kingdom is involved in bilateral and trilateral agreements with specific NATO and WEU countries [628]. The FRG is not among them [790].

France. Very little has been disclosed in the open literature about the French CB R&D organization, and requests for information made of French officials by the authors of this study have not been productive.

Within the *Ministre des Armées,* the principal responsibility for CB R&D appears to lie with the *Délégation Ministérielle pour l'Armement* (DMA), in particular with its *Direction des Recherches et Moyens d'Essais*

[73] US standardization of agent CS around 1960 followed the development of the agent at Porton and its successful first employment in Cyprus in 1959 [787]. The manufacturing process used in the United States for VX is said to have been based on initial British process research [788] at Nancekuke.

(DRME), its *Direction Technique des Armements Terrestres*, both of which have sub-directorates concerned with chemistry and biology, and with its *Direction des Poudres*. A second chain of responsibility for CB R&D seems to lie through the individual service branches of the Ministry, namely the four *États-Major*; included among their responsibilities are the *Service de Santé des Armées* (SSA) and the *Service biologique et vétérinaire des Armées* (SBVA), together with the various training schools that handle CBW instruction [791].[74]

Under the heading "Aux études d'armement", the ground-forces section of the 1970 defence budget included NF 5 million for "études d'armes biologiques et chimiques" [792]. Specific CB R&D estimates are rarely isolated in the annual defence estimates put before the National Assembly, and this particular line-item presumably did not encompass all the French work planned for 1970.

French BW R&D activities appear to be divided between the SSA, the SBVA [621] and the DRME, laboratory work being conducted in facilities at Tarbes, in the Hautes-Pyrénées, at Le Bouchet, near Paris, and at Lyon [609, 793]. The Lyon facilities are constituted by the *Division de Microbiologie expérimentale* of the *Centre de Recherches du Service de Santé des Armées* (CRSSA).[75] Also at Lyon are the laboratories of the *Division de Chimie-Pharmacologie* of the CRSSA, where work is done on CW defence problems, technical liaison with the *Centre d'Études du Bouchet* of the DRME and with university and industrial laboratories being maintained for the purpose. One of the major missions of the CRSSA is the study of NBC defence problems, working in close coordination with DRME and other organs of the DMA. In all, it employs about 500 people, half of whom are scientists [793]. A number of reviews of its CB defence work have been published [794–796]; one of these is at pains to point out that the SSA work is purely defensive: "In view of its vocation, and the obligations of the Geneva Conventions,[76] the Service de Santé cannot contribute to the toxicology of aggression; its role consists essentially of the creation and development of effective therapeutics,

[74] Among these may be noted the Air Force's *Centre d'Instruction Spécialisé*, located on Base aérienne no. 120 at Cazaux, Gironde, which gives specialist NBC training [1393], and the Army's *Centre d'Instruction du Corps des Vétérinaires Biologistes des Armées*, at Compiègne, Oise, and *École Militaire des Armes spéciales* at Lyon [791].

[75] Responsible to the *Direction Centrale du SSA* under the *État-Major des Armées*. The old *Section Technique du Service de Santé* became the CRSSA in 1961 [793].

[76] This is an allusion, presumably, to the Oath of Geneva, a modernization of the Hippocratic Oath formulated in 1948 at Geneva by the World Medical Association: "... I will not permit considerations of religion, nationality, race, party, politics, or social standing to intervene between my duty and my patient ... even under threat I will not use my medical knowledge contrary to the laws of humanity".

and of the training of personnel charged with applying these treatments, including the combatants themselves." The author went on to describe the SSA training activities, which take in not only officers of the SSA, but also *Officiers AS* (armes spéciales) and personnel of the *Service Nationale de Protection Civile* [795].[77]

The division of DRME that is concerned with CBW is the *Section d'Études de Biologie et de Chimie,* which is based at the *Centre d'Études du Bouchet.*[78] The facilities here appear to be shared with the *Service des Poudres.* Related development work is done at Aubervilliers and at Toulouse, where there appear to be pilot-plant or other production facilities for nerve gases or their intermediates. The present location of the principal open-air testing ground for CBW matériel is not known. Until 1966 or so, the 5 000 km^2 test area at Beni Ounif in the Algerian Sahara,[79] designated *B II-Namous,* was used for this purpose. Prior to World War II, and therefore perhaps also after it, the *Polygone d'Entressen* in the Bouches-du-Rhône served a similar function.

The *Service des Poudres* is primarily concerned with the development and production of explosives and military propellants, including rocket fuels. It also has responsibilities for CW agents. It operates four R&D establishments and 13 factories, the Pont-de-Claix factory specializing in chemical armaments.[80] Of its R&D establishments, it is the one at Le Bouchet where most of the Service's CW-related R&D seems to be conducted; in addition, the factory at Saint-Médard-en-Jalles includes toxic agent test facilities. [625] The Service's journal, *Mémorial des Poudres,* regularly prints bibliographies of papers published in the open literature by its members,[81] and in the issue for 1962 it published one of the most

[77] The National Civil Defence Service is responsible to the Minister of the Interior. NBC courses are taught at the *École nationale de la Protection civile* at Nainville-les-Roches [795].

[78] For the early history of this establishment, see Volume I, pp. 112, note 37 and 290–91.

[79] For details of this establishment see Volume I pp. 273 and 291. After World War II and the occupation of Beni Ounif by the German Army, the testing of French chemical weapons and other equipments was resumed there, and continued after Algerian independence. It has been used by other NATO countries for the evaluation of defensive items, such as alarms, against CW agent challenges.

[80] On full production, this factory employs 1 700 workers. The factories at Angoulême and Sorgues, which were the principal World War II mustard-gas production centres (see Volume I, p. 291), are apparently no longer used to make CW agents [625].

[81] The published bibliographies covering the literature of 1952–64 listed 83 papers that had direct relevance to CW problems. Of these, 16 concerned the preparation and properties of sarin, of nerve-gas precursors and of other organophosphorus and carbamate anticholinesterase agents; 25 were pharmacological, toxicologial or therapeutic studies of anticholinesterase agents, hydrogen cyanide and sulphur or nitrogen mustards; 20 concerned other types of toxic agent including chloropicrin and its homologues, phytotoxins and zootoxins; and five concerned herbicides.

detailed European expositions of the technical aspects of CBW, both offensive and defensive [797].

West Germany. In line with current FRG practice concerning military research, all CB defence R&D is carried out by Defence Ministry contractees. Part of the work is done within university and industrial laboratories,[82] part of it is contracted out to the *Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V* [643]. The testing and evaluation of new equipments is performed in-house at Defence Ministry establishments, primarily at the *Erprobungsstelle der Bundeswehr für ABC Abwehr* ("E-53"), Munsterlager, on Lüneberg Heath [643, 798], and, to a limited extent, at the ABC Defence School facilities at Sonthofen in Bavaria. In 1969, the FRG spent DM 4.1 million on "chemical protection" [643], a figure which covered all CB defence research and development but not the in-house test and evaluation activities.

The *Fraunhofer-Gesellschaft* is a non-profit-making organization originally founded in 1949 to further the practical development of optics, but later expanded with Federal support to provide, *inter alia,* a means for coordinating and funding certain military R&D projects [643, 799–800]. In 1959 it set up its *Institut für Aerobiologie* at Grafschaft in Sauerland in order to provide the specialized facilities, unavailable elsewhere in the FRG, needed for certain CB defence-research projects.[83] Its activities, which came under the supervision of the Ministry of Defence, were conducted in strictest secrecy. This situation was relaxed somewhat soon after a change at the head of the FRG Defence Ministry. At the beginning of 1968 all employees—14 scientists and about 65 supporting staff [801]—were asked to sign a document containing the following passage:

By virtue of the Paris Treaties of 23 October 1954 the Federal Republic of Germany on 24 March 1955 acceded to the Brussels Treaty of 17 March 1948 (Bundesgesetzblatt 1955 II p. 256 et seq.). In those treaties it has undertaken not to manufacture atomic, biological and chemical weapons (Annexes I and II to Protocol No. III on the Control of Armaments) and agreed to supervision

[82] What purports to be a listing of these laboratories is given in the *Memorandum concerning the Biological and Chemical Armaments of the West German Federal Republic* prepared by the DRG Foreign Ministry and circulated at the UN General Assembly in October 1969 at the request of the Soviet Union [646].

[83] There were actually two elements at the institute—*IFA-1* and *IFA-2*—one concerned with CB defence and the other with nonmilitary aerosol work contracted to Fraunhofer-Gesellschaft. In addition to the Grafschaft Institute, there are several other research stations concerned with different fields of science and technology that are run by the Fraunhofer-Gesellschaft [802]. Of those of them that include CBW relevant research areas within their purview, it appears that only the *Institut für hygienisch-bacteriologische Arbeitsverfahren* in Munich, has performed CB defence contract work—a small, short-lived project to do with BW alarms.

by multinational WEU organs to ensure that such undertaking is observed. ... I have taken note of the facts mentioned above and of the provisions contained in Annexes I and II to Protocol No. III of 23 October 1954, and I hereby undertake to inform the authorities in case I should notice any failure in the Institute to comply with the aforementioned provisions or if I have reason to suspect such non-compliance.

Visits to the Institute have been made by the WEU Armaments Control Agency. It is officially stated that since 1967 all the research reports from the Institute have been published, and, according to the *White Paper 1970,* "security restrictions concerning the results of earlier research will be lifted". This was done in October 1970 [1593]. Publication has been made both in the scientific and technical literature and, since 1970, in the Defence Ministry's (unclassified) *Forschungsbericht aus der Wehrtechnik* ("BMVg-FBWT"). Regular listings and abstracts of Grafschaft publications in the scientific and technical journals are to be found in the *Mitteilungsblatt der Fraunhofer-Gesellschaft;* they are also to be found in the reports of the Federal Ministry of Science and Education, which, at the beginning of 1972, took over the supervision of the Grafschaft Institute from the Ministry of Defence. There is now a preponderance of nonmilitary research at the Institute, with defence contracts contributing only about one-third of its income. It received DM 1.7 mn for CB defence studies during 1971/72; DM 1.0 mn are allocated for 1972/73.

When reading recent official statements on the Grafschaft Institute, it is difficult to avoid the impression that during its early years, the relationship between some of its work and the borderline that distinguishes offensive research from defensive research must have been somewhat equivocal. At the best of times, this borderline is not easy to define, particularly at the level of basic research (as opposed to development). To an outsider ignorant of the actual objectives of research that he chances to observe, work that is in fact concerned with, say, evaluating a potential CBW hazard for purposes of developing defences against it may appear to be offensive work aimed at developing methods for creating the hazard. And in addition to this there is the added complication that certain civilian R&D activities, notably in the field of pest control, may resemble CBW agent development. These dualities may, of course, operate in the other direction: an outsider observing certain types of work that was being performed in support of a weapon programme might be led to suppose that it was defensive or *bona fide* civilian R&D. Likewise, the results of defensive studies may subsequently prove valuable in the design of novel weapons.

The problems of offence–defence and civil–military overlaps are dis-

cussed further in chapter 4. Given the suspicions that West German military activities tend to arouse, they may well have provoked some of the allegations that have been made about the *Institut für Aerobiologie:* a Grafschaft study of the toxic behaviour of soman [e.g., 803], say, may easily be construed as part of a nerve-gas weapon programme, just as a Bayer insecticide patent might if it included nerve-gas-like chemicals within its scope [e.g., 804]. By itself, scrutiny of the contents of such publications cannot provide conclusive evidence that the work described is or is not part of an offensive CBW programme; and it is possible to infer specific defensive or nonmilitary objectives from almost all the studies that have yet been published by Grafschaft, or by other sectors of the West German CB R&D organization. Suspicions of course grow when such inferences become difficult to make in the absence of supplementary information. Noteworthy here are the Grafschaft studies of the survival of micro-organisms at high altitudes [e.g., 805–806], which involved field observations of biological payloads disseminated from French *Véronique* rockets at the Hammaguir test facility in Algeria [806]. It was this type of work, or at least early rumours of it, that was a source of some alarm among Western scientists during the mid-1960s [807], to say nothing of their counterparts in Eastern Europe. The publicity given to the allegations made in December 1968 by Dr Ehrenfried Petras [645], a former worker at Grafschaft who had returned to East Germany during the previous month, provides an illustration of this.[84] However, the recent reorientation of FRG Defence Ministry policy towards the workings of the Institute, in particular its policy of openness, has done much to allay earlier misgivings.

Small quantities of CW agents and of potential BW agents are produced in academic and industrial laboratories in the FRG for nonmilitary research purposes, for example the mustard-gas congeners that are being studied as cancer chemotherapeutics. The rather larger amounts that are

[84] At a press conference organized by the DRG Ministry for Foreign Affairs, Dr Petras spoke at length about the Grafschaft institute, emphasizing the work done there on such things as the nerve gases and botulinal toxins. Afterwards, State Secretary Günter Kohrt stated that the speech had provided "irrefutable evidence ... that in the West German Federal Republic biological and chemical weapons are being systematically developed on the basis of long-term plans" [645]. However, a dispassionate and critical reading of what Dr Petras actually had to say, irrespective of whether it was true or false, indicates that so categorical a statement on the part of Secretary Kohrt would require a good deal more factual backing than it received. Dr Petras was one of three scientists transferring to the DRG within a week or two of each other after working in Western European research stations. One of the other two made comparable allegations about FRG nuclear-weapon plans. Western newspapers reported the allegations extensively; some of them carried speculations that the three scientists were part of a "blown spy-ring" [e.g., 808]; others reported Bonn officials as saying that the three departures were unrelated [e.g., 809].

needed to test and evaluate protective measures are imported from allied countries, samples of nerve gas being obtained from France and the United States, for example. These shipments do not generally exceed a few kilograms per year.

The Netherlands. The organization of CB R&D in the Netherlands resembles that of West Germany. Dutch government-sponsored applied-science research is directed through the Organization for Applied Scientific Research, known by its Dutch initials as *TNO,* set up in 1930. Of its five component bodies, one is responsible for defence research: the *Rijksverdedigingsorganisatie* (RVO-TNO), created in 1946. RVO-TNO is intimately coordinated with the Ministry of Defence but is not responsible to it, although most of its funding comes from the defence vote. It controls and finances five laboratories; of these, the study of CB defence problems, both civil and military, falls within the mission of the Medical Biological Laboratory and of the Chemical Laboratory.[85] These two establishments are now situated next to each other in the *Prins Mauritsgebouw* complex at Rijswijk, near Delft [810].

The Medical Biological Laboratory has a total staff of about 130 [810], and its basic subvention for 1970 from the Ministry of Defence was 5.285 million guilders [811]; about 30 per cent of this was allocated to CB defence work [812]. For the Chemical Laboratory, with a staff of 90, about 85 per cent of the 3.615 million guilders subvention for 1970 went towards chemical defence research [811–812]. Both laboratories maintain close liaison with industrial and academic research establishments.

Although none of the basic research performed at RVO-TNO is secret, some of the development work is, either because it makes use of confidential information provided by allied countries, or because it relates to the vulnerability of existing defences, or because it involves commercial secrets. The Chemical Laboratory published a detailed account of its current chemical defence R&D preoccupations in a leading Dutch chemical journal in 1970 [813], and bibliographies of its publications in the scientific and technical literature, and of those from the Medical Biological Laboratory, are contained in the RVO-TNO histories [814–815] and in the annual reports of the TNO [e.g., 811, 816].

Part of the CB development work is done in support of Dutch manufacture of CB defence equipments. Not all of the issued equipments are

[85] Formerly Dutch CW R&D was conducted in the Chemical Laboratory of the Netherlands Government Artillery Works and in the Central Laboratory of the Headquarters of the Commander-in-Chief of Army and Navy. The latter laboratory was evacuated to Imperial College, London, during World War II [814].

home-produced, however. The British CB Suit MkII, and the French 600-litre decontaminant (bleach) dispenser, for example, have been procured for the Dutch services, and one of the standard Dutch decontaminants is the US DS-2 composition. The Dutch-produced service respirator is soon to be replaced by a foreign model.

Canada. Although the Canadian CB R&D programme was cut back heavily in 1968, Canada has been very active in this area since the time of World War II. The early stages of the programme are described briefly in Volume I of this study (pages 118–119). In 1944, the Director of Special Weapons and Vehicles in the Canadian War Office wrote: "For various reasons, the contribution which Canada has made to chemical warfare in all its facets has been out of all proportion to the contribution that could rightly have been expected from the Dominion" [817]. Much of this was due to the unique (for the Western Allies at that time) test facilities at Suffield, Alberta. These were set up as a joint Anglo-Canadian venture in 1941, after the loss of the French proving-grounds in Algeria [818]. Canada continued to make a major contribution to Western CB R&D efforts after the war; writing in 1958, the historian of the Canadian Defence Research Board (DRB)—which administers the programme—stated:

> Much of the work done at Suffield, of course, is of a classified nature, for the facilities of the establishment have been used very freely by both of Canada's major allies. In 1950, for instance, after a lapse of some years, most of the field trials of chemical warfare agents which were being conducted in the free world were done at Suffield. Throughout 1952 the chief emphasis at Suffield was on the testing of CW ammunitions for both the United Kingdom and the United States equipments. A new type of dynamic bursting chamber was constructed in this same year for the testing of BW ammunitions. [819]

Defence Research Establishment Suffield (DRES) has nearly 4 000 km^2 available for field-testing [820]. Some of its activities were described in remarkable detail in a 1967 press interview given by Mr A. M. Pennie, Deputy-Chairman of the DRB, and a former Chief Superintendent of the establishment [713]. British funding for it ended in 1946 [818]. During autumn 1968, it was the venue for *Exercise Vacuum,* a large-scale manoeuvre in which 1 500 Canadian, US and British troops exercised their protective countermeasures against CW attacks simulated with CS and other devices [292, 821]. In addition to nuclear defence studies, DRES is at present responsible for all of the Canadian BW defence effort,[86]

[86] The principal Canadian BW research stations at the time of World War II were Kingston Laboratory, a part of Queen's University, concerned with antipersonnel BW, and the War Disease Control Station on Grosse Ile, Quebec, concerned with anti-

and for those CW defence studies that concern medical countermeasures and hazard assessments [822]. The remainder of the chemical defence R&D effort is performed at another DRB station, the Defence Research Establishment Ottawa (DREO), located at Shirley Bay, Ontario. In addition, publications from the Defence Research Medical Laboratories at Downsview near Toronto (now known as DRET—Defence Research Establishment Toronto) have occasionally touched on chemical-defence-related topics [e.g., 823–824].

Some field-testing of Canadian CB defence equipments has been conducted outside the DRES. In 1967, for example, the NBC collective protection system fitted to certain Canadian naval vessels was evaluated against a simulated BW agent challenge at sea, off Vancouver Island [709]. As noted earlier, Canada cooperates actively with Australia, the United Kingdom and the United States in the quadripartite Technical Cooperation Programme; it also participates in the NATO NBC Panel. A possible bilateral collaboration with France in CB R&D was being discussed in 1967 [709].

The Canadian Government has emphasized that its CB R&D studies are purely defensive in their objectives [617]. Bibliographies of unclassified publications deriving from them are contained in the annual reports of the Defence Research Board, but only those up to 1968 [709, 825–826].[87] In 1968 the DRB undertook a major review of all its R&D programmes, after which the resources devoted to CB defence research were halved [617]. For 1972 the DRES had an operating budget of about Canadian $4 million for a total manpower strength of about 200, 34 of which are professional scientists. Of these resources, about 6 per cent are allocated to BW defence and 33 per cent to CW defence. The DREO has an operating budget of $3.9 million for a total staff of about 200, 60 of which are professional scientists; 18 per cent of these resources are devoted to CW defence studies [827].[88] In addition, the DRB includes CB defence studies in its grants-in-aid to universities; for BW defence, there were six such

animal BW. In 1955, the Harkness Committee report on the DRB's BW programme recommended various reorganizations, together with a restriction of the programme to purely defensive studies [818]. In the following year, the Kingston Laboratory was merged (administratively, not geographically), with the Defence Research Chemical Laboratories at Shirley Bay (subsequently designated DCBRE and then DREO), and in 1960 all its BW activities were transferred to Shirley Bay. In 1958 the Grosse Ile establishment was turned over to the Department of Agriculture. All BW studies were concentrated at DRES in 1968.

[87] Thereafter the bibliographies were included only in the annual reports of the establishments concerned; these are classified.

[88] One major item developed at DREO, announced in 1969, is a new form of CW protective clothing, described as a "second generation system" [709]. It is regarded by some NATO authorities as the best protective clothing yet available.

grants in 1969 worth about $53 000 in all [822]; and for studies related to CW defence there were 19 grants in 1968, worth about $0.12 million [826].

Other NATO countries. It has not proved possible to obtain much information about the CB R&D organizations of other NATO countries. Norway maintains a Defence Microbiological Laboratory in Oslo [828], and a number of chemical defence-related studies (for example, on zootoxins [829], on nerve-gas therapy [830–832] and on aerosol behaviour [833]) have been published from the Norwegian Defence Research Establishment at Kjeller. The Danish Civil Defence Analytical-Chemical Laboratory in Copenhagen has published a comprehensive review of the literature on cholinesterase reactivators and other nerve-gas antagonists [834]. The Belgian Army maintains a laboratory within the ABC Establishment of its Centre of Military Studies at Vilvoorde from which several important studies of chemical defence problems have been published [e.g., 835–836], including one of the earliest open publications on V-agent toxicology [837].

Capabilities in CBW defence

CB defence of the civilian population

Little information is available about the arrangements for CB protection that have been incorporated into the civil defence planning of NATO countries. In the USA, where the civil defence organization is in any case not so highly developed as it is in certain European countries, the probability of counter-civilian CBW attack is judged very low. CB filters are apparently not built into the existing US shelter systems [438]. A civilian respirator has been designed, but not procured on any scale, and there is apparently no stockpiling of vaccines or medicaments for the treatment of civilian CB mass casualties [45]. In the United Kingdom, the civil defence organization has been cut back almost to the point of extinction; a substantial, but ageing, residuum is left from earlier days in the form of capital constructions, stockpiling and the training of specialized cadres [838]. The development of new civilian CB protective equipments, such as respirators, continues, however [839]. Greater preparedness is maintained elsewhere in Europe. In France there is an active central and regional organization in which close attention is paid to CB countermeasures [840–841]. In West Germany, where there is a Federal Office for Defence of the Civilian Population, responsible to the Ministry of the Interior, new civil defence legislation is pending [842]; the organization of the *LS-ABC-Dienst* has been described in detail in civil defence publications [e.g., 843].

CB defence of military units

As there are substantial similarities among the military CB defences of the different NATO countries, only those of West Germany are described here. The following account draws principally from the *ABC-Schutzfibel* published by Verlag Offene Worte, Bonn [299–302], and from articles in West German military and civil defence journals [843–849]. It is to be noted that the US Army runs a series of CBW training courses that are attended by CB specialist officers from other NATO countries, and which include instruction in CB defence.[89]

Organization. There are two principal elements in the CB defence organization of the Bundeswehr. The first, the *ABC-Abwehr aller Truppen,* covers the arrangements made within each and every branch of the army for its own CB protection. The second, the *ABC-Abwehrtruppe* (NBC-Defence Troops), is a separate arm of the Bundeswehr responsible for specialized CB-defence duties. (As their designations indicate, these two elements are also concerned with protection against the effects of nuclear weapons.) The organization is thus based on army-wide dissemination of expertise in the basic CW defensive countermeasures augmented by the skills of specialist CB defence units. The following examples show how this is put into practice.

Attached to each division of the Bundeswehr (until recently to each brigade) is a company of NBC-defence troops, at the disposal of the divisional commander. The company has two principal duties: to reconnoitre for CBW-agent contamination in the event, or in the supposition, of CBW attack (or radioactive fallout following nuclear attack), and to establish and operate a central decontamination area, known as the *Haupt-E-Platz* (HEP; the *E* stands for *Entstrahlung, Entseuchung* and *Entgiftung).* The company, which on war-footing comprises 147 men, is divided into two platoons, one having responsibility for personnel decontamination at the HEP, and the other for decontamination of equipments and vehicles.

As for the *ABC-Abwehr aller Truppe* organization, each combat platoon incorporates a small NBC-defence unit, designated the *ABC-Abw-Trp,* in addition to the complement of individual protective equipments and skills of each soldier. This unit comprises a non-commissioned officer and three men. Its principal function is to perform CBW agent reconnaissance within the platoon's area of operations, but it may also be assigned to decontamina-

[89] *Turkey* took up 25 places on these courses during 1955–65; *Italy,* 7 during 1952–62, *Greece,* 24 during 1955–68; *Norway,* 7 during 1956–63; *Denmark,* 9 during 1952–64; *Belgium,* 2 during 1966–68; *West Germany,* 56 during 1956–69; *France,* 3 during 1955–56; *Canada,* 12 during 1953–68; and the *United Kingdom,* 13 during 1963–70. These courses also cover offensive CBW instruction [850].

tion duties, for example at the battalion decontamination area. For the latter purposes, each battalion commander has a four-man decontamination squad at his disposal, which has responsibility for setting up and operating a local decontamination area, the *Truppen-E-Platz* (TEP). TEPs are intended to provide emergency decontamination facilities for use prior to more rigorous decontamination at an HEP. In addition to these CB defence units, the battalion has further CB defence personnel in its service and repair unit, and on its staff. A mechanized battalion on war-footing will have up to 76 men whose duties are wholly or partly concerned with NBC defence.

An additional battalion of NBC-defence troops, comprising three companies, is available to each army corps commander. Like those at division level, each of these NBC-defence companies is organized into two platoons, but each platoon is twice as large, being divided into two personnel-decontamination groups and two equipment-decontamination groups, instead of into one of each. This allows for the establishment of six corps HEPs, in addition to those at division level. This arrangement permits rapid concentration of expertise and special facilities in areas most afflicted by CBW attack.

Training. The Bundeswehr allocates a considerable amount of time to CB defence instruction during its training programmes, and the instruction given is regularly put into practice on field exercises and manoeuvres.

The basic training period of a recruit lasts for three months. In the course of this time he will receive 20 hours of instruction in CB defence, learning how to take cover when under CBW attack and how to use and look after his respirator and the other items of protective equipment with which he is to be issued. Starting from the sixth week, his schedule will include an 'NBC-day' every other week in which he will participate in NBC-defence exercises, practising, for example, the procedure to be followed after the CBW alarm, during transit across contaminated ground, or when under fire from chemical weapons. Irritant agents, and simulant agents capable of triggering CBW agent detectors, are widely used to confer realism to these exercises.

NBC-days continue after the basic training period and through the professional training period of the following four months. During this second phase, the recruit will receive a further 40 hours of NBC-defence training. Recruits into the medical services will receive 90 hours.

During the eighth to the eighteenth month the recruit will be training with the unit to which he has been assigned. If he is in a platoon ABC-Abw-Trp, he will get another 142 hours of NBC-defence training. The training of the ABC-Abw-Trp personnel concentrates on the techniques for using the detection and decontamination equipment with which each

such unit is supplied; they are also taught TEP duties. Recruits assigned to the NBC-defence companies and battalions receive more detailed training from their own officers within the framework of the brigade (or higher unit, as the case may be).

The core of the Bundeswehr NBC defence training programmes is the *ABC- und Selbstschutzschule* (ABC/SeS) at Sonthofen. Here the training courses are worked out, the NBC-defence manuals are written and the cadres of NBC-defence personnel receive their instruction. The school runs special courses to be attended by all non-commissioned officers having NBC-defence duties at company level or TEP responsibility at battalion level; by all officers of the NBC-defence troops; and by all battalion NBC-defence equipment mechanics.

Equipments. The individual CB protective equipments issued to each soldier comprise a respirator (the *ABC-Schutzmaske 62*); a small first aid kit containing decontaminants, protective ointment and bandages; an auto-injector containing nerve-gas antidote (the *Atropin-Spritzampulle*); and a set of disposable protective clothing comprising an impermeable coverall, sock-like leggings and gloves. The coverall, the *ABC-Schutzplane*, is a large ground-sheet that can be thrown over the body.

For each platoon there is an issue of special NBC-defence equipment for the ABC-Abw-Trp. This includes a set of manually operated CW-agent detectors comprising an air-sampler and tubes of colour reagents, together with powders of colour reagents for detecting ground contamination, and containers for soil and water samples. It also includes special protective clothing for the four ABC-Abw-Trp personnel (trousers, shirt and hood, to be used with rubber boots and gloves). The decontamination equipments to be used by the ABC-Abw-Trp are included within company stores, together with reserves of individual protective equipments for all company personnel.

The matériel needed to operate the battalion TEP comprises a shower and shower tent, a water heater, a mechanized water/decontaminant sprayer fitted with hoses for cleansing vehicles, a warm water sprayer, a water tank, and bulk stocks of decontaminating agents. All this is transported in the battalion decontamination squad vehicle. Also supplied to each battalion are equipments for testing and repairing CB protective items.

In contrast to the US Army, for example, collective CB protective field shelters do not form part of the *ABC-Abwehr aller Truppen*; nor are they supplied to the *ABC-Abwehrtruppen*. However, all combat vehicles such as tanks and armoured personnel carriers can be made air-tight and are fitted with CBW-agent filters; their occupants can thus be

protected from a CB environment without having to wear respirators or protective clothing.

The CB protective equipments issued to the NBC-defence companies and battalions are similar to those described above, with certain augmentations. The most important of these are the extra supplies needed for the HEPs. These include a variety of sophisticated heavy-duty equipments, for example, large generators for steam and decontaminant aerosol for the rigorous decontamination of matériel. They also include large tents within which personnel decontamination can be performed. The CBW-agent detectors of the NBC-defence units are manually operated; in contrast to the US Army, for example, automatic detectors are not yet in issue.[90]

Tactics and techniques. The basic requirements made of an effective CB defence in the field are twofold: that immediate CB casualties be minimized, and that the residual effects of CBW-agent contamination be neutralised with the minimum of delay. In the Bundeswehr, as in all other armed forces where the possibility of CBW attack is taken seriously, the first requirement is met by general issue of individual protective equipments and careful training in their use, backed up by an army-wide detection and warning system. The latter follows NATO standards. If CBW agents are encountered in the field, the fact is immediately transmitted to the *ABC-Melde-Stelle* (AMS) at brigade headquarters and from there to the *ABC-Melde-Zentrale* (AMZ) at division/corps level, and upwards to the *Leit-AMZ* (*LAMZ*). A general CBW alert is then issued. Local NBC-defence companies provide additional reconnaissance. The alarm may be given visually where necessary by means of purple smoke rounds.

The second requirement calls for decontamination arrangements that will restore the combat efficiency of afflicted fighting units within the shortest possible time, but which will impose only a small logistical burden when not needed. The approach adopted in the Bundeswehr is to make each combat battalion organically capable of performing its own preliminary decontamination at short notice, and having the special NBC-defence companies available to provide supplementary decontamination facilities where they are most needed. The initial responsibility for decontamination thus rests with the unit that has come under attack. For this purpose, the individual soldier is trained and equipped for decontaminating his person —if he can—within seconds or minutes of the attack; drivers have to decontaminate critical areas of their vehicles—door handles, controls, and so forth—at the earliest opportunity; and all available personnel will be expected to cope with the rough decontamination of their unit's most

[90] L. Scheichl has recently published an account of some of the R&D work being done in the FRG on automatic CBW agent detection equipment [851].

important weapons and other equipments. More rigorous decontamination has to wait until the unit can be withdrawn to the battalion TEP. Here, contaminated personnel take shower baths and change their clothing. Equipment is swabbed or washed down with water, where appropriate, and/or treated with one of the several different decontaminating agents maintained for the purpose. Vehicles are spray-scrubbed with water and then moved on for final decontamination to the HEP, where they are steam treated, sprayed or dusted with decontaminant and then, after a 15 minute wait, washed down with high pressure water jets. The generous allocation of vehicles and heavy duty equipments to NBC-defence duties is intended to facilitate the rapid establishment of decontamination facilities close by stricken areas.

Capabilities in CBW offence

Organization and training. As noted earlier, the United States and perhaps also France are the only NATO countries to stockpile CB weapons. No information is available on whether other NATO countries have access to these stockpiles.[91] US chemical weapons are stored in the continental United States,[92] in West Germany (see above, page 192) and on Johnston Island in the mid-Pacific.[93] US officials have denied rumours that any are stored in other overseas locations (e.g., South Korea, the Philippines,

[91] Some information is available on past contingency plans for issuing US nuclear and CB weapons to friendly foreign partisan units operating behind enemy lines in the event of "unconventional warfare" operations being conducted during a European war. This came to light in 1969 when several Western European journals received anonymous letters containing a photocopy of parts of an operations plan prepared at the headquarters of the US Army Special Forces Group in Europe, and classified top-secret [861]. Official US sources are subsequently reported to have confirmed that the contingency operations plans were genuine, but long since obsolete [862]. They are thought to have been prepared around 1962.

[92] At the Army Ammunition Depots at Anniston, Alabama; Richmond, Kentucky (the Lexington-Blue Grass AAD); Hermiston, Oregon (the Umatilla AAD); Tooele, Utah; and Pueblo, Colorado [727, 1394–1395]. Toxic storage facilities are also available at Edgewood Arsenal, Rocky Mountain Arsenal and Pine Bluff Arsenal. No information is available about the dispositions of US Navy and US Air Force chemical weapons. Prior to its destruction, the antipersonnel BW-agent stockpile (part bulk agent and part filled into munitions) was at Pine Bluff Arsenal; antiplant BW agents, none of which were loaded into munitions, were stored at Fort Detrick, Rocky Mountain Arsenal and, temporarily, at Beale Air Force Base, California [863].

[93] They were moved there from Okinawa during January–September 1971 following a fierce public outcry from Japan when the existence of the weapons on Okinawa (at Chibana Ammunition Depot) was disclosed in 1969 after a storage accident involving 24 US personnel [864]. The stockpile seems to consist of about 13 000 tons of weapons containing 4 320 tons of CW agents [865]: 2 865 tons of mustard-gas weapons, 8 322 tons of sarin weapons and 2 057 tons of VX weapons [866]. The last shipment of chemical weapons to Okinawa seems to have taken place in 1963 [855]; the first presumably at the end of World War II or during the Korean War.

Taiwan or South Viet-Nam [852–855]) apart from irritant-agent weapons and herbicides [856]. British officials have stated that there are no US CB weapons in the UK [857].

In the French armed services, CB weapons are classed together with nuclear weapons as *armes spéciales* (AS). The organization and training of specialist personnel for their employment and for the defence against them is conducted through special AS channels administered by *officiers AS* [1392]. The Army's *Ecole Militaire des Armes Spéciales* at Lyons, referred to earlier, was founded in 1956 and "is charged with scientific and technical instruction for the use of NBC weapons and protection against them" [791].

In the US Army, chemical weapons (other than irritant-agent ones) are handled by the same "special ammunition" units that are responsible for nuclear weapon supply [42, 858–860]. All US Army personnel receive some measure of CBW training, both offensive and defensive, the central training school being at the US Army Chemical Center and School at Fort McClellan, Alabama.[94] Instruction in offensive chemical operations is included within the basic combat-training phase of US soldiers, and selected personnel in units below divisional level are required to receive further chemical operations training [42]. As of 1968, the US Army had 5 300 officers and enlisted men assigned to chemical duties; in addition to those at the R&D and manufacturing installations, they constituted one chemical battalion, seven chemical companies, four chemical platoons and 31 chemical detachments [869].[95]

In the field, chemical operations are organized through the Chemical, Biological and Radiological Element (CBRE) of the tactical operations centre at divison, corps or army headquarters. The mission of a CBRE is to "coordinate chemical ... operations with other support operations,

[94] The US Army Chemical School at Fort McClellan offers advanced training in most aspects of CBR warfare and defence to members of all the US armed services and to foreign military personnel. The establishment is the repository for Chemical Corps historical documentation. The US Navy maintains a training unit there, and it also accommodates liaison officers from the US Air Force and the US Marine Corps. Fort McClellan also houses the US Army Combat Developments Command CBR Agency, whose mission is to formulate and document CBR doctrine for the Army, including the determination of future CBR organizational and matériel requirements [867–868].

[95] As of 1961, a typical Chemical Company (Combat Support) comprised nine officers and 237 enlisted men, organized into six platoons. It was assigned to a field army and attached to a corps. Each platoon was intended to support a division, under the control of the divisional chemical officer. At that time, there were about 5 400 military and 8 400 civilian personnel in the US Army Chemical Corps; together they constituted about 1 per cent of the US Department of the Army establishment [591]. As of 1967, chemical specialists would amount to about 1.2 per cent of the total strength of a field army [42].

to predict fallout resulting from the employment of nuclear weapons by friendly and enemy forces, and to evaluate and disseminate chemical, biological and radiological contamination information". A divisional CBRE is operated by personnel from the division chemical staff section with attachments from the CBR element of the appropriate TOE team. Ten is the specified minimum number of people required for 24-hour operation of the CBRE. The CBRE is also responsible for ensuring supplies of chemical ammunition [296].

Equipments. No information is available on the CB weapons, if any, currently available to the French armed forces.

In the United States, chemical munitions are available for most of the weapon-delivery systems deployed by the armed services. The biological-weapon stockpile is being destroyed. Table 1.5 (pages 82–89 above) provides information on some of the US CB weapons that have been standardized or under development over the past thirty years; and tables 2.2 and 2.3 (pages 127–129) give details of the standardized CBW agents. It is not known to what extent the armed services of other NATO countries are trained in the use of this ammunition. As regards the United Kingdom, it may be noted that the M-34 sarin cluster bombs of the US Air Force were fitted with a second set of holding-lugs that matched the bomb-release mechanisms of British aircraft [870] (these bombs were manufactured at a time when the United Kingdom maintained an offensive CW capability of its own); and in evidence before a Parliamentary Select Committee, the Director of CDE agreed that his establishment was capable of advising British forces on how to use offensive CW "equipment already in possession of others", provided the forces had the complete weapon system available to them [628]. According to *The Times* (London), 12 British Army officers visit Dugway each June for an annual course designed to keep US Allies up to date in CBW developments; lessons learned there are then relayed to the British NBC School at Winterbourne Gunner, near Porton [871].

As regards the size of the current US chemical-weapon stockpile, it was noted earlier that at the close of World War II, the USA had manufactured about 135 000 tons of CW agents. The greater part of this has now been destroyed, dumped at sea, or otherwise disposed of, for all the World War II agents are now regarded as obsolete. By 1969, less than half of the mustard gas was said to remain, and this is now scheduled for burning at Rocky Mountain Arsenal [872–873]. The remaining stocks of phosgene, about 3 500 tons, were sold to industry in 1969 [53]. The nerve gases sarin and VX are the dominant agents in the present arsenal. In 1956, while stocks of the former were being built up, a Chemical Corps officer published the following account:

In view of the international situation, accelerated action was taken in 1950 to obtain an additional degree of preparedness in chemical warfare. The Chief Chemical Officer was given full responsibility for the expansion of the country's nerve gas capability[96] and was authorised to take necessary steps to obtain immediate positive results. Funds for initial design, engineering and construction were furnished from contingency monies available to the Secretary of Defense [874].

Most of the sarin was made at Rocky Mountain Arsenal near Denver, Colorado (the "di-di" precursor being produced at the Phosphate Development Works in Alabama, now designated Muscle Shoals Army Chemical Plant) from 1954 through 1956. Some of the output was filled into aircraft bombs and artillery shell as soon as it was made, but the greater part was stored in bulk, ready for emergency weapon-filling or for loading into the many new types of nerve-gas munition that were being developed.[97] Full-scale VX production commenced in April 1961 at Newport Chemical Plant, Indiana, and lasted until June 1968 [876]. At the present time, the nerve gas production centres are in layaway status [876]. A Department of Defense official has stated that it would take 8–9 months to put them back into production [878]. Table 3.5 sets out the year-by-year fundings for US procurement of CBW matériel.

In June 1969, a Department of Defense official stated that about three-quarters of the CW agent stockpile was stored in bulk and one-quarter in filled munitions, and that about half of the total stockpile comprised mustard gas and the other half nerve gas [45]. It was said to be sufficient for 12 months of fighting [877]. From this and other indications, one may estimate that there are around 15 000 to 30 000 tons of nerve gas in the stockpile.[98] Chemical incapacitating agents do not form a large part of the stockpile. Around 10 tons of bulk agent BZ were on hand in 1969 [45].

[96] At that time, probably comprising little more than 1 000 tons of imported German tabun [875].

[97] One of the most heavily manufactured of the new weapons was the M-55 rocket for the 115 mm 45-tube multiple rocket launcher M-91. $31.5 million was authorized for procurement of these in 1960 [881], enough to buy about a quarter of a million, as the rockets are reported to have cost about $120 each [882].

[98] As is indicated in table 3.5 approximately $85 million was founded for procurement of "lethal chemicals" between mid-1962 and June 1968. This figure probably relates only to the purchase and filling of unfilled munitions, not to the costs of making the actual agents. According to a Department of Defense official, VX cost the Army $2–3 per pound, and sarin $1–2 [45]. The payload accounts for about a quarter or a third of the cost of a sarin weapon such as the M-34 cluster bomb or the M-55 rocket [882]. The process used for making di-di at Muscle Shoals generated 3–4 tons of phosphoryl chloride per ton of sarin that could be made from the di-di; it is reported that by August 1954, Muscle Shoals was expected to generate about 1 200 tons of phosphoryl chloride per month [655, 889]. The estimated tonnage of "chemical class V" supplies (i.e., toxic ammunition) needed to sustain US combat ground forces is 0.006 short tons per man per month [42].

Table 3.5. Annual CB procurement funding for the US Department of Defense, 1960–1973

Fiscal year:	1960	61	62	63	64	65	66	67	68	69	70	71	72	73
Figures published by the General Accounting Office[a]														
Funding ($ mn)	..	..	..	>70	>54	>42	>134	147	248	242	..	..	..	..
Service breakdown:														
Army	..	..	..	64	42	30	86	35	180	156	..	..	..	..
Navy	..	..	..	>4	>8	>9	>16	16	5	12	..	..	..	..
Air Force	..	..	..	>3	>4	>2	>33	96	64	74	..	..	..	..
Commodity breakdown:														
Smoke, flame, incendiaries	..	..	..	..	..	>9	>66	71	122	138	..	..	..	..
Riot control systems	..	..	..	..	..	1	17	17	66	81	..	..	..	..
Herbicides	..	..	..	..	..	2	20	40	31	5	..	..	..	..
Lethal chemical weapons[h]	..	..	..	..	..	11	12	9	3	0	..	..	..	..
Defensive equipments and miscellaneous	..	..	..	..	..	19	19	11	25	18	..	..	..	..
Figures published by the Department of Defense[b]														
Funding ($ mn)	31	46[c]	..	..	137[d]	79	..	..	297	291	149	77	70	58
Commodity breakdown:														
Smoke, flame, incendiaries	..	..	..	..	..	41	..	..	139	185	103	58	57	43
Riot control systems	..	..	..	..	..	1	..	..	70	83	22	2	0	0
Herbicides	..	..	..	..	..	2	..	..	31	2	0	0	0	0
CB weapons[h]	..	..	..	..	..	21	..	..	7[e]		0[g]	0	0	0
Defensive equipments	..	..	..	..	..	8	..	..	21					
Production-base support and other support equipment	..	..	..	..	..	5	..	..	28	21[f]	16	13	9	11
											8	4	4	4

Notes and sources:

[a] Published in *Congressional Record* 8 August 1969, p. S9495. They refer to actual expenditures.

[b] The published sources are as follows: 1960 [591]; 1961 and 1964 [658]; 1965 and 1968 [876]; 1969 [45]; and 1970–73 [1600]. The figures refer to actual or programmed expenditures, except 1961 and 1964, which are appropriations.

[c] Only the Army had CB procurement appropriations. The budget request was $53.7 mn [591]. $31.5 mn was programmed for procurement of M-55 sarin rockets [881].

[d] The Army, Navy and Air Force appropriations for CB procurement were $117 mn, $11 mn and $8.7 mn, respectively [658].

[e] Another Defense Department release gives the following commodity breakdown for the $297 mn procurement programme: $139 mn for smoke, flame and incendiaries; $70 mn for riot control; $31 mn for herbicides; $54 mn for "defensive equipments and miscellaneous"; and $3 mn for lethal chemicals [45]. This suggests that $4 mn was programmed for biological weapons.

[f] The following breakdown was given: $21 mn for "defensive equipments and miscellaneous"; and $0 mn for "lethal chemicals" [45]. It is conceivable (see note *e* above) that the "miscellaneous" includes the biological-weapons procurement that was proceeding at this time.

[g] Although no funds were included in the Defense Department appropriations for CB weapons procurement in FY 1970, Rocky Mountain Arsenal was still (as of 1 July 1969) filling sarin into *Honest John* warheads and Mk116 bombs (for the Army and the Navy, respectively), using unexpended procurement funds from earlier years [876].

[h] Presumably does not include the costs of CBW agents manufactured in government factories. Such costs have usually been carried in the "Operations and Maintenance" budget.

No information has been published about the quantity of filled BZ weapons available, but it seems unlikely to be large. Construction of a $2 million BZ loading plant was completed at Pine Bluff Arsenal in 1962 [879]. Two other chemical incapacitating agents are at present in an

advanced state of development (see page 303 below). If they are procured they will be bought from industry, as was BZ [45].

The shelf-life of a nerve-gas weapon is about 5 or 10 years, beyond which the munition (particularly its fusing), begins to deteriorate. The agent itself has a longer lifetime. The same applies to incapacitating chemical weapons [45].

Toxins were included in the biological-weapon procurement programme. This commenced around 1943 and ended in 1969. Most of the 1969 inventory, now being destroyed, was manufactured since 1962. About $726 million was spent on biological weapons [880], a figure that presumably includes the R&D back-up and the construction of plant. Immediately prior to their destruction, there were reported to be about 40 000 litres of antipersonnel BW agents stored at Pine Bluff Arsenal [883], together with 45 000 toxin-containing bullets and flechettes [98, 884]. Around 5 000 kg of antiplant BW agents are said to have been available in the early 1960s [574]; and it is rumoured that they have always formed the larger part of the total BW-agent stockpile [610].

BW agents have a shorter storage lifetime than CW agents. According to a Department of Defense official, some of them have a half-life of 3–4 years; for others, the half-life is only 3–6 months, and then only if kept under refrigeration [45] (see also table 2.3). Less time is needed than with CW agents to get a laid-away BW agent factory onto full-scale production, a matter of weeks with some agents [878]. This presumably explains what seems to have been the Army Matériel Command's policy of maintaining a relatively small BW-agent stockpile but a large production capacity.

The original US factory for BW agents was the Vigo Plant, set up in 1944 at Terre Haute, Indiana.[99] A munitions-loading building was constructed at Fort Detrick at about this time [728]. The Vigo Plant was apparently still active in 1953 [885], a year in which construction of a new antipersonnel BW agent and weapon factory was completed at Pine Bluff Arsenal [879]. This was expanded in 1964 [879] and remained in operation until President Nixon's 1969 policy statement. Antiplant BW agents seem to have been made at Rocky Mountain Arsenal [863, 886]. In January 1971 it was announced that the Biological Operations Directorate of Pine Bluff Arsenal was to be converted into a National Center for Toxicological Research under the control of the Food and Drug Administration. The Army would remain there until the biological-agent destruction programme had been completed [887]. Much of the process

[99] For further details of the Vigo Plant, see Volume I, pp. 120–21.

equipment has been offered for sale on the commercial market. These redeployment activities do not affect the chemical operations at Pine Bluff (i.e., the loading of toxic, flame, incendiary and smoke agents into munitions, and their subsequent storage).

No information is available about the types of chemical weapon that the United Kingdom was developing when the programme ended in the mid-1950s.[100]

All the major NATO countries possess and have used irritant-agent weapons domestically. CN is the currently favoured agent in the Netherlands, for example, while CS is used in the UK and France. Both these, and others have been used heavily in the United States, where a wide range of different weapons has been developed commercially and by government agencies [222, 888].

III. *Countries outside NATO or the Warsaw Pact*

Little is known about the CBW activities of most of the countries outside the NATO or WPO alliances. At the UN General Assembly, and elsewhere, the representatives of many of these countries have spoken out against CB weapons, or voted in favour of resolutions condemning CBW (as is described in Volumes III and IV of this study). It is not known, however, whether these expressions adequately reflect the views of the military authorities in the countries concerned. There is no reason to suppose that they do not; but CB weapons, though they may be nothing more than the superfluities of an over-industrialized and over-militarized society, could be thought to possess much military significance in nuclear-free regions of the world.

Latin America and the Caribbean countries

Some of the earliest agreements aimed at outlawing CBW were concluded between Latin American countries. The actions taken with regard to chemical weapons at the 1923 Washington Conference of the five Central American Republics, at the Fifth International Conference of American States at Santiago in the same year, and at the 1936 Buenos Aires Inter-Ameri-

[100] Secrecy is still maintained around the British chemical weapons of World War II. *Gas Warfare*, by D. J. C. Wiseman, Volume I of the War Office's Historical Monograph series *The Second World War: 1939–1945, Army: Special Weapons and Types of Warfare* (London: War Office, 1951) [890], is still classified secret.

can Peace Conference, are noted elsewhere in this study.[101] The agreements reached at the first two of these conferences are not considered to have much legal significance today [891]; neither, perhaps, does the agreement reached at the third—a proscription of CW concluded in the aftermath of the Chaco Wars—although it seems to have escaped the note of recent commentators on the international law pertaining to CBW.[102] Several Latin American countries are parties to the Geneva Protocol, and have signed the 1972 Biological Weapons Convention, as is shown in table 3.6. Many of them voted in favour of the "Swedish" General Assembly resolution of 1969. Mexico, to take one example, attaches great significance to this; its representative spoke as follows to the General Assembly in 1971:

> ... we consider that the question of the total prohibition of the use of chemical and microbiological weapons is something that has already been definitely settled in resolution 2603A (XXIV) of 16 December 1969, in which the United Nations General Assembly declared that the use of such weapons would be contrary to the tenets of generally recognised international law embodied in the Geneva Protocol, and also defined the scope of that prohibition when it stated that it included any chemical and biological means of warfare without any exception [892].

Like many other countries that supported this resolution, Mexico has often used irritant-agent weapons domestically for police purposes.

The military establishments within the Latin American countries may or may not be concerned to develop CB weapons or the defences against them; and their interest in doing so may or may not have been stimulated by their outside friends and allies. In this connection, it may be noted that according to a British newspaper report, East Germany has supplied Cuba with "large quantities of materials for chemical warfare" [894]. Like-

[101] See Volume I, p. 245; Volume III, appendix 1; and Volume IV, p. 59, note 1.

[102] The 1936 agreement was concluded between Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, the Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, the United States, Uruguay and Venezuela. It was reached at the Inter-American Conference for the Maintenance of Peace, held at Buenos Aires in December 1936 at the instigation of the United States. The Conference agreed to a large number of different resolutions on a variety of topics, among them, on 21 December 1936, the following one:

"XXXIV. Humanization of War.

... The Inter-American Conference for the Maintenance of Peace resolves:

... 2. To proscribe the use of chemical elements whose use in war may cause cruelly unnecessary damage.

... 4. To recommend to the American Governments that in the pacts of limitation of armaments which they may sign they include stipulations of a humanitarian character such as those rejecting the poisoning of water, the dissemination of pathogenic bacteria, the use of poisonous gas, the war use of inflammable liquids or substances, etc., in accordance with maximum possibilities calculated by their technical representations. [893]

Table 3.6. The Geneva Protocol and the Biological Weapons Convention: Positions of the Latin American and Carribean countries[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention: Signature
	Accession	Reservations[b]	
Argentina	May 1969	None	Not signed
Barbados	Not a party	—	Not signed
Bolivia	Not a party	—	April 1972
Brazil	August 1970	None	April 1972
Chile	July 1935	I, II and III	April 1972
Colombia	Not a party	—	April 1972
Costa Rica	Not a party	—	April 1972
Cuba	June 1966	None	April 1972
Dominican Republic	December 1970	None	April 1972
Ecuador	September 1970	None	June 1972
El Salvador	Not a party	—	April 1972
Guatemala	Not a party	—	May 1972
Guyana	Not a party	—	Not signed
Haiti	Not a party	—	April 1972
Honduras	Not a party	—	April 1972
Jamaica	July 1970	Succession to British?	Not signed
Mexico	May 1932	None	April 1972
Nicaragua	Not a party	—	April 1972
Panama	December 1970	None	May 1972
Paraguay	October 1933	None	Not signed
Peru	Not a party	—	April 1972
Trinidad and Tobago	October 1970	Succession to British?	Not signed
Uruguay	Not a party	—	Not signed
Venezuela	February 1928	None	April 1972

Notes:
[a] As of July 1972.
[b] See table 3.1, note *b* for the key.

wise, the US Agency for International Development (AID) is reported to have furnished substantial supplies of, *inter alia*, irritant-agent weapons to the internal security forces of several other Latin American countries [895]. Similar supplies are also said to have been provided through the Military Assistance Program (MAP) of the US Department of Defense, and training in their use is given to Latin American nationals at US military schools [895–897].[103] As regards other forms of CBW, 12 officers from Argentina, Brazil, Chile, Mexico and Venezuela attended training courses between 1953 and 1965 given by the US Army Chemical Corps at Fort McClellan. These courses have included instruction in the design, effectiveness and employment of chemical and biological weapons, in addition to defensive instruction [850].

[103] For example, the US Army School of the Americas in the Panama Canal Zone, a US Air Force school, also in the Canal Zone, and the US Army Special Warfare School at Fort Bragg. In addition, there are 17 Mobile Training Teams organized for despatch to Latin American areas by the Special Action Force for Latin America of the US Army 8th Special Force stationed in the Canal Zone [899].

Table 3.7. The Geneva Protocol and the Biological Weapons Convention: Positions of the African and Middle Eastern countries[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention:
	Accession	Reservations[b]	Signature
Botswana	Not a party	—	April 1972
Burundi	Not a party	—	April 1972
Cameroon	Not a party	—	Not signed
Central African Republic	July 1970	None	April 1972
Chad	Not a party	—	Not signed
Congo (Brazzaville)	Not a party	—	Not signed
Dahomey	Not a party	—	April 1972
Equatorial Guinea	Not a party	—	Not signed
Ethiopia	September 1935	None	April 1972
Gabon	Not a party	—	April 1972
Gambia	October 1966	Succession to British?	Not signed
Ghana	May 1967	None	April 1972
Guinea	Not a party	—	Not signed
Ivory Coast	July 1970	None	May 1972
Kenya	July 1970	None	Not signed
Lesotho	Not a party	—	April 1972
Liberia	June 1927	—	April 1972
Malagasy Republic	August 1967	None	Not signed
Malawi	September 1970	None	April 1972
Mali	Not a party	—	April 1972
Maldives	December 1966	None	Not signed
Mauritius	November 1970	None	April 1972
Mauritania	Not a party	—	Not signed
Niger	March 1967	Succession to French?	April 1972[e]
Nigeria	October 1968	I, II and III	July 1972
Rwanda	March 1964	Succession to Belgian?	April 1972
Senegal	Not a party	—	April 1972
Sierra Leone	March 1967	None	Not signed
Somali Republic	Not a party	—	July 1972
South Africa	May 1930	I, II and III	April 1972
Sudan	Not a party	—	Not signed
Swaziland	Not a party	—	Not signed
Tanzania	April 1963	None	Not signed
Togo	April 1971	None	April 1972
Uganda	May 1965	None	Not signed
Upper Volta	March 1971	None	Not signed
Zaïre	Not a party	—	April 1972
Zambia	Not a party	—	Not signed
Algeria	Not a party	—	Not signed
Egypt	December 1928	None	April 1972
Iran	November 1929	None	April 1972
Iraq	September 1931	I, II and III	May 1972
Israel	February 1969	I, II and III[c]	Not signed
Jordan	Not a party	—	April 1972
Kuwait	December 1971	II	April 1972
Libya	December 1971	II and III	Not signed
Lebanon	April 1969	None	April 1972
Morocco	October 1970	None	May 1972
Saudi Arabia	January 1971	None	April 1972[f]
Syria	December 1968	None[d]	Not signed
Tunisia	July 1967	None	April 1972
Yemen, Arab Republic of	March 1971	None	April 1972
Yemen, Southern	Not a party	—	April 1972

A number of institutes in Latin American countries have received US Army contracts for CBW-related research work [717].

Africa and the Middle East

Table 3.7 lists those African and Middle Eastern countries that are parties to the Geneva Protocol, and which have signed the 1972 Biological Weapons Convention. Rumours of CBW or of imminent CBW have long been associated with this area of the world. These have not only concerned the Arab–Israeli conflict and the Black–White confrontation in southern Africa. In the late 1960s, there were rumours that the possibilities of biological weapons had aroused interest in local military circles during the Ethiopia–Somalia border dispute; and during the Nigerian Civil War, Biafran Radio Enugu at one point stated that an East German freighter carrying "napalm and poison gas bombs" for the Federal Government forces was on its way from Rostock to Lagos [898].

As noted earlier in this chapter, Portugal has been accused of using CB weapons, particularly antiplant chemicals, against the forces and cultivations of dissident areas of its African colonies. These have led to strong expressions of condemnation of CBW in general, and Portugal in particular, from the governments of several Black African states. The Tanzanian representative, for example, spoke as follows to the UN General Assembly in November 1971:

> A few of the signers of the Protocol maintain that it does not apply to all gases and does not prohibit, for example, the use of tear gas or the use of herbicides. Such interpretations of the Geneva Protocol are used as a cover for the extensive use of napalm and defoliants in Viet-Nam by the so-called allied forces and in the territories in Africa illegally occupied by the Portuguese [900].

Just as it is not known conclusively, at the time of writing, whether Portuguese colonial forces have in fact been using CB weapons, neither is it known whether Black African countries have been stimulated into embarking on their own CBW activities, whether defensive or offensive. A news-

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Notes:

[a] As of July 1972.

[b] See table 3.1, note *b* for the key.

[c] Israel also reserved the right to retaliate in kind against enemy states from whose territory operate "regular or irregular forces, or groups or individuals".

[d] Except that Syria noted that its ratification "does not in any case imply recognition of Israel or lead to the establishment of relations with the latter concerning the provisions laid down in this Protocol".

[e] Ratified on 23 June 1972.

[f] Ratified on 24 May 1972.

paper report originating in Lisbon in 1971 claimed that an unidentified aircraft, presumed to be Zambian, had disseminated CW agent over Angolan territory [901].

A number of commentators have taken the view that, whatever the strength of the constraints on using CB weapons may be during other conflicts, they are likely to become very much weaker during a Black–White racial war in Africa, particularly one involving a country as isolated from the world community as South Africa [902]. Fears of this kind were increased in November 1963, when Professor le Roux, vice-president of the South African Council for Scientific and Industrial Research, stated that a special group of scientists "was learning everything there was to know" about the nerve gases. He was speaking to the South African Association for the Advancement of Science; as reported, his speech also remarked "that the Defence Research Council realized chemical and bacteriological warfare was no longer impracticable, as it had been during the early stages of the Second World War" [903]. East German writers have alleged that West German chemical firms have constructed CW-agent factories in South Africa, and that in 1960, the West German Government supplied South Africa with irritant-agent bombs [312]. According to a South African Government spokesman quoted in a British newspaper during 1963, irritant-agent weapons had long been provided by the British Government, but the report went on to say that these supplies were to cease, and that South Africa was to undertake its own "tear gas" manufacture in a new factory at Modderfontein, jointly owned by de Beers and ICI (UK) [904]. The alleged involvement of South Africa in Portuguese antiplant CW in Angola and Mozambique is referred to on page 198 above. In June 1971, TASS, the Soviet news agency, reported that two chemical bombs manufactured in South Africa had been snared in the nets of a Bulgarian fishing vessel [905].

Egypt has long been reputed to be conducting a CB R&D programme. During the 1950s it made efforts to recruit wartime CW workers from Germany, according to one who declined the offers made [906]. During the early 1960s, particularly at the time when Egyptian forces were first alleged to have been using chemical weapons in the Yemen, it was reported that CBW specialists were included among the team of German scientists then working in Egypt [907, 908]. In a statement to the Israeli Knesset on 20 March 1963, Mrs Golda Meir stated that the Egyptian missile programme encompassed work on CB warheads [909], a suggestion that has been made by others [e.g., 910]. In 1965, the Egyptian government-controlled Middle East News Agency reported that CW exercises had taken place during Egyptian desert manoeuvres, but the report was re-

tracted almost immediately [911]. According to unpublished Israeli sources, the last German chemist in Egypt ceased work in 1966, but the chemical-weapon programme continued.[104] In 1970, the Deputy Chief Scientist of the Israeli Defence Ministry was quoted as saying: "We assume that they will have the capability for producing a nuclear weapon by 1990, and that they could produce serious chemical or biological weapons before that" [912]. After the June 1967 Arab–Israeli War, stores of Egyptian CW matériel were captured in the Sinai desert. According to some reports, these included stocks of nerve gas, mustard gas and phosgene [913], and Chinese-made irritant agents [914], but little credence can be attached to them. Reports of greater reliability and credibility refer to the capture of Soviet-made mobile decontamination units [e.g., 528, 914] and filtered-air supply units for CB collective shelters, making no mention of chemical weapons.

Very recently, Egypt has announced that it possesses biological weapons. On 17 February 1972, at the Arab Socialist Union National Congress, President Sadat was asked about the Egyptian reply to the possibility of an Israeli BW attack. He answered as follows:

> The only reply to biological warfare is that we too should use biological warfare. I believe that the density of the Israeli population confined in a small area would provide the opportunity to reply with the same weapon if they should begin using it. Briefly, we have the instruments of biological warfare in the refrigerators and we will not use them unless they begin to use them.

This startling announcement was reported in *Al Ahram*, but was not publicized in the foreign press. On 10 April, Egypt signed the Biological Weapons Convention. On 22 June, according to subsequent reports in the Cairo press, the Deputy Prime Minister and Minister of Interior Mamduh Salim stated in Alexandria that he did not believe "the enemy" would dare to resort to biological warfare "since we have adequate means of retaliating without delay". No further information about Egyptian possession of biological weapons is available. It is not possible to ascertain whether the foregoing statements can be taken at face value. There is, of course, a great

[104] Publications by Egyptian scientists on topics that have a bearing on CBW problems are to be found in the scientific and technical literature. For example, several studies of anticholinesterase (organophosphorus and carbamate) toxicology have been published by workers at Cairo University, at the Department of Biology of the Cairo Atomic Energy Establishment, and at the National Research Centre at Dokki, near Cairo, but these all relate to pesticides [e.g., 922–924]. Egyptian toxicologists have also worked on organophosphorus poisons at the *Forschungsstelle für Toxikologie* at Leipzig (see above, p. 168). A study of cholera has been published from the Army Research Institute for Biological Warfare Defence in Amman, Jordan [925].

difference between stocks of pathogenic cultures stored in refrigerators and a significant military capability for waging BW.

Very little is known about the Israeli CBW programme. At least half of all Israeli R&D funding is spent in the military field, but close security is maintained around most of it [912]. Israeli scientists working at the Israeli Institute for Biological Research, Ness-Ziona [915–918] and under various Defence Ministry auspices [919–920] have published on topics that relate to CBW problems, and for one such publication [915] it is hard to see much rationale except in connection with V-agent synthesis. The US Army has long been supporting studies of toxins at the Rogoff–Wellcome Medical Research Institute, Petah Tikwa [e.g., 717]. In 1963, the Egyptian UN delegate stated that Israel was experimenting with bacteriological warfare, at the Weizmann Institute in particular, but this was immediately denied by his Israeli counterpart [921].

Neither is there much information about the CBW matériel issued to the Israeli armed forces or civilian population. The bomb shelters that have been and are being built throughout the country [912] are often equipped with CBW-agent filters. Prior to the June War of 1967, it was authoritatively reported that Israel had been supplied with British CS weapons [926]. During the period of mounting crisis that preceded the war, Israeli concern about the possibility of Arab CW attack received much publicity in newspaper reports that gas masks were being sought from abroad; 200 000 of these were subsequently flown in from the United States [927], and another 20 000 (subsequently returned) from West Germany [928–929]. After the June War, much of the captured Soviet-Egyptian CB defensive equipment entered Israeli Army service; so also did such captured weapons as the Soviet-supplied BM-24 240 mm multiple rocket launcher [930], a weapon for which, as noted earlier, a CW capability is believed to exist. The United States continues to provide Israel with CB defence equipment and with technical assistance in CBW matters [931]. An Israeli officer attended a US Army CBW training course in 1963; in contrast, 17 Iraqi officers have done so (during 1957–67), four Lebanese (1967–68), one Jordanian (1965), one Egyptian (1954) and eleven Iranians (1955–60) [850].

There have been rumours recently of an interest in CB weapons on the part of the Palestinian guerrillas. In January 1971, the Bavarian State Interior Ministry referred to these when explaining certain new security measures at Munich airport; in this case the rumours concerned Palestinian plans for using nerve-gas spray cans in future aircraft hijacking attempts [932]. In September 1968, a Swedish newspaper reported that the First Congress of the Arab Pharmaceutical Association, held in Da-

mascus, had on the one hand urged all Arab governments and organizations to give moral and material support to the Palestinian commando groups, and on the other urged all Arab chemists to train their pupils in chemical warfare [933].

Australasia, India, China, Japan and other Asian countries

Table 3.8 lists the countries in this region of the world that are parties to the Geneva Protocol, and which have signed the 1972 Biological Weapons Convention. Notable exceptions among the latter, at the time of writing, are India and China [934]. China is also blocking further progress on the complementary UN Security Council resolution that would expedite the verification by challenge procedure; but this is related to its dispute with Taiwan, and apparently has nothing to do with biological weapons. China's attitude to the Convention itself is not entirely clear, but is presumably related to the comment issued by the Albanian news agency in August 1971, stating that the Convention was "the fruit of the collaboration of the American imperialists with the Soviet revisionists for deceiving world public opinion and giving the impression that something is being done in the field of disarmament" [935] (a sentiment rather similar, in part, to that subsequently expressed by France; see page 187, note 34 above).

Virtually nothing is known of Chinese CBW activities [936]. To judge from US Congressional testimony and other such official sources on the matter, US intelligence efforts, including satellite monitoring, have been unable to locate either large-scale field testing or nerve-gas production. The Chinese scientific and technical literature occasionally publishes work on CB related topics, for example a 1965 review from the First Shanghai Medical College on oxime antidotes for anticholinesterase poisoning [937]. Chinese respirators are in use in the Viet-Nam War; so also, it is alleged, are Chinese irritant-agent weapons.[105] During the Yemeni Civil War of the mid-1960s, China was reported to have provided the Republican forces with gas bombs;[106] these were reputed to have been World War II US weapons that had been stockpiled in China,[107] reports of the existence of which appeared in US newspapers during the Chinese Civil War of the late 1940s [e.g., 938]. During the Cultural Revolution, a wire-story from Hong Kong in August 1967 quoted the Kweichow provincial radio on

[105] See Volume I, pp. 191 and 193–94. The report that Chinese-made irritant agent was found among abandoned Egyptian matériel in the Sinai desert after the June 1967 War is referred to on page 241 above.
[106] See Volume I, p. 161.
[107] During World War II substantial stocks of weapons and ammunition were shipped to China under lend-lease by the US Army Chemical Warfare Service [942].

Table 3.8. The Geneva Protocol and the Biological Weapons Convention: Positions of the Australasian and Far Eastern countries[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention: Signature
	Accession	Reservations[b]	
Afghanistan	Not a party	—	April 1972
Australia	May 1930	I, II and III	April 1972
Bangladesh	Not a party	—	Not signed
Burma	Not a party	—	April 1972
Cambodia	Not a party	—	Not signed
Ceylon	January 1954	None	April 1972
China	August 1929 (1952[c])	I, II and III[c]	Not signed
Fiji	Not a party	—	Not signed
India	April 1930	—	Not signed
Indonesia	January 1971	Succession to Dutch?	June 1972
Japan	May 1970	None	April 1972
Korea, North	Not a party	—	Not signed
Korea, South	Not a party	—	April 1972
Malaysia	December 1970	None	April 1972
Mongolia	December 1968	II and III	April 1972
Nepal	May 1969	None	April 1972
New Zealand	May 1930	I, II and III	April 1972
Pakistan	April 1960	Succession to Indian?	April 1972
Philippines	Not a party	—	April 1972
Singapore	Not a party	—	June 1972
Taiwan	August 1929	None	April 1972
Thailand	June 1931	None	Not signed
Tonga	July 1971	None	Not signed
Viet-Nam, North	Not a party	—	Not signed
Viet-Nam, South	Not a party	—	April 1972
Western Samoa	Not a party	—	Not signed

Notes:

[a] As of July 1972.

[b] See table 3.1, note *b* for the key.

[c] In July 1952, the Peoples' Republic of China issued a statement recognizing as binding upon it the accession to the Protocol in the name of China. On doing so, it made a unique, and somewhat obscure, type of reservation: "The Peoples' Republic of China considers itself bound by the Protocol on condition of reciprocity on the part of all the other contracting and acceding powers."

the use of "poisonous chemical gas" during fighting at Kweiyang [939]. A photograph taken from *Jenmin Jihpao* (no. 7188 of 1968) showing Chinese soldiers studying the works of Chairman Mao which was reproduced in a US publication is said by the latter to be of "soldiers of the 7th Chemical Company of a certain unit of the Chemical Corps, PLA" [940]. A February 1970 broadcast by the Harbin-Heilungkiang Provincial Service announced that "party branch members of the Anti-Chemical Warfare Company of a certain PLA unit stationed in Heilungkiang have gone out to join poor and lower middle peasants to recollect class sufferings" [941].

India has been an active participant in the CB disarmament negotiations at Geneva, but has made no public statements about its CBW preparedness. Such CB R&D as it does, if any, is presumably performed within

the various technical establishments and laboratories of the Defence Research and Development Organisation [943]. The present status of the old British Chemical Defence Research Establishment (India) in Northern India [944] is not known. The Delhi-published *Military Yearbook 1970,* which describes Indian military activities in great detail, including R&D and training, makes no reference to any form of CBW preparedness. No Indian officers seem to have attended the US Army CBW training courses, although five Pakistani officers did between 1958 and 1964 [850]. Irritant-agent weapons have been used domestically by Indian police forces, but the Indian Government regards their use in war as illegal; the Indian delegate at the CCD has strongly criticized the British Government's stand on this [945].

Like India, Japan has been an active participant in the CB disarmament negotiations at Geneva, and, also like India, little is known about Japanese CBW preparedness today. (On Japanese CBW activities prior to, and at the time of World War II, see Volume I, pages 112–116 and 287–289). The Defence Agency's budget estimate for 1970, which represented a 20 per cent increase over the previous year, included provisions for the establishment of a chemical warfare unit [946]. There is a Chemical School located at Omiya City, under the command of the Western Army of the Ground Self-Defence Forces [947]. Japanese officers took up 18 places on US Army CBW training courses between 1955 and 1967 [850]. In December 1971, Japanese newspapers quoted Defence Agency officials to the effect that small quantitites of CW agents had apparently been imported into Japan during 1964–66 for training purposes; the material was said to have been shipped from Edgewood Arsenal to the US Navy arsenal at Sasebo [948]. Allegations that US CB weapons are stored at the US Marine Corps Air Station at Iwakumi [949] have been denied by the Defence Agency [950]. Irritant-agent weapons have been extensively used by Japanese police forces. No official statements were made about the relationship of irritant-agent weapons to the Geneva Protocol when Japan ratified its signature of it in 1970; it is understood that, although the government had prepared a statement indicating that it considered irritant agents to lie outside the scope of the Protocol, no opportunity arose for the statement to be read during the Diet debate.

Australia joined the Canada–UK–USA Technical Cooperation Programme in July 1965, 7 years after its inception [951], but before then it had been cooperating with the UK in CB R&D matters [952]. According to a British Ministry of Defence reply to a parliamentary question, facilities at Innisfail, Queensland, have been used to test British CW matériel [953]. Located at Innisfail is the Joint Tropical Research Unit, which

has a permanent staff of about 14 people and is run jointly by the Australian Government and the UK Ministry of Technology. It is used as a hot-wet environmental test centre for various items of military equipment, among them CB protective clothing [954]. It is rumoured that other types of CBW matériel, notably antiplant chemicals, have been field tested in the vicinity of Innisfail, although not by the JTRU [954]. The Australian Ministry of Defence stated in 1969 that no CBW tests had been conducted by the JTRU at Innisfail [955].

Australian CB R&D is performed by the Department of Supply within its Defence Standards Laboratories (DSL), an organization which "provides a scientific service to the Defence Services, Civil Defence Organisation and defence industry covering problems arising in the provision and use of defence material" [956]. DSL is located at Maribyrnong in Victoria, with branches at Alexandria in New South Wales, at Woodville North in South Australia [957] and elsewhere. The *Defence Report 1967* [957] contains a photograph of a developmental field shelter undergoing a DSL field-trial against a simulated CBR agent challenge. Among other matters, the 1968–69 DSL annual report [958] refers to synthesis work in the field of organophosphorus chemistry, to X-ray diffraction studies of CS crystals, and to studies of *Chironex fleckeri* ("box jellyfish" or "sea wasp") toxin. Work on the latter substance, which is said to be among the most deadly zootoxins known [959], has been supported at the University of Queensland by the US Navy [717]. DSL Melbourne publications in the scientific and technical literature include reports of work on nerve-gas antidotes [960], and on the toxins of *Octopus maculosus* [961] and *Chironex fleckeri* [962–965]; the latter has also been studied at DSL Maribyrnong [401], whence work has also been reported on novel irritant agents related to capsaicin [967].

Australian Army officers have attended CBW training courses in the United States [850], and Australian forces serving in Viet-Nam have employed irritant-agent weapons supplied, apparently, by the USA [968]. Australia does not regard this as contravening the Geneva Protocol; explaining his vote against the 1969 "Swedish" General Assembly resolution, the Australian representative spoke as follows:

> It is the view of the Australian Government that the use of nonlethal substances such as riot control agents, herbicides and defoliants does not contravene the Geneva Protocol nor customary international law. There are a number of such substances which are widely used throughout the world and which have important civilian applications. It is difficult to accept that agents which are employed by civilian police forces, as well as by the armed forces in many Member States, are "contrary to the generally recognised rules of international law". [969]

Australian irritant-agent weapons have been used for police purposes both in Australia and in outlying territories, such as New Guinea.

US Army CBW training courses have been heavily attended by serving officers from several Far Eastern countries. Sixty-four places were taken up by South Viet-Namese officers during 1958–68, 21 by Philippine officers during 1956–66, 19 by Thai officers during 1953–69, 50 by Taiwanese during 1954–68, and 94 by South Koreans during 1953–69 [850]. Most, if not all, of these countries have been supplied with US irritant-agent weapons under AID or MAP auspices. The first irritant-agent weapons to be used in the Viet-Nam War are reported to have been MAP stores provided during 1962 and 1964;[108] and South Viet-Namese Air Force personnel have been closely involved in the antiplant CW operations of the war.[109] Testing grounds for these have been provided by Thailand (see page 210 above). In the Philippines, the US Army has established a counterinsurgency training school, and the Philippines Constabulary is experienced in the use of CS weapons against the Huk dissidents.[110]

European countries outside NATO or the WPO

The positions with respect to the Geneva Protocol and the Biological Weapons Convention of these countries are shown in table 3.9. Most is known about the CBW preparedness of Sweden, and this is described in some detail below as an illustration of how one non-aligned country has organized its CB defences.

As regards the other countries, Austria has undertaken, in the 1955 Austrian State Treaty, not to "possess, construct or experiment with ... asphyxiant, vesicant or poisonous materials or biological substances in quantities greater than, or of types other than, are required for legitimate civil purposes, or any apparatus designed to produce, project or spread such materials or substances for war purposes".[111] Little information is available on the CB defence arrangements of the Austrian civil defence organization or of the armed services. Two Austrian officers attended CBW training courses in the USA during 1960–64 [850]. Articles on CB matters have been published in the technical and military literature by Austrian officers [e.g., 970].

Like Austria, Finland is also debarred from possessing CB weapons

[108] See Volume I, p. 185.
[109] The South Viet-Namese Air Force is reported to have continued herbicide operations in Viet-Nam after US Air Force herbicide operations there had ceased [971].
[110] See Volume I, p. 214.
[111] For further details, see Volume V, p. 215.

Table 3.9. The Geneva Protocol and the Biological Weapons Convention: Positions of the European countries outside NATO or the Warsaw Pact[a]

Country	The 1925 Geneva Protocol		The 1972 Biological Weapons Convention:
	Accession	Reservations[b]	Signature
Austria	May 1928	None	April 1972
Cyprus	November 1966	Succession to British	April 1972
Finland	June 1929	None	April 1972
Holy See	October 1966	None	Not signed
Ireland	August 1930	I, II and III	April 1972
Liechtenstein	Not a party	—	Not signed
Malta	September 1970	Succession to British	Not signed
Monaco	January 1967	None	Not signed
San Marino	Not a party	—	Not signed
Spain	August 1929	I and II	April 1972
Sweden	April 1930	None	Not signed
Switzerland	July 1932	None	April 1972
Yugoslavia	April 1929	II and III	April 1972

Notes:
[a] As of July 1972.
[b] See table 3.1, note *b* for the key.

under the term of its World War II peace treaty with the Allied Powers.[112] The 1972 budget of the *Maanpuolustuksen Tieteelinen Neurottelikunta,* the Finnish defence research organization [972], included FMk 40 000 for a small CB working group.

In Switzerland, the federal Military Department maintains an *AC-Schutzdienst* at Bern within its *Abteilung für Sanität.* At least until recently, its CB R&D activities were confined to a scanning of the world's literature on the subject. Members of its staff have published on CBW matters in technical and military journals [973]. The CB defence arrangements of the Swiss civil defence organization and the armed services are said to be extremely efficient. A Swiss army officer attended a US Army CBW training course in 1965 [850]. Three Spanish Army officers did the same in 1956 [850].

In Yugoslavia, the armed forces incorporate an ABHO arm responsible for NBC defence. This has expanded and taken over the functions of the previous chemical defence service, which was established immediately after World War II. The latter was initially equipped with captured CW matériel, supplemented with imported equipments. The institution of an ambitious R&D programme led to the home manufacture of the basic protective devices [974]. This programme has since been expanded, but little is known of its organization and level of funding. Several basic studies on nerve-gas pharmacology, among them some of the earliest open publications

[112] For further details, see Volume V, p. 214.

on the V-agents, have been published from the Institute of Toxicology of the Military Academy in Belgrade [e.g., 975–978], from the Institute of Pharmacology and Toxicology of the Medical Faculty of Belgrade University [e.g., 979] and from the High Military Technical School in Zagreb [e.g., 980]. Yugoslav military personnel have published several detailed studies of other technical and military aspects of CB defence [308, 981–996].

For the Yugoslav armed forces, CB defence in the field is provided for by service-wide instruction in the use of the issued protective equipments, supplemented by the deployment of ABHO units specializing in CBW-agent reconnaissance and decontamination, and in meteorological services. ABHO units no longer have such combat responsibilities as the laying of smoke screens. The ABHO arm is responsible for the NBC-defence instruction of the armed services, and cooperates with the civil defence forces [974]. Yugoslav officers attended US Army CBW training courses during 1956–61 [850]. Yugoslavia participates actively in the CB disarmament negotiations at Geneva, and, prior to the conclusion of the 1972 Biological Weapons Convention, it was one of the countries that had unilaterally renounced any intention of using or possessing biological weapons [997].

Sweden

Policy

When Sweden ratified its signature of the Geneva Protocol in April 1930, it did so without reservation, but the interpretation of the Protocol which the government of the time put before the Swedish Parliament emphasized the contractual nature of the agreement. In that the Protocol, thus construed, would not apply in a conflict where one or other side was a non-party, and would become void were a belligerent to violate it, "it would be essential for States to be able in peacetime to make the preparations that might be necessary for an eventual resort to the weapons in question in time of war" [998]. For this reason the government regarded the types of reservation made by many of the earlier acceding States as superfluous.

This interpretation, however, did not lead the government to build up a retaliatory CBW capability; and Sweden has never since done so. On 29 April 1970, the government declared to Parliament that it "considers it important to call attention to the fact that Sweden does not possess, nor does it intend to manufacture, any biological or chemical means of

warfare". This declaration was repeated verbatim on 21 July 1970 at the CCD in Geneva [999], where throughout the 1960s the Swedish delegation, under the leadership of the Minister responsible for disarmament matters, Alva Myrdal, had been pressing for international disarmament.

Although Sweden has committed itself against possessing an offensive capability either in biological warfare or in chemical warfare, it places importance on maintaining an imposing CB defensive stance. As a Royal Commission report (subsequently accepted by the government) put it in 1968, the objective is that "the defence is so formed that a limited use of ... biological and chemical weapons does not in a decisive way reduce our possibilities of defence" [1000]. Accordingly, Sweden's "total defence" (comprising the armed forces, the civil defence organization, the "economic defence" and the "psychological defence") includes a carefully integrated array of countermeasures designed to contain the worst effects of any CBW operations that might form part of an invader's attack. The CB protective equipments in issue to the armed forces and to the civil defence organization are as efficient as any in Europe, and are backed up by a well-endowed research and development organization.

A concept that underlies the Swedish approach to CB defence is the view that an enemy can be deterred from initiating CBW by the excessive costs of overwhelming a well-developed protective array. Thus, sufficient antichemical protection is given to Swedish combat troops, as well as to the civilian population, to make it probable that the weight of the CW attack which an enemy would have to mount in order to achieve worthwhile results would be uneconomical in terms of manpower and matériel. Against BW attack, for which the defence is technologically more difficult, importance is attached in some quarters to the idea of constructing the defence so as, among other things, to increase the *political* costs of BW attack, of forcing on the attacker "an increased burden of political stigma" [1001]. This approach, which is perhaps more realistic for a small, exposed and neutral country than it would be for a member of one of the major alliances, was expounded in a 1967 policy-planning paper as follows:

> For the moment, Sweden cannot carry out reprisal action with B weapons or with nuclear weapons. A quick unmasking of a [BW] attacker would, however, be a serious political embarrassment to him, and such a crime against the concepts of international law would, for the attacker, mean that he would open up the way for others to wage war in the same way. A further point of clear strategic importance is that our ability to save lives and to maintain the important parts of our total defence system intact is a reality which has to be taken into consideration. A strategic objective of B defence may therefore be to maintain such a level of preparedness that the attacker, in order

to achieve a decisive effect, is forced to plan types of attack which can easily be detected and which identify the attacker. At the same time, this provides the capability to combat limited attacks and sabotage which an attacker might use for the purpose of disruption rather than using B weapons to produce a direct conclusive result [1001].

Such an approach would thus place importance on means for positively identifying BW attack, as well as a detection capability for providing early warning, together with a sustained effort in the international arena for ensuring that world opinion remained adamant against biological means of warfare. The latter requirement is in keeping with Sweden's efforts at the UN General Assembly and the Geneva disarmament conferences during the past decade directed towards securing international CB disarmament and the strengthening of international law prohibiting CBW.[113]

Research and development

The greater part of Swedish CB defence R&D is performed by *Försvarets forskningsanstalt* (FOA), the Research Institute of National Defence, which is subordinate to the Defence Ministry. FOA has several departments[114] of which Department 1 (FOA 1), with responsibility for R&D in the field of military chemistry and medicine, is the one primarily concerned with CBW. FOA 1 took over the facilities of the former *Försvarsväsendets Kemiska Anstalt* (FKA: the Defence Organization Chemical Institute) at Ursvik near Stockholm, when FOA was established in 1945. The FKA itself had been set up in 1937; before then, since the mid-1920s, Swe-

[113] For an account of the Swedish negotiating efforts in this connection, see Volume IV of this study.

[114] For an account of the organization, terms of reference and facilities of FOA, see *Forskningen vid FOA*, an illustrated descriptive brochure published by FOA Information, Stockholm. In contrast to the military R&D organizations of other countries, FOA goes to considerable lengths to keep the public informed about its activities, although in common with other countries certain areas are kept secret. FOA Information not only runs a reprint service for all FOA publications that appear in the scientific and technical journals, but it also publishes a series entitled *FOA Reports* that provides an easily accessible outlet for other non-secret FOA reports considered to be of wide interest, together with *FOA Tidningen*, a quarterly news magazine, and a series entitled *FOA orienterar om* in which current FOA activities in selected areas of military R&D (e.g., hydroacoustics, CBW [326], missile technology, and so on) are reviewed in considerable detail for the informed, but non-specialist, reader. Several of these publications are presented wholly or partially in English translation. In addition, all non-secret FOA reports are readily obtainable, news of their existence being announced by FOA in a regular abstract series entitled *FRÖ* (Försvarsforsknings Referat, öppen del). Alongside all this, some of the individual departments of FOA put out special publications of their own, in addition to their research reports. FOA 1, for instance, has a quarterly publication entitled *Tekniska Notiser från FOA 1* which comprises a collection of photocopies or Swedish translations of recent articles published outside Sweden that are relevant to its work.

dish chemical defence research had been conducted in the Gas Laboratory at the University of Lund [326]. There are 90–100 people concerned with CB defence on the present establishment of FOA 1.

During the 1971/72 financial year, FOA was allocated Sw. Kr. 8.305 mn from the defence vote for CB defence research, of which Sw. Kr. 2.89 mn went towards BW defence and Sw. Kr. 5.41 mn towards CW defence [1002]. Procurement of CB defence matériel is primarily the responsibility of the *Försvarets Materielverk* (the Matériel Administration of the Armed Forces) and of the *Civilförsvarsstyrelsen* (the Civil Defence Administration), advised by FOA; figures on their annual budgets for CB defence equipments are not available.

For part of its CB defence work, FOA 1 is assisted by other Swedish organizations, notably the *Statens Bakteriologiska Laboratorium* (the State Bacteriological Laboratory), which has a general responsibility in Sweden for vaccine production, epidemiology and microbiological diagnostic work, and the *Statens Veterinärsmedicinska Anstalt* (the State Institute for Veterinary Medicine), which has similar responsibilities with regard to animal diseases. Likewise, some CB defence work is financed from the education vote via the Medical Research Council. For this purpose, in cooperation with FOA 1, the Medical Research Council supports the Departments of Bacteriological Bioengineering and of Toxicology at the Karolinska Institute. The facilities available for the former department, which as a staff of about 20, include a pilot-plant for large-scale cultivation and handling of micro-organisms, used for preparing antigens, enzymes and toxoids. The latter department, with a staff of about ten, performs toxicological studies of, among others, substances that are potential CW agents [1003].

Facilities are maintained for testing CB defence equipments at FOA 1 and at the nearby NBC-defence school. Related trials and field experiments have been conducted elsewhere in Sweden, notably a series of large-scale releases of CBW agent simulants for observing the field behaviour of aerosol clouds under varying conditions of weather and terrain.

The greater part of the work done at FOA 1 is reported in the scientific and technical journals, and in other non-secret publications. Some of the work is kept secret, but the proportion appears to be considerably lower than in other countries. FOA 1 was, for example, the first laboratory to publish in the open literature detailed scientific studies of tabun and related nerve gases [1004]; it was also the first to publish on the V-agent nerve gases [1005].

Capabilities in CBW defence

CB DEFENCE OF THE CIVILIAN POPULATION[115]

Sweden has one of the most highly developed civil defence organizations in the world, and its civil defence policy is integrated into its overall "total defence" policy. About Sw. Kr. 120 mn ($23 mn) is spent on civil defence annually.[116] Countermeasures against CBW attack are included within the civil defence arrangements.

For the protection of the civilian population against enemy attack, the existing plans incorporate both evacuation measures and the use of collective air-raid shelters. The evacuation plans are aimed at reducing the population of each built-up area to no more than 5 000 people. Together with the evacuation plans for border and coastal areas, this would mean the removal of about 3.8 million people, about half of Sweden's population. As the country is relatively large and underpopulated, the billetting of even this number of people away from the towns is not thought to present insuperable problems. The details of warning and transportation involved have long been under careful study.

Protective shelters have been, or are being, provided for about 200 areas where the population exceeds 5 000. For the 14 largest towns, these shelters are on the outskirts; the inhabitants at the centres are expected either to evacuate themselves, or to make use of the general rock shelters that exist there. Stockholm, for example, has many large excavations deep into its underlying granite that are normally used as storage depots, garages, and such-like. These are equipped with air-conditioning units that incorporate CBW agent filters. Individual shelters are located close to dwelling houses, and general shelters close to offices or factories; it is estimated that by mid-1972 there will be about 4.4 million places available in them.

Preparations have been made for the issue of individual protective masks (respirators) at least to those members of the population for whom there is no collective protection available. At present about 1.8 million masks have been produced, but public funds for procuring the remainder have not yet been released. Provisions for emergency procurement have, however, been made. The civilian mask is simpler in design than the service one; a new model, estimated to cost Sw. Kr. 25–30 to make, has recently been announced [1006].

[115] This account is based on recent publications of the *Civilförsvarsstyrelsen*, the Civil Defence Administration [1007–1009].

[116] This is derived from the budget figure. The true economic cost is believed to be greater because of the costs incurred by private and public enterprises in conforming with building and other regulations laid down for civil defence purposes.

As regards post-attack duties, the local and regional formations of civil defence workers are expected to complete rescue work within 12 hours, to transport the injured to hospitals and medical aid posts within 24 hours, and to billet the homeless within 24 hours. Units specially trained in CB detection, decontamination and medical countermeasures are included within these formations. Civil defence units and armed forces which are grouped in the same area cooperate closely. The requisite instruction and field training is given either at the national Civil Defence School at Rosersberg [1010] or at one of the four field schools. Besides the specialist training programmes, there is also a scheme open to the general public for voluntary instruction in individual protection; during 1961–1970 about 1.4 million people took part in this.

In time of war, present plans envisage civil defence duties being assigned to something like a quarter of a million Swedes: everyone between the ages of 16 and 65 years, male or female, is liable to be called up for this duty (unless they are in the armed forces). The peacetime establishment is very much smaller, comprising planning and administrative personnel, small local and regional cadres, and the small proportion of conscripts into the armed forces that have been transferred to civil defence duties. They are backed up by a volunteer organization, the Civil Defence Association of Sweden.

CB DEFENCE OF MILITARY UNITS[117]

Organization. In the CB defence arrangements of the Swedish armed forces, the emphasis is on training and protective equipments for the individual soldier. CB defence units are included within the organization for specialist reconnaissance and decontamination duties, but there is no separate CB defence arm within the Army or any of the other armed services.

Within the Army, the CB defence organization is as follows. For each company, the staff non-commissioned officer is responsible for CB protection duties. As soon as a CBW attack is expected, he will organize a two-man detection patrol for each of the company's CW agent detection kits, of which there will be one per platoon. These patrols may also be assigned to post-attack decontamination duties. For the battalion, the adjutant (a lieutenant) is the CB protection officer. For CB defence duties he has a non-commissioned officer and a seven-man *grupp* (squad) or two four-man squads at his disposal. Also within each battalion is a pla-

[117] As regards published source material, this section draws primarily from Swedish military manuals dealing with CB defence [1011–1013], and also from a recent issue of the Swedish Army journal, *Armé Nytt*, which contains several authoritative articles on the Swedish CB defence organization (together with photographs of current protective equipments) [1014].

toon-sized "rescue and clearing force" which includes CBW-agent detection and decontamination duties within its responsibilities. For the brigade, there are no special CB defence units, although the brigade operations officer has one or two *skyddsingenjörer* (NBC-protection engineers) at his disposal. Attached to each brigade, however, there is generally a *tropp* (section) of the divisional *ISB-pluton* (*Indikering*—detection, *Sanering*—decontamination, *Brand*—fire Platoon), which is usually split up so that there is one ISB-section for each of the three brigades in a division, its staff section remaining at division headquarters where there will also be the divisional CB protection officer assisted by an NBC-protection engineer. An ISB-section is also attached to each rear supply battalion. CB protection officers are established in all lower and higher regional staffs, sharing staff facilities with their counterparts in the civil defence.

Each ISB-section is a self-contained unit. Its principal duty is the decontamination of matériel and vehicles, but it may also be used for NBC reconnaissance and fire-fighting. At the time of writing, an expansion of the ISB organization is being planned.

As regards CB defence in the Swedish Navy, the crew of each ship usually includes NBC protection specialists whose job is to direct the crew in the shipboard anti-CB countermeasures in which they have been instructed. Similar arrangements exist in naval shore bases and in Air Force ground installations where there are also variously-sized protection units. In the war organization, certain rear area laboratory units are also incorporated as part of the precautions against BW (and CW) attack. They are at the disposal of the commanders of the six Military Regions of Sweden.

Training. The Swedish armed forces allocate a good deal of time in their training schedules to CB defence. On training exercises and manoeuvres, irritant agents, and simulant agents capable of triggering CW-agent detectors, are used extensively. In the gas chambers used for protective mask testing, bromoacetone (BA) used to be the irritant agent generally used, but this is now being replaced by burning-type devices based on CS (Swedish code-name: K62). These are also used in open-air exercises.

For personnel who are not to be assigned to specialist CB defence duties, the length of CB defence training given during the basic training period ranges from 50 hours for the ordinary soldier up to 170 hours for staff non-commissioned officers. CB defence is also included on the four-yearly refresher course training schedules. CB specialist personnel receive considerably more CB defence instruction, ranging from 220 hours for battalion CB protection-squad personnel up to 485 hours for ISB-platoon commanders. Most of the 14-month basic training period of the NBC-

protection engineers is given over to CB defence instruction, including a 10-month course at the NBC Defence School. Additional CB defence training is given during the group training and exercises of the units to which personnel are assigned after completing their basic training.

The core of Swedish CB defence training is the *Försvarets Skyddsskola* (*SkyddS:* NBC Defence School of the Armed Forces), located at Kungsängen to the west of Stockholm. It serves all the Swedish armed forces, although CB defence training is also given in Navy, Coastal Artillery and Air Force schools. *SkyddS* is responsible for devising the CB training programmes, testing certain CB defence equipments, preparing the CB defence manuals, and running CB defence training courses. The latter are attended by all CB defence specialists.

Equipments. The CB defence equipments supplied to the civil defence and the armed forces are for the most part manufactured in Sweden. The individual soldier is issued with a bag of protective equipment comprising a protective mask (the *Skyddsmask 51*): an eye-shield for protection against liquid CW agents when the respirator is not worn; a pad of detection papers that change colour in contact with certain liquid CW agents (the mustards and the nerve gases); and a kit of personal decontaminants comprising three dusting-tins containing a mixture of powdered magnesia and bleaching powder (*klorkalk*), and a cotton wad for mopping up liquid droplets. He also carries a rechargeable auto-injector containing nerve-gas antidote. The latter comprises a formulation of 2 mg of atropine plus, from 1968 onwards, 150 mg of obidoxime [1015–1016]. There is no general issue of protective clothing: the soldier is instead taught how to use his rain cape to protect his skin against liquid CW agents.

Company stores include CW agent detection equipment, water purifying materials, bulk decontaminants, reserves of individual protective equipment, and rolls of *gasskyddspapper* (gas protection paper). The latter comprise 25 metre lengths of asphalt-impregnated multi-layer crepe paper which can be used to shield matériel from liquid contaminants, for example, or to provide safe passageway across contaminated ground. The detection equipment comprises kits of non-automatic detectors of various types for use by each of the company CB reconnaissance patrols. Company stores also include supplies of protective overgarments (aprons, gloves and leggings) for use by personnel assigned to decontamination duties.

Battalion stores include further reserves of individual protective equipments, and detection and decontamination equipment for use by the battalion CB protection squad. The latter is also provided with complete suits of impermeable CB protective clothing made from nylon coated with butyl rubber (the *ABC-skyddsdräkt 701*), together with rubber gloves and boots.

The decontamination equipment includes spraying apparatus (primarily for soda solutions[118]) that can be used for decontaminating matériel and vehicles. Further reserves of CB defence matériel are held by brigade supply battalions.

The major part of ISB-platoon stores are carried by each brigade-attached ISB-section. Each of these has heavy decontamination equipment with it, including an engine-driven high-pressure spray-unit and one or more of the pulse-jet hot-air blowers that are a unique feature of Swedish CB defence matériel.[119] In addition, the supplies include impermeable CB protective suits, bulk stocks of decontaminants, and tents for personnel and matériel decontamination.

Tactics and techniques. The basic requirements of an effective CB defence in the field are maximization of the time available to personnel for donning physical protection prior to or during CBW attack, and swift rehabilitation of contaminated combat units. Efficient detection and warning systems are crucial to the first; speedy deployment of decontamination facilities are crucial to the second.

As regards detection, the Swedish armed forces make the most of the various CW agent detection papers and other non-automatic devices that are in general issue. Sentries, for example, are taught to fix detection papers to their rain capes and to points around them where they will be able to observe any characteristic colour changes. On marches, detection papers are fixed to the outside of vehicles.

If an aerosol- or vapour-cloud CBW attack is detected, the warning is immediately given to the adjacent downwind unit. The progress of the cloud is then predicted and tracked, and the appropriate stand-to or stand-down signals are transmitted to other units via higher command posts. Suitable warnings are also issued to the civilian population over the radio and via the automatic telephone network. Once the enemy has begun to use chemical weapons, the "gas protection rule" comes into force whereby protective masks are to be donned whenever CW attack is suspected, even though the alarm has not been given.

Reconnaissance for ground contamination can be carried out by all personnel using their detections papers, but it is more efficiently done with the special detectors issued to the company CB reconnaissance patrols. Additional patrolling by the battalion CB protection squad may also

[118] Besides bleaching-powder and soda, the other decontaminants available to the Swedish armed forces include sodium hydroxide and chloramine. Different formulations of these basic agents have been standardized for different uses. Procurement of the US-developed DS-2 decontaminant (see p. 99) is planned.

[119] See pp. 99–100.

be necessary. Outside battalion areas, CB reconnaissance is left to the ISB units.

For the present, the various automatic CB alarms that have been developed [326, 1017] are not considered efficient or cheap enough for procurement. Against BW, the current emphasis is on identification rather than rapid detection, and for this purpose mobile diagnostic laboratories are available. To compensate for the absence of BW detection capabilities in the field, consideration is being given to immunization measures for the individual soldier.

In any army, the decontamination tactics that are adopted must balance the risk of losses from residual contamination against the risk of greater losses due to withdrawal of contaminated units for decontamination in the van of an enemy advance: decontamination must be performed with the least impingement on defensive operations. For the Swedish Army this problem is exacerbated by the likelihood of having to fight in cold weather, for decontamination becomes increasingly difficult with falling temperature. The one favourable factor is the ready availability of water from Sweden's innumerable lakes.

The Swedish approach to decontamination, which is similar to that of most other armies, seeks to maximize the small unit's ability to keep itself free from contaminants, and to minimize its reliance on specialized CB defence units, although unavoidably the latter have a central role. The individual soldier thus carries rather a large quantity of personal decontaminants with him, and there is a change of clothing for him in company stores. A decontamination area is set up at platoon level in all defensive positions. This has facilities for the complete decontamination of personnel and for the smaller items of equipment. Larger equipments and vehicles receive preliminary decontamination there before being moved on to the battalion decontamination area, or in the case of the largest weapons and vehicles, to the decontamination area set up by the ISB section at brigade level.

Decontamination of terrain is undertaken only when absolutely essential, as in the case, for example, of an important road. ISB-sections have special equipments for this purpose, although in an emergency, flame or bleaching powder (300–500 grams per square metre) can be applied by other units, for example by detachments of the "rescue and clearing forces".

The specialized CB defence units, particularly the battalion CB protection squads, are as mobile as possible so that they can be brought in speedily to areas where damage from CBW attack is greatest.

Capabilities in CBW offence

As noted earlier, Swedish CBW policy excludes the maintenance of an offensive CBW capability. The manufacture of CBW agents, except for chemical irritants, is limited to the quantities needed for defence research and testing purposes, and for the most part is conducted in the FOA 1 laboratories.

Irritant-agent weapons are, however, available in Sweden. Their possession by members of the general public requires a police licence, which is generally only granted to such people as taxidrivers, and then only for weapons that have met the stringent safety requirements of the *Giftnämnden* (Poisons Board) after examination at the *Statens Kriminaltekniska Laboratorium* (State Criminology Technical Laboratory). Irritant-agent weapons are available to the police forces themselves, but their use is generally confined to such specialized operations as capture of armed, barricaded criminals. The principal weapon is a small spray can designed at FOA 1 containing a solution of CS, an agent which has recently been standardized (in preference to CN) in place of BA [18, 1018]. On one or two occasions, such weapons have been used for riot-control-like functions, albeit on a very small scale, notably in the case of the anti-Rhodesian demonstrations at Båstad in southern Sweden in 1968 [1019–1020].

Chapter 4. Research and development: implications for the future of CBW

In this chapter we move away from CBW as it is known today. Because current preoccupations in CB research may become the weapons, defences and employment concepts of tomorrow, we provide an account of existing CB research and development (R&D) programmes. We describe the trends and priorities in these, the manner in which they are conducted, and the practical results which they may bring. Our aim is to identify and illustrate the various risks and benefits of continued CB R&D, and to relate these to possible arms control or disarmament measures.

I. *Risks and benefits of CB research and development*

The one common feature possessed by the multitude of different CB weapons and CBW techniques is their unconventionality. CBW has long remained outside the mainstream of military theory and practice, where the interest has always been with explosives, projectiles and other means of physical destruction. Isolated in a separate category of their own, CB weapons have acquired a unique array of moral and legal proscriptions which may serve to perpetuate their isolation and to discourage serious military interest. In addition, the weapons are difficult to use in comparison with other weapons, and are subject to a variety of other technical and operational limitations. Few countries today appear to have been sufficiently impressed by the weapons actually to acquire them, and in the case of at least one country, the United States, the weapons are special purpose stores poorly assimilated by the armed services.

But all this, it may be argued, suggests nothing more than the hesitation which the military traditionally displays before accepting radically new types of weapon. Greek Fire, gunpowder, and even the arbalest[1], survived lengthy periods of military disfavour and moral opprobrium be-

[1] In 1135, the Second Lateran Council launched the threat of excommunication against those who used the arbalest against Christian troops [1021].

fore becoming assimilated into military armamentaria. During World War I, German flamethrowers incurred as much odium as German poison gas, and in the League of Nations disarmament negotiations after the war, flame and other incendiary weapons were accorded the same special treatment given to CB weapons.[2]

The barriers across which incendiaries had to pass before becoming accepted as conventional weapons (as they are in a number of armed services today) were twofold: psychological and technological. CB weapons may be facing analogous barriers. The flame-projecting *Flammenwerfer* of World War I was too complicated and unreliable a weapon for its military benefits to overcome the professional distaste associated with its use. But once new and better flame agents and disseminating devices had been developed—in particular, the napalm weapons of World War II and the Korean War—flame was seen as an altogether more tractable and militarily advantageous weapon. The inhibitions about using it declined rapidly as the technology advanced. The prejudices may be stronger in the case of CB weapons, supported as they are by a greater weight of international law. But nowadays technology is being relied upon as never before for the solution of military problems, and this, together with the changing character of armed conflict, may rapidly be eroding the remaining inhibitions. Once CBW loses military inexpediency, the inhibitions may disappear completely. Concepts of *justum bellum*, of *Kriegsraison* and of national security have long been relied upon for justifying acts of the utmost depravity considered expedient in times of strife.

On this analysis, then, the fuller assimilation of CB weapons depends very largely on advances made during CB R&D programmes. If improved CB weapons are found—ones that lack the various unpredictabilities, weather dependencies and other unreliabilities of existing CB weapons—it seems probable that military establishments around the world will pay a good deal more attention to them. This is surely a consideration of central importance to CB disarmament negotiations. The fact that international disarmament is today being approached by way of a succession of partial measures, rather than comprehensive ones, reflects tacit acceptance of the impossibility of persuading military authorities to forego anything but their most marginal weapons. A weapon that has become assimilated and conventional has ceased to be marginal. The greater the unconventionality of a weapon, the greater are the chances of negotiating its demise through a partial disarmament measure. The less it has been assimilated by the military, the less reluctant they may be to do without

[2] See Volume IV of this study.

it. Conversely, for such illegal methods of warfare as CBW, the more a proscribed weapon gains in military attractiveness, the more likely is its proscription to be ignored.

It follows that the scope of any partial disarmament treaty must be broad enough not merely to prohibit possession of the weapons concerned, but also to inhibit activities likely to increase their military attractions. If this is not done, the treaty may be short-lived.

If it is not possible to write adequate wording into the treaty, other ways and means may have to be sought. For example, in the case of outlawed CB R&D, informal non-governmental controls might be valuable in supplementing formal verification procedures. One aspect of CB weapon development which is discussed later in this chapter is the extent to which serendipitous progress may occur. Discoveries made in research projects unrelated to CBW have often proved of central importance to CBW programmes. It is a fact, for example, that all the leading CW agents were first encountered during nonmilitary research: mustard gas was discovered in an academic laboratory [1022], and the nerve gases in industrial ones. Formal treaty restrictions on the activities of such laboratories would neither be enforceable nor acceptable.

Traditional modes and patterns of conflict are now in a high state of flux, and this itself may spur assimilation by stimulating CB weapon development. For instance, present-day strategies of deterrence are based on mass destruction capabilities, and CB weapons might provide these for countries to whom nuclear weapons are not available, or in situations where nuclear weapons would be inappropriate. Likewise, the incidence of wars of revolution, counterinsurgency and intervention appears to be increasing, and, in such types of warfare, CBW is claimed to possess singular attractions. While CB weapons might not have been sufficiently amenable to past modes of warfare, they could become increasingly suited to newer military requirements. In the past, the development of a CB weapon has tended to precede the military requirement for it; this may now be changing.

The mere fact that CB R&D programmes continue will promote belief in the utility and potential military value of CB weapons, and may encourage countries that have not already done so to divert resources to CBW activities. New programmes of this type would benefit from the knowledge and expertise that inevitably diffuse out of existing programmes, however secretly they are conducted. The more people working in CB technology, whether offensive or defensive, and the more professional and institutional prestige is invested in it, the more normal and conventional will CBW come to appear.

Grave though these eventualities may be, there is one important mitigating factor. It is quite conceivable that present and future CB R&D programmes on CB defences may bring far-reaching advances. Just as weapons of increased military attractiveness may appear, so may protective equipments of increased efficiency. For combat units, if not for civilian populations, nearly perfect protection against CBW attack is not too far from the realm of feasibility. Were it even to be approached, CB weapons, whatever their refinement, might not be worth very much for battlefield employment. They would join Greek Fire, gunpowder, the arbalest and all the other antique remnants of military history. But this is a vision of the distant future; in the meanwhile, the danger will remain that progress in CB defence technology will bring with it countervailing progress in weapon technology.

II. *The priorities in CB research and development*

We describe, first of all, the relative priorities given to the various projects which make up contemporary CB R&D programmes. Later we provide a technical account of some of the progress being made in selected areas.

Our descriptions are necessarily based on the open literature. Governments tend to keep secret much of their military R&D work, and in the case of CBW the political sensitivity of the subject often (but not always) adds to the military reasons for close security. This has undoubtedly limited the amount of factual information at our disposal, and we have no reliable means of judging whether what we do know about the general trends represents a significant proportion of what there is to know.

But there is justification for supposing that a reasonably good picture can be constructed from the open literature. In the first place, the CB R&D establishments of some countries publish much of their work in the professional scientific journals (in order, as much as anything else, to retain good workers). Of the work done at MRE Porton Down in the United Kingdom, for example, 80–90 per cent is said to be openly published [1023]. A similar, perhaps greater, openness characterizes the Swedish, Dutch and West German CB defence establishments. Although each such publication is usually highly technical, and generally gives little indication of the background objectives against which the work was done, much can be learned about the latter by monitoring successive publications. In the second place, the very fact that CBW is politically sensitive has meant that the CB R&D establishments of some countries have occasionally felt compelled to disclose detailed information about their ac-

tivities in order to dispel damaging misconceptions, and to do so under circumstances where excessive secrecy would be detrimental. Finally, in those countries where the allocation of public funds comes under parliamentary scrutiny, the CBW authorities have often been required to make detailed and public representations in support of budget requests. Disclosures from the USA, where there is in any case a tradition of greater openness about military matters than there is almost anywhere else in the world, have been particularly informative. They have, moreover, permitted insight into offensive CBW trends, as well as defensive ones: not only has the United States been pursuing an active CB weapon programme, but also, in justifying this, it has published some of its perceptions of offensive CBW work in the Soviet Union. The latter are valuable even if they are incorrect, for in some measure they must reflect expert thinking about offensive CBW.

Much of the following discussion is based on the US CB R&D programme. This may appear lopsided, but as far as general trends and priorities go, what holds for the United States is likely also to hold, *mutatis mutandis,* for other countries as well. There may be differences in time scales, resources or underlying policies, but the basic technological problems are international.

In June 1969 the US Department of Defense gave a Congressional appropriations committee a list of its CB R&D priorities.[3] The list provides a convenient point of departure; it was as follows:

THE CHEMICAL AND BIOLOGICAL R. D. T. & E. PROGRAM

The current R. D. T. & E. program in chemical and biological warfare has been divided into three priority groups, which are described in the following paragraphs.

First Priority

1. *New and improved items for individual and collective CB protection.*— This refers to improved overgarments and protective clothing with less physiological stress than those currently available; to an improved mask with less bulk and improved visibility and communication capability; to helmets with CB protection for aircraft pilots; and to protective filters and shelters for missile vans, communication centers, command posts, etc.

[3] It should be noted, however, that in 1969 the hostility of US public opinion towards the US CBW programme reached its peak, culminating in November with President Nixon's announcement of his redefinition of US CBW policy and his decision to dismantle the US biological weapon programme. Against such a background, it is perhaps not surprising that the list gives a rather greater emphasis to the defensive elements of the R&D programme than might be expected from a comparison of the funds allocated to offensive and to defensive CB R&D (see table 3.3). The biological weapon programme, for example, barely shows up at all.

2. *Rapid detection and warning devices for chemical and biological agents.*—There has recently been developed a rapid automatic alarm for lethal chemical agents for Army use. Alarms for incapacitating chemical agents and for biological agents are not available but are necessary for complete defense. Specialized alarms for Navy and for Air Force use are also needed.

3. *New and improved materials and methods for prevention and treatment of CB casualties.*—Atropine and oximes provide effective treatment for some nerve agents, but other agents are refractory to therapy. There is no prophylaxis for chemical agents. A few biological agents can be treated with antibiotics, but there is no therapy for most known agents. A substantial effort is devoted to development of vaccines for both prophylactic and possible therapeutic use.

4. *Improved nonlethal and riot control chemical agents.*—The concept of reducing battlefield deaths and permanent disability by using incapacitating chemical weapons instead of bullets and explosives is relatively new. No completely acceptable agent of this type has been developed as yet; however, an extensive program to do so is under way.

5. *Binary chemical weapons.*—It is possible to make nerve agent weapons which are nontoxic in storage and shipment. This is done by allowing two nontoxic components to react chemically during the time a shell or bomb is in its final trajectory to target. The safety advantages of such a system are obvious, and a substantial program to develop such weapons has been started.

6. *New and improved methods for personnel marking and detection.*—There has been modest success in detecting ambushes with a personnel "sniffer," and its improvement as well as development of other methods of detecting or marking people in some reliable but harmless manner is being investigated.

Second priority

1. *Universal decontamination system.*—This is an attempt to develop one material which will decontaminate all CB agents and be harmless to personnel, equipment, and structures.

2. *Advanced collective protective equipment, especially field shelters.*—The field shelter is intended to provide opportunity for troops to remove their individual protective clothing and masks and be in a safe environment while they eat, rest, and accomplish personal hygiene. Other improvements sought are decrease in weight and increased mobility.

3. *Automatic biological agent sampling system.*—Automatic biological warning devices do not provide agent identification, as is the case with chemical alarms. It is desired to have a sampling system which will be activated by the biological alarm. Laboratory analysis of the sample can then provide identification for medical planning and other purposes.

4. *Advanced field laboratory.*—A field laboratory to analyze biological samples (see above) and to investigate new or unusual chemical agents would contribute significantly to overall CB protective capability.

5. *Improved defoliant dispensers for aerial dissemination.*—The present C-123 aircraft and helicopter dispensers would be unusable against an enemy with more effective antiaircraft weapons. Dispensers for high performance aircraft possessing standoff capability are needed.

6. *Research in biological agent and munition systems.*—The nature and ex-

tent of the threat to our nationl security from enemy use of biological weapons has not been completely defined. Questions such as efficiency of dissemination, whether viruses and bacteria can be mutated to new forms resistant to vaccines, the longevity of microbes in aerosols, and others must be quantitated so that we can accurately assess our vulnerability and develop effective defense.

Third priority

1. *Prevention of technological surprise in CB.*—A broad continuing research program is required to provide some attention to areas of potential technological advances not covered by the specific R. & D. efforts enumerated above. This is particularly necessary in view of the very rapid strides being made worldwide in molecular biology, pharmacology, and related sciences.

2. *Vehicle, structure, and medical CB decontamination systems.*—Pending development of a universal decontaminant, specialized decontaminating materials are needed for medical use, on vehicles and for structures, especially those containing communication equipment.

3. *Large area incapacitating weapon systems.*—A modest effort is being devoted to exploration of munitions which would be effective over relatively large areas (greater than 500 km^2 per aircraft, for example).

In addition, there are a number of areas which represent either continuing research efforts, or special problems of short duration not easily categorized in any of the priority areas above. For example, continuing safety research and inspection is carried on at all in-house CB installations. Analyses and special investigations for intelligence purposes are done as material may become available. A search for realistic but harmless training agents is carried out to improve troop training, and vulnerability studies of critical installations and facilities are done (e.g., missile silos). [45]

Trends in CB protection R&D

As regards the defensive side of the above programme, it seems likely that all armies which take the threat of CBW seriously also accord the highest priority to improving individual and collective physical CB protection. The vulnerability of existing defences against antipersonnel CBW attack lies primarily in the fact that on the one hand physical protection (i.e., respirators, protective clothing, etc.) is the only reasonably certain means of defence, while on the other hand casualty-producing dosages of modern CBW agents may not be detected by the unaided human senses. This has been described in chapter 1. Medical protection, in the form of prophylaxis, has too limited a range of application to be relied upon by itself. At the present time, it is feasible against some, but not all, potential BW agents, and is not feasible against any CW agents with the exception of certain toxins. Active research programmes are under way for developing new and better anti-BW vaccines, and in time these may well greatly reduce the potentialities of BW; this is described later in the chap-

ter. Programmes are also under way for developing immunoprophylactics against nonprotein poisons such as the nerve gases [1024–1026], but fundamental physiological considerations militate against their success. Certain other approaches towards nerve-gas prophylaxis are rather more promising.

Nor will it be possible, now or in the future, to rely on therapeutic as opposed to prophylactic countermeasures. Against some classes of CBW agent, there are antidotes that can prevent death if the victim is treated soon enough; but they can do little to reduce the number of casualties. The status of medical countermeasures against CBW will remain subordinate to that of the physical countermeasures, and this will be reflected in the R&D programmes. To say this is not to deny the importance of medical protection; on the contrary, its damage-limiting function will remain crucial so long as the physical countermeasures remain vulnerable. The range of effective therapies presently available against the effects of CBW agents has several broad gaps in it, and attempts to fill those are among the highest priorities of CB defence R&D programmes. Noteworthy are the searches for treatments of viral diseases, and of nerve-gas poisoning that is unresponsive to standard oxime therapy (as in the case of soman).

Physical protection is effective only if erected in time. Certain modes of CBW attack may themselves provide adequate warning—visible and unexplained discharges from aircraft spray tanks, for example. But an attack may easily be delivered without such warning, and for this reason the development of automatic warning devices is given high priority in several countries. On the BW side, some of the approaches are described in appendix 1 and in Volume VI. But here again, the counter-countermeasures may be relatively simple: an attacker may choose to saturate a target with large numbers of small CBW missiles, for example, rather than release a drifting CBW agent cloud towards it. Under such circumstances, about the only value of the alarm would be to indicate when it was safe to relax physical protection. This can be done adequately with rather simple manual devices, although automatic devices would no doubt be more convenient. As regards battlefield applications, then, R&D programmes for automatic alarms are more of a luxury than a necessity. It is to be noted, however, that once they are available, automatic alarms might force a potential attacker to forgo one mode of attack in favour of another—an on-target rather than an off-target attack. In the context of civilian or rear area defence, rather than military operations on a battlefield, this might be regarded as a major benefit since, from the point of view of cost-effectiveness, the CB attack of such targets might be judged worthwhile only if off-target attacks were likely to succeed.

Against battlefield CBW, therefore, the physical countermeasures of respirators, protective clothing and air-conditioned collective shelters will remain the most important line of defence. As is noted in the previous chapter, the levels of physical protection provided for ground soldiers vary considerably from country to country, but most of them are being improved continuously. However, no army yet has the capability for keeping its soldiers in a state of continuous physical protection while on combat duty. This, it is argued in some quarters, is not only technologically feasible within the not-too-distant future, but is also the only possible means for removing the threat of CBW from the battlefield. CB weapons have the singular characteristic that in principle, if not yet in practice, nearly perfect protection against their effects can be given to ground soldiers: were this ideal to be achieved, the weapons would be of no use to an attacker, however sophisticated they had become. Respirator filters and such-like have now attained such a degree of nonspecificity that *any* CBW agent is likely to be retained by them. Moreover, there are other approaches to filtration that hold out substantial promise, for example the use of electrostatic precipitators for removing suspended aerosol particles from air. Here one may note the interesting work being done at the Dutch chemical defence laboratories in which the application of electrets to aerosol filtration is being studied [1027].

In all armies the existing level of physical protection is vulnerable to some form of CBW attack. It can be argued that if an enemy is intent on securing whatever advantages he may see in battlefield CBW, he will bide his time until the areas of vulnerability are exposed. The surprise-dosage attack, for example, is a standard feature of present-day offensive CBW manuals—the attack designed to exploit the fraction of a minute which it takes a defender to don physical protection. And if the defender decides, in order to guard against this, to put up his physical defences whenever CBW attack seems possible, the time will always come—given the degree of interference which the protection has on routine activities —when the defences have to be relaxed. Against this it can be argued that the opportunities open to the attacker for successful use of CB weapons would then become so circumscribed as to be unattractive—in other words, that existing levels of physical protection are sufficient to deter CBW attack. But in relying on such an appraisal, a definite risk is being accepted.

If this risk were judged too great, the only solution would be to keep combat soldiers encapsulated within protective garments whenever they left collective shelter. The garments would have to be considerably more durable and tolerable than those available today, and would almost cer-

tainly have to embody some radically new design concept. Intensive R&D efforts towards this end have been in progress for several years. One approach that is currently being explored envisages a garment similar to a diver's suit made from air-permeable protective fabric, incorporating a transparent helmet, and maintained under positive pressure. It is not impossible for the muscular movements of the wearer to provide the power source needed to maintain internal air circulation.

Countermeasures as extreme as this might appear excessive when set against the chances of CBW actually occurring. Yet they are in keeping with certain other military developments. In the United States and in the United Kingdom, for example, a lot of work is being done on diminishing the vulnerability of the individual soldier to all types of weapon. Some of the results have been startlingly good. The new lightweight ballistic-protective materials are one example; body armour made from fibreglass/boron nitride composite exists that is capable of pulverizing a 30-calibre bullet fired against it at a range of 30 metres. Then there are the flame-protective suits made of, for example, woven polybenzimidazole fibre [1028]. So promising are these developments that it may not be unrealistic to foresee combat soldiers wearing the twentieth century equivalent of mediaeval armour. Under such circumstances, the notion of permanent CB protection may not seem so far-fetched.

It is instructive to note some of the progress which the US Army has announced that it has made in recent years in CB protection R&D. The following account was given for the year 1968–69 to a Congressional appropriations committee at about the same time as the list of priorities reproduced above (asterisks—****—indicate security deletions).

[Exploratory development:] the research on a sorbent chemical decontamination system was completed, moving the effort to advanced development for fiscal year 1970; a new technique of protective mask production employing the simultaneous molding of two different types of silicone elastomer was successfully achieved; a producible tedlardacron laminate fabric was developed for chemical and biological protective shelter systems. The chemiluminescent biological agent detector and alarm system was breadboarded and the principle proven, thereby progressing the effort to advanced development in fiscal year 1970. Research has indicated that a pyrolizer air inlet can be added to the M-8 automatic chemical agent detector and alarm to provide an incapacitating agent detection capability. Infra red—IR—studies were completed on long path IR chemical agent detectors which predict that these systems can operate in dusty and high humidity environments. Laser technology was shown to be adaptable to IR chemical detection devices. A principal chemical reaction for the detection of chemical incapacitating agents was developed. A breakthrough has been indicated for an effective prophylactic against anticholinesterase agents

—nerve agents—and a specific treatment for poisoning by oxime-resistant anticholinesterase agents has proven successful in initial experiments. ...

We currently have the following items scheduled in advanced development for fiscal year 1970: the Chemiluminescent and Partichrome biological agent automatic detectors and alarms, the new protective mask, new decontamination materials and equipment, a combat vehicle chemical alarm, and collective protection modules for vehicles, missile vans and protective shelters. ... [The chemical agent] contamination survey system is scheduled to begin advanced development in fiscal year ****. It will probably include ground vehicle and aerial chemical detection means with rapid reporting and plotting techniques to conduct large tactical area surveys. ... There are no firm plans to procure and deploy the Partichrome biological alarm for it will probably be a year or so before a decision will be made on whether to advance the Partichrome or its competitor, the Chemiluminescence biological alarm, to engineering development. ... The scheduled type classification date for an automatic biological alarm is the fourth quarter of fiscal year ****. ...

[Engineering development] We will start engineering development on a modular type collective protection system for the improved Hawk missile system shelter. It is comprised of an air filtering and purification unit, air ducts, airlock entryway and the necessary controls for maintaining the required positive pressure in the working van. We will complete engineering development on similar collective protection systems for the M-577 command post vehicle and the M-292 expandable van truck. [1029]

Trends in CB weapon R&D

If the offensive elements are separated from the 1969 list of US CB R&D priorities (pp. 264–266 above) and considered together, they give the impression of a rather incoherent R&D programme. It thus seems likely that the list underrepresented certain elements of the CB weapon programme as it was then being conducted. This is borne out by testimony given earlier in the committee hearings. When asked if a search was going on for lethal CW agents more effective than the nerve gases, a US Department of Defense spokesman replied:

We think from a toxicity standpoint that they are toxic enough. Where we are losing most of the effectiveness is in the dissemination process. So our R&D emphasis is on increasing the operational utility of the ones we have. [45]

Such a view is to be expected, even though it is at variance with testimony given in earlier years (see below). As is described in appendix 3 considerably more has to be done to a chemical weapon to improve its performance than merely to increase the toxicity of its payload. Moreover, the nerve gases are so intensely poisonous that any increase in toxicity might so increase the manufacturing, transportation and storage hazards as to be counter-productive. Indeed, it was a desire to lower the present

hazards that led to the "binary chemical weapons" programme mentioned in the list, and described later in this chapter. Using existing weapons the minimum amount of nerve gas that is judged sufficient to neutralise a square-kilometre target is theoretically enough to kill the entire population of China. This serves to illustrate the relative inefficiency of present CB weapons and the scope for advances open to weapon designers.

Improvements in agent-dissemination technology thus have a high, perhaps the highest, priority in CB weapon programmes. Two major research areas are involved: aerosol studies and micrometeorology. As noted in chapter 1, the state of the weather is critical to the performance of many types of CB weapon; maximum effectiveness thus depends upon an ability to predict or measure prevailing weather conditions, and to exploit the air streams occurring over the target. This is further described in chapter 2 (pages 136–138) and in appendix 3. The particle-size range in which the payload of a CB weapon is disseminated is also critical, as is described in chapter 1 (pages 29–30). The particles in cigarette smoke provide a good illustration. They are approximately 0.2 microns in diameter—too small to be retained efficiently in the lungs. If they were ten times larger, they would be retained so efficiently that a heavy smoker would probably die in a matter of days. If they were ten times larger again, penetration into the lungs would decline, and he could inhale as many of them as he liked without suffocating himself (albeit without much satisfaction). A nerve-gas weapon using a special generator to disseminate its payload as a 1–5 micron aerosol would have several hundred times the effective area coverage of a typical present-day weapon having the same payload but using high-explosive burst dissemination (see appendix 3).

Efforts to improve aerosol generating techniques are presumably a prominent feature of the "large area incapacitating weapon systems" project noted in the R&D priorities list. For effective area coverages greater than 500 km^2, the agent employed would probably have to be a toxin or a pathogen. Some form of aerobiological stabilization would therefore also be needed, for all such incapacitating agents are rapidly degraded in the open air. Aerosol stabilizers, for example certain payload additives and micro-encapsulants, are discussed later in this chapter. Little has been published about current work, but it is obvious enough that if significant advances are made, toxin or pathogen weapons are likely to improve very greatly in performance, in predictability, and therefore in military attractiveness. Breakthroughs in this area cannot be far in the future.

The figure of 500 km^2 mentioned in the list is instructive because it seems to imply that the effective area coverages obtainable from individual aircraft/BW systems do not at present exceed it. This is considerably

at variance with a good deal of the publicity surrounding biological weapons. For example, in 1968 a French authority estimated that a single *Mystère IV* ground-support aircraft dispensing 350 litres of BW-agent slurry could secure 70 per cent casualties among unprotected personnel over an area of 2 500 km² [609]. Likewise, in 1960 the head of the US Army Chemical Corps told a Congressional committee that securing 30 per cent casualties among the entire US population (as opposed to higher casualty rates in areas of high population density) was within the capabilities of ten enemy aircraft [1]. On this basis, the effective area-coverage of each aircraft would have to approach 100 000 km². In a similar vein, 2 years later, he informed the committee as follows:

> Studies and experimental work performed over the past several years by the Chemical Corps have indicated that, utilizing appropriate dissemination techniques, appreciable to large area coverages can be obtained, irrespective of wind direction, employing C-B weapons systems. These studies have shown that large scale air mass movements can be utilized to carry materials artificially introduced into the air mass over extended distances and for relatively long periods of time. Series of experiments conducted in 1957 and 1958 provided definite information that a tracer material could be detected thousands of miles downwind and could be recovered by sampling stations at such distances for periods up to several days. Climatological surveys have also been completed which indicate that the predictable synoptic systems occur over all of the large land masses of the world that would lend themselves to the transport of particulate material to the distances mentioned above. [611][4]

It now seems clear that the more horrendous estimates of the potency of biological weapons were based on the field behaviour of inanimate aerosol clouds. There is nothing particularly startling in finely-divided particulate material remaining airborne for several days and travelling immense distances downwind in the process. But the chances are not high of living pathogens remaining alive for very long during such transport, exposed as they would be to many lethal environmental factors. Ultraviolet radiation is, after all, one of the most powerful disinfectants known, and is only one of these factors. If the aerosol stabilizers referred to above were to live up to the promise which some of them have apparently displayed in the laboratory, the situation might be very different. There is nothing to suggest that this is yet the case. A 1965 publication from the RAND Corporation included the following comment on BW agents:

[4] In his book *Tomorrow's Weapons* [395], Brigadier J. H. Rothschild, former commanding general of the US Chemical Corps Research and Development Command, has translated these observations into antipersonnel and anticrop BW attack scenarios which he illustrates with diagrams of the prevailing air flows over China, the USSR and the USA.

It is the difficulty of disseminating them over hostile territories that constitutes the chief problem in their effective employment. Twenty square miles is about as much as can be effectively covered by a single aircraft. Large-area coverage is a task for vast fleets of fairly vulnerable planes flying tight patterns at modest or low altitudes. [1030]

This seems an altogether more plausible estimate, and is in keeping with the calculations made in appendix 3.

Even if radical improvements do not occur in agent-dissemination technology, continuous improvements in agent-delivery vehicles will be made, so long as offensive CB R&D continues. To be of much value, CB weapons have to be adaptable to conventional weapon-delivery systems, and these are in a state of continuous development. The reason why the US Army decided to dispose of 25 million dollars-worth of 1 000-pound nerve-gas cluster bombs in 1969 was that they had been designed for aircraft of the early 1950s, and were unsuitable for use from the wing stations of modern supersonic aircraft [69].

Although searches for novel CBW agents may not have a particularly high priority in CB weapon R&D programmes, they will not be neglected. To a certain extent they may also form part of purely defensive programmes, not so much in connection with physical protection as with medical countermeasures, alarms and decontaminants. It is necessary to know, for example, whether there are any candidate agents that an enemy might use for which existing therapeutic measures are ineffective. The fact that they might be ineffective is itself an incentive for CB weapon designers. Thus, in 1960 a US Army Chemical Corps spokesman said:

To improve our posture in the lethal agent field we seek agents which act by a mechanism different from that of nerve gas action, so that an enemy cannot defend himself by measures which he may have developed for defense against the nerve-gas type of agent. We also seek agents which are much more effective than those we now know. [1]

In recent years, the other main incentive has come from the notion of incapacitating agents. However exaggerated the hopes and claims for these materials might have been when they were first publicized in the late 1950s, they do nonetheless represent a radically new element in weapon technology, and one that could have substantial politico-military attractions were satisfactory agents to be developed. Much R&D money is being spent on them, as is clear from the following 1969 Congressional testimony from the US Department of Defense:

Incapacitating agents are largely in the R&D phase. In fact the prime emphasis in agent R&D is on developing better incapacitating agents. We are not em-

phasizing new lethal agents at all. ... As far as R&D is concerned, the amount of R&D dollars we are spending on developing more toxic lethal agents is no more than $500 000 per year. We are concentrating on incapacitants. [45]

The spokesman was referring to CW agents. At least in the US programme, biological incapacitating agents passed from R&D into procurement in the early 1960s.

The following excerpts from Department of Defense Congressional testimony indicate some of the progress made in CB weapon R&D during 1968–69:

A chemical incapacitating agent having **** hour effects was developed and tested. ... A very low hazard incapacitating chemical **** agent having a **** hour effective time was tested and its field characteristics established. ... Some major accomplishments [in exploratory development work] were: Chemical: Developed a castable, polymer-bonded smoke mixture with which to facilitate the production of agent CS pyrotechnic mixes. Selected agent **** for further development from ****. Developed methods of synthesis for economic production and developed munition design concepts. Developed munition design concepts for an explosive incendiary bomblet suitable for antipersonnel and antimateriel applications. Developed concepts for, proved the feasibility of, and fielded a personnel marking and identification system using ****. Developed concepts for and proved feasibility of a retroreflector intrusion detection system using ****. Verified munition design concepts for a number of binary-type candidate lethal agents. Biological: Established feasibility for a pneumatic feeder for handling dry biological agents. Developed a geomagnetic sensor system for instrumenting and telemetering small biological weapon systems during testing. Identified a tissue cell line for ****. ...

Major accomplishments ... for chemical weapons advanced development: Proved the feasibility of the 155-millimeter **** and demonstrated the practicality of such a round. Improved the color rendition of certain pyrotechnic colored smoke mixes. Developed production procedures for blending and filling thickened pyrophoric flame agents and applied these procedures to production of triethyl aluminum (TEA) for filling into the warhead of the XM191 multishot portable flame weapon (FLASH).

For biological advanced development: **** Demonstrated the feasibility of an automatic **** pilot production plant. **** Completed engineering studies on cryogenic storage **** demonstrating the feasibility of long term storage under these conditions. Demonstrated the capability for production of tissue cells in deep tank culture without the use of antibiotics.

Plans for fiscal year 1970 are: For chemical weapons advanced development: Initiate process scale-up evaluation on two candidate ****. Let an advanced development contract for a **** flame incendiary module system with a 4-gallon TEA-type warhead. Investigate sound and light for potential in applications ****. Continue investigations of new riot control agents and delivery systems. For biological weapons advanced development: Continue the development of processes for tissue culture of **** to demonstrate the potential of such

weapons for application to defensive studies. Continue studies to demonstrate if the aerosol stability of agents under adverse environmental conditions can be improved. [1031]

It is important to note that US perceptions of the utility of CB weapons may differ from those that are current in other countries. For example, while US CBW authorities see the value of biological weapons as lying primarily in their strategic applications against enemy populations, they value chemical weapons for their battlefield applications against military targets. After estimating that 300 to 400 tons of sarin nerve gas would be needed to "immobilize" New York, a Department of Defense official concluded that "the high logistics burden imposed makes chemical warfare weapons clearly tactical rather than strategic" [45]. But it seems that the USA believes the USSR to have a rather different perception, at least insofar as chemical weapons are concerned. Thus, during Congressional hearings in 1969 the following exchange took place between a committee member, a Department of Defense Intelligence officer and the head of the US Army CBR and Nuclear Operations Directorate:

Mr Black. Sir, if I understand your question, you want to know what differences we see, if any, between the Soviet CBW program and our own. To the best of our knowledge, both programs are quite similar. ****.
Q. Do they have different types of agents, different types of delivery systems than we do, or just how do we quantify this?
Mr Black. ****.
Q. Is this an advantage?
Mr Black. ****.
Q. ****.
General Stone. Sir, we have tailored our selection of agents that we have produced in terms of our visualization of operations with chemical weapons. There is apparently a difference in the way we visualize using these weapons.
Q. What are the differences?
General Stone. Sir ****.
Mr Black. ****.
Q. Don't we ****.
Mr Black. No, sir.
Q. We don't?
General Stone. Sir, we envision military use predominantly against targets. They may be talking about large populations of civilians.
Q. Well, suppose our cities were attacked with biological or chemical agents? Would we not reciprocate in kind?
General Stone. I imagine we would do our best, sir. ****. [1032]

The suggestion apparently was that there were elements in the Soviet CW capability which indicated an interest in the counter-civilian use of chemical weapons.

The foregoing account should give some idea of where the emphasis lies in current defensive and offensive CB R&D activities. Before noting the specifics of some of the projects, it is instructive to look at the *milieu* within which this sort of work is performed.

III. *The conduct of CB research and development*

In table 4.1 figures taken from chapter 3 are collected together that indicate how much certain countries are spending on CB research and development, and how many people are involved in spending it. Of these countries, only the USA is conducting a CB weapon programme; for the year in question, offensive work probably accounted for about one third of the CB R&D budget. The table also includes percentages relating CB defence R&D expenditure to total military R&D expenditure in the countries concerned. It has been estimated that the world is spending rather more than $15 000 million per year on military R&D [1034]. At the present rate one might guess that over the next ten years something like $1 300 million will be spent on CB defence R&D studies (to say nothing of offensive studies) involving some 25 000 man-years of work by qualified scientists.

Two aspects of this are of immediate concern to the present study. One has to do with the relationship between offensive and defensive CB R&D work. For example, to what extent can advances made in purely defensive studies aid concurrent or future weapon programmes? Likewise, to what extent does an offensive programme resemble a defensive one: are there similarities that could confound parliamentary scrutiny or the task of verifying CB disarmament? The second aspect has to do with the relationship between military R&D concerned with CBW and nonmilitary R&D concerned with purely civilian matters. To what extent, for example, might advances made in entirely peaceful areas of research aid CB R&D? These questions of overlap are discussed in the following sections; a fuller treatment is given in appendix 5.

Defence/offence overlap

In some of the countries where there is no CB weapon programme, CB defence authorities have experienced difficulty in persuading domestic critics that their work has been entirely concerned with protection against CBW attack. There have been two principal reasons for this. First, secrecy: if the authorities concerned consider it necessary to conceal some of their

Table 4.1. CB research and development programmes in six Western European and North American countries: Expenditures and personnel involved

Country	Year[a]	Funding for CB R&D ($ mn)[b]	Approximate number of people[c] working in the programme		Percentage of total military R&D funding devoted to CB R&D[d]
			All	Qualified scientists	
Canada	1971	1.9	120	25	*2.4*
Netherlands	1970	1.3	140	..	*9.3*
Sweden	1971	1.6	110	..	*1.9*
United Kingdom	1971	8.4	1 250	140	*1.3*
United States[d]	1971	60	5 700	1 000	*0.7*[e]
West Germany	1969	1.0	100	14	*0.4*

Notes:

[a] The financial year beginning during the year indicated (e.g., FY 1972 in the case of the USA).

[b] These figures are taken from chapter 3 of this volume.

[c] These figures, which are taken from chapter 3 of this volume, do not include university or industrial workers engaged on CB defence R&D contract work.

[d] Based on national military R&D expenditure figures published in *World Armaments and Disarmament, SIPRI Yearbook 1972*, Stockholm 1972, p. 222–25.

[e] The CB R&D percentage has been shrinking steadily since its peak during 1962–65, when it exceeded 1.5 per cent.

work from public scrutiny, then they can scarcely expect to allay public misgivings about it. To a sceptic, secrecy may as well be used to keep the domestic population in ignorance as potential enemies. The need for secrecy is discussed elsewhere in this study[5] and does not concern us here. Second, there is the fact that in order to develop effective defences it is necessary to have some idea of the form which a CBW attack may take, and this will involve at least some study of offensive techniques.

In this context, the need for such studies seems indisputable. Where questions may reasonably be asked is on the amount of detail sought from the work. For instance, there are some toxic chemicals whose molecules so closely resemble those of oxygen that a respirator filter capable of removing them from inspired air might at the same time seriously reduce the amount of oxygen reaching the wearer's lungs. Special equipment would then have to be developed to cope with this. Carbon monoxide is one such agent. But its physical properties, in particular its relative

[5] See above, pp. 18, 155; Volume V, pp. 184–85; and Volume VI, chapter 1. Officials tend to justify their secrecy in two ways. First given the fact that existing CB defences are by no means perfect, it is important not to advertise their deficiencies to potential enemies, who may later—so the justification continues—be led to exploit them. Second, some secrecy is said to be necessary for commercial reasons: fruitful cooperation with industry may be jeopardised if reports are openly published describing materials or processes which are commercial secrets. And in some countries a third reason is often cited, namely obligations not to disclose confidential information provided by allied countries.

vapour density, suggest that it is unsuited for use as a CW agent. Is it then safe to conclude that there is no military requirement for a carbon monoxide filter? Or must actual carbon monoxide weapons be constructed and tested in order to prove or disprove the basic assumption by means of field experiment?

The balance struck between deduction and observation in such matters varies from country to country. In West Germany, for example, the CB R&D programme is confined to protection against known agents (see above, p. 192): no attempt, apparently, is made to discover novel agents that might attract potential enemies, and possibly be used by them. Searches of this type figure prominently in the CB R&D programmes of such countries as the UK and Sweden. In the USA the view goes—or at least used to go—to the opposite extreme. In 1958, General Creasy, head of the US Army Chemical Corps, spoke as follows to a Congressional appropriations committee:

> A defensive program not supported by an offensive program can well be worthless. . . . You cannot know how to defend against something unless you can visualize various methods which can be used against you, so you can be living in a fool's paradise if you do not have a vigorous munitions and dissemination-type program. [443]

The USA was, of course, in the middle of an active CB weapon programme at that time and indeed was seeking to expand it—so much so that in later years it was less the defensive programme that was being supported by the offensive programme as the other way round. When Secretary of Defense McNamara testified before the Senate Armed Services Committee in 1963, he said:

> I do not wish to mislead you into thinking that there is a very extensive capability at the present time in the US forces for [CB] warfare. I think our offensive capability is substantially superior to our defensive. [1035]

The order tended to be, first, weapon development, then development of safety measures for troops using the weapons, and, last, development of protective countermeasures against enemy CBW. This at least was how certain European CB defence authorities within NATO, until rather recently, viewed the work of their US counterparts; in practical terms it meant that US protective equipments were designed more for protection against the sorts of CBW attack that US forces might mount than against those based on the doctrine and weapons of potential enemies. It was not until its January 1972 edition that the *Vulnerability Assessment Pamphlet* of the NATO Weapon Systems Department in SHAPE illustrated the damage that NATO forces might suffer from CW attack with reference to anything other than the properties of US chemical weapons.

The following illustration shows how offence/defence overlaps arise or become necessary. It relates to the hypothetical development of a weapon system that apparently does not yet exist, but which conceivably might appear in years to come. Because of its possible imminence, it would exercise the ingenuities not only of weapon designers but also of CB defence workers.

The advent of the so-called "tactical" nuclear weapons has meant that dispositions of combat units in the field are more dispersed than hitherto: concentrations of troops or armour might attract nuclear attack to an extent that scattered deployments might not. Non-nuclear area-effective weapons have been developed to allow engagement of battlefield targets that offer no specific aiming point, but existing ones—flame, blast or fragmentation munitions delivered by multiple rocket launcher, missile or ground-support aircraft—are effective over a few square kilometres at most. A military requirement can thus be envisaged for a weapon having an area of effectiveness of several tens or even hundreds of square kilometres, for this could be valuable in surprise operations against dispersed battalion or brigade-sized battlefield targets.[6] CBW agents are about the only possibility. The weapon system would have to be one that could create a line source of agent several kilometres long upwind of the target area and across the mean wind direction. The delivery vehicles would have to be capable of setting up this line source without warning the target population in the process. The agent would have to be potent enough for the resultant aerosol cloud to produce a significant number of casualties—and this means upwards of 25 per cent or so—even after it had become diluted during 10–20 km of downwind travel. Moreover, in view of existing levels of CB protection, the agent would have to be so potent that not more than one or two breathfuls of the aerosol sufficed to produce casualties.

To meet these requirements, a weapon-design team would have to embark upon three major areas of study: first, a search for a suitable agent; second, the elaboration of hardware capable of setting up the necessary line source; and third, micrometeorological studies to allow the eventual user of the weapon to be given reliable operating instructions. In the last two areas, adequate solutions may well be within existing levels of knowledge, and maybe also of know-how. Aircraft spray systems, for example,

[6] If used in Europe, such a weapon would probably cause many more civilian than military casualties. A brigade might be expected to occupy a zone about 20–25 km square, corresponding to an average population density of about ten soldiers per km^2. Selected estimates of population density as of mid-1969 taken from the *UN Demographic Yearbook* (1969) are as follows: France, 92 people per km^2; Czechoslovakia, 113; East Germany, 149; West Germany, 237; and Belgium, 316.

have been in a state of continuous development since the 1920s, and some work has apparently also been done on adapting them to unmanned level-flight cruise missiles [254]. It follows from this that in developing defences against the weapon, feasibility in these two areas could be assumed. Only in the first area does the present state of knowledge seem to lag significantly behind the military requirement. In other words, the feasibility of the weapon, and hence the need for defensive countermeasures, may in large part depend on the discovery of a novel CBW agent. The primary objective of both the weapon designers and the defence designers would thus be identical.

Here, then, is a particularly sensitive area of offence/defence overlap. The discovery of an appropriate agent during defensive studies could bring into existence a major new class of weapon having definite military attractions.

The necessary properties of the agent can be specified from first principles. Foremost are its toxicity and its stability. Its casualty-producing dose must be exceedingly small; call it d micrograms per man. For a single breathful to be effective, it would have to be present in concentrations exceeding d micrograms per half-litre of air, or $2d$ mg/m^3. The requirement is that this concentration should exist at ground level even after 10–20 km of downwind travel; to compensate for fallout, dilution and deposition during transport, then, the concentration of agent in the initial line source would have to be a large factor, F, greater than $2d$ mg/m^3. To permit adequate downwind transport, at least part of the agent payload would have to be disseminated as particles or droplets smaller than about 5 microns in diameter. There would therefore have to be something like $Fd.10^7$ particles per cubic metre in the agent line source. But the larger the particle count, the greater are the chances of the particles impinging on one another, and, depending on the physical and chemical properties of the agent, the particles may then agglomerate into clusters that precipitate rapidly. If agglomeration becomes significant at Q particles/m^3, d would have to be smaller than $Q/F.10^{-7}$ micrograms per man. The agent capacity of the delivery vehicle would also impose limitations on the source strength. Some idea of the values of Q/F can be obtained from appendix 3. Because it seems unlikely that the ratio would ever exceed 10^8 or 10^9, the agent would have to be at least an order of magnitude more potent than a V-agent nerve gas,[7] probably several hundred times more potent.

Certain pathogenic microbes have such a potency (see table 1.3), but

[7] As noted on page 42, the LCt50 of VX in man is estimated to be 36 mg-min/m^3. This would correspond to a d-value of 360 micrograms per man.

because of the incubation period they entail before producing casualties, they would be poorly suited to the basic military requirement. A toxic rather than an infective agent would be needed. Poisons which exceed the nerve gases in toxicity are certainly known, and, as is described later in this chapter, more may be found. But few, if any, of them can yet meet the stability and other requirements. These are severe. Candidate agents must be screened for their ability to withstand the thermal and/or mechanical stresses of aerosolization; for inertness towards environmental chemicals such as oxygen and water vapour; and for stability during long periods of storage in contact with container materials. If they are deficient in any of these respects, as will generally be the case, possible stabilizers must also be screened. Then it must be determined whether the candidate agent can be mass-produced economically from accessible raw materials.

The experimental facilities needed for this search would be much the same whether the objective was weapons-oriented or protection-oriented. In addition to toxicity-screening laboratories supported by a copious supply of experimental animals, there would have to be a laboratory that included facilities for studying the properties of aerosolized materials. A pilot plant for verifying the feasibility of different large-scale agent manufacturing processes would certainly be needed for a weapon programme, and might also be considered prudent for a defensive one. In either case, the plant could be used to provide supplies of candidate agents for offensive or defensive development work.

In US parlance, the foregoing work would correspond to the "basic research" and "exploratory development" phases of the programme. In the subsequent phases of "advanced development", "engineering development" and "test and evaluation" the offence/defence overlap would rapidly diminish.[8] A weapon programme and a protection programme would then become distinguishable to an outside observer of, for example, the qualifications of personnel involved or the facilities which they were using.

Suppose that an agent that seemed to meet all the above requirements were discovered. The next stage of the offensive programme would be to ascertain whether the promising observations made in the laboratory held up in the open air under anticipated target conditions, and then to validate design concepts for munition/agent combinations by the construction and testing of prototype weapons. For these purposes an essential requirement

[8] It is significant to note that when, in 1969, a US Department of Defense official was asked to specify the proportion of offensive work in the US CB R&D programme, he replied: "It is difficult to quantify specifically how much exploratory development work is offensive in nature, since much of this work contributes equally to the defensive as well as the offensive effort" [587]. As table 3.3 shows, at least half of the US programme is usually in the exploratory development phase.

would be open-air testing grounds. These would have to be in areas remote from human habitation, and possess climatic and topographical features similar to those of possible target areas. For a full evaluation of the final weapon system, they would have to be many times larger than the area of effectiveness that was being sought. The number of experimental venues of this type around the world is not unlimited, and for this reason the design team might have to rely on scaled-down trials, and the use of simulant weapon-fills that resembled the real agent in all respects except toxicity.

For the development of protective equipments to meet the threat posed by the existence of the novel agent, open-air test facilities might also be considered necessary, but they would not need to be nearly so extensive. Their main function would be to provide a site where possible decontamination methods could be studied, where developmental alarms could be challenged with small agent releases, and where observations could be made of the field persistency of the agent in contact with soil chemicals, vegetation and so forth. Experimental releases of aerosols over larger areas might perhaps be necessary, but as their function would be to validate predictions about aerosol diffusion under different weather conditions, they could be conducted with conventional aerosol generators and tracer materials (such as fluorescent pigment powder) at low source strength over any convenient stretch of country, whether populated or not.

The bulk of the protection development programme could be conducted within much the same sort of facilities as the earlier research and exploratory development phases. The main task would be to see how well existing CB defensive equipment stood up to the new agent—for example, how well the agent was retained by standard respirator filters and protective clothing—and to develop any modifications that might be necessary. Radical changes in existing items of physical protection would probably not be called for, but there might well be a need for new forms of agent detector and of medical countermeasures. The results of work done in these connections could, of course, be highly relevant to offensive studies. As noted earlier, agents against which physical protection or therapy was difficult might make attractive weapons, whether or not they met the particular requirements of the weapon system under consideration here.

Civil/military overlap

In some countries it has been common practice for CBW authorities faced with domestic criticism to emphasize the peacetime benefits of their

R&D programmes. Many illustrations of beneficial "spin-off" from, for example, the US [441, 1037–1043] and British [1044] CB R&D establishments have been published. Examples include the Porton Needleless Injector, which has proved valuable in emergency mass inoculation programmes in several parts of the world, and the Fort Detrick vaccine which was recently used to control a major VEE epizootic spreading across the southern USA. Tear gas and related riot-control equipment are another prominent illustration. What is less emphasized, however, is the spin-off in the opposite direction. As noted earlier in this chapter, there are many instances where discoveries made in academic or industrial laboratories have brought about major developments in CB technology. The CB R&D establishments are well aware of their indebtedness, and in several countries they have made arrangements to link themselves more closely with potentially fruitful areas of civilian research endeavour. These arrangements include direct grants and other subventions for promising academic research projects; applied-research contracts to university and industrial laboratories having experience in promising areas; and information exchange arrangements whereby relevant discoveries are channelled automatically to the CB R&D establishments. Prominent in the latter connection is the Industrial Liaison Program linking Edgewood Arsenal with the US chemical and pharmaceutical industries [1045–1047]: by 1959, eight years after the inception of the programme, samples of about 400 novel toxic chemicals per month were passing from drug houses and the like to Edgewood Arsenal [443]. In some countries, for example the Netherlands, virtually all the CB defence R&D is performed in the civilian sector; in others, for example France, it is mostly done in the military sector. In the USA during the mid-1960s, the CB R&D budget was split almost equally between the in-house laboratories and outside contractees. In earlier years, the universities and industry had made a much smaller contribution: during fiscal year 1960 they received 18 per cent of the budget [1]. In later years also their participation was smaller: 26 per cent during fiscal year 1969 [45]. (The late 1960s were, of course, years in which the US CBW programme came under strong domestic criticism, and this may account for the decline in civilian participation, particularly from the universities.)

It is important to distinguish between intentional and serendipitous overlap—between formal involvement of civilian laboratories in CB R&D, and the chance contributions that they may make to it. Formal arrangements can be subjected to formal controls, for example those of CB disarmament verification. But serendipity is beyond control, and has in the past figured largely in the progress of CB technology, both offensive and defensive. No disarmament treaty could have prevented Gerhard Schrader

from discovering the G-agent nerve gases, or Ranajit Ghosh the V-agent ones:[9] both were members of industrial research teams engaged on purely peaceful and worthwhile searches for new pesticides.

Pesticide research is likely to continue providing impetus to CB weapon programmes. With the exception of their ultimate target organisms, there is not a great deal of difference between methods for applying pesticides and those for CBW agents. The hardware, the meteorological and topographical considerations, and even the mode of action of some of the chemicals, have many similarities, so that improvements in pesticide techniques may mean potential improvements in CBW techniques. Manufacturing facilities set up to produce pesticidal agents and hardware might in the future be more adaptable to CB weapon supply than they are now. For instance, the comparatively recent insecticide technique known as "ultra-low volume spraying" [1048] has led to hardware design specifications that make agricultural spray systems much more like military ones. Likewise, the search for pesticides that impose a lesser burden on the environment may lead to the use of organophosphorus pesticides that are nearer to the nerve gases in chemical structure, and therefore also in production technology. For instance, developmental methylphosphonothioate pesticides, such as Monsanto's *Colep* [1049], are now receiving serious attention. Then there is the growing interest in biological pesticides —pest control by pest pathogens, rather than by poison [1050–1053]. This has meant a substantial increase in the numbers of people around the world studying such problems as the mass production, storage, dissemination and aerobiological stabilization of pathogenic microbes.

There are other areas where serendipitous advances may occur: molecular biology, weather forecasting, aerosol physics, drug design and endocrinology, to mention only a few. Some of them are exemplified later in this chapter.

IV. *Some CBW related research areas*

This section provides a technical account of certain research areas from which significant advances in CBW technology could result. Its coverage is not intended to be comprehensive, for its purpose is to exemplify and substantiate some of the general comments made in the two preceding sections. The examples which it offers are taken both from current CB R&D projects and from civilian research projects that could provide spin-off into CB programmes.

[9] See Volume I of this study, pp. 70–75.

Micro-encapsulation

Micro-encapsulation is a technique for wrapping microscopic particles or droplets in individual protective coatings. Its development was begun by the National Cash Register Company (NCR) of the USA before World War II, and came into commercial use with NCR's carbonless copying paper in 1954.[10] From then on, a rapidly expanding range of applications was developed for microcapsules, and new ones are continually being found. They are used in the pharmaceutical industry to mask the taste of unpleasant drugs, to prolong shelf-life, and to provide for sustained drug release inside the body. They are used in adhesives and sealing compounds, in food and drink preparations, in liquid-crystal applications, and in a host of other fields [1054].

Solids, liquids or even gases can be held within capsules made from many different types of material, and ranging in size from less than a micron in diameter to a centimetre or more. The technique may be valuable wherever a material has to be kept in a certain place for a period of time, protected from light or from its environment, its physical properties modified, its taste or smell masked, or its release controlled. Problems of this type are common in CBW operations, so that the participation of CB laboratories in the development of the technique is scarcely surprising. Prominent in this connection has been the work done in the USA by the Stanford Research Institute (SRI) for Edgewood Arsenal on CW agent micro-encapsulation, and the Illinois Institute of Technology Research Institute (IITRI) for the US Air Force on BW agent micro-encapsulation.

As regards CW agents, the following possibilities were being explored by SRI in 1964: the encapsulation of solid and liquid agents to provide protection during pyrotechnic dissemination; sustained release capsules for maintaining effective concentrations of volatile agents over an area for prolonged and predetermined periods of time; "leaky" capsules to assure release of liquid agent on contact with the skin; agent capsules in which the wall provides the major source of fuel for pyrotechnic dissemination; the encapsulation of protein agents and other photosensitive materials to protect against degradation by sunlight; and rupture capsules, for use in area denial, that release agent when trodden on [170]. A more recent SRI publication refers to capsules that

[10] The obverse of the top-copy sheet is coated with an invisible layer of microscopic dried-oil capsules containing a solution of two leuco-dyes. The microcapsules rupture when struck by the typewriter key, allowing their contents to flow out onto the copy sheet. This is coated with a layer of acidic clay to absorb the dyestuff and convert it to an exact coloured replica of the type face.

can be released from a jet airplane at a speed of 1.2 mach without breakage, but do break on impact at the ground. The capsules are loaded into the airplane as a slurry in water, and the capsules are dried by passage through the air. Small capsules that can be fired from a shotgun without breaking have been prepared for application to a small area difficult to reach, as the tops of trees. [1055]

This work was done for the US Air Force and, although the account made no mention of what could be put into the capsules, their CBW relevance is obvious enough.

Perhaps the most significant CB weapon application of micro-encapsulation is in the stabilization of aerosolized CBW agents, as in the photoprotection technique mentioned above. In 1960, SRI contracted with Edgewood Arsenal to "obtain fundamental information on the formation of encapsulated aerosols for possible application to the solution of problems on the dissemination of chemical agents" [1056]. Three years later, SRI filed a patent application on an aerosol micro-encapsulation technique [1057]. The specification gives rather little information on the properties of the microcapsules produced, but to judge from the contract progress reports of the time [1058–1059], they left something to be desired as regards size, stability and payload.[11] In 1967 SRI observed that the encapsulation efficiency was "sometimes low but could probably be improved" [1055].

Meanwhile, the IITRI team had been studying the application of their own aerosol-encapsulation techniques[12] to biological agents. The following is an abstract of a report prepared in March 1967:

The study provides information on the feasibility of disseminating microencapsulated biological agents. Experiments with encapsulation of biological materials has been limited to small-scale studies using the more hardy forms of bacteria and viruses, and results are equivocal because of the lack of a definite assay procedure. Nevertheless, several techniques show promise for successfully encapsulating biological agents. The requirements for a coating material are set forth in this report: they limit the selection possibilities: several promising materials are available. Of the three major problem areas associated with the dissemination of biological agents, microencapsulation shows definite possibilities for solving only one—protecting the agent from ultraviolet light. Microencapsulation does not appear to be a feasible method for overcoming present delivery altitude limitations because of particle size and host release restriction.

[11] The micro-encapsulated aerosol generator that SRI was paying most attention to in 1962 was capable of coating a variety of liquids with solid polymer, up to 90 per cent of the agent charge becoming encapsulated. The microcapsules ranged in diameter from 3 to 15 microns, the coating accounting for about half their weight [1054].
[12] US patents nos. 3 208 951, 3 294 704 and 3 159 874.

A microcapsule consisting of a subliming material is suggested for this problem area. Preliminary tests indicated that the development of a macrocapsule is technically sound but required solutions of a number of complicated problems before a practical system could be developed. [1060]

The progress made in subsequent work in this field is not recorded in the open literature.

Just as micro-encapsulation can be used to increase the effectiveness of CBW agents, so it can be used to enhance the performance of pesticides. The objectives, the types of protection sought and the technologies are closely related. The NCR Company has gained considerable experience in applying its micro-encapsulation methods to viruses and bacteria [1061], and in 1963 it was able to provide samples of micro-encapsulated *Bacillus thuringiensis* spore clumps made in five different ways. These were successfully field-tested as insecticides against the European corn-borer. The purpose of the micro-encapsulation was to give a product suitable for use with gravity-flow equipment, and to lengthen the activity period of the biological-control agent in the face of hostile environmental conditions. The samples were as efficient as DDT and the standard clay granular formulations of the bacteria; and the report noted the possibility of applying formulations containing insecticides for immediate release concurrently with materials encapsulated for later breakdown and release [1062], making it natural to talk about "time capsules" [1063]. Since a continual small and timed release from capsules could kill insects in soil and plant foliage with less residue risk than conventional pesticide applications, a civilian need is stimulating work in this area; in 1967 NCR obtained contracts from the US Department of Agriculture to develop capsules of polyhedrosis virus or chemical insecticides that would dissolve in water or otherwise break down to release their contents over a period of 1–6 weeks [1064]. The targets envisaged for such attack were weevils, grasshoppers, European corn-borers, corn root-worms and cotton boll-worms.

The possibilities for spin-off into CB technology from such activities are obvious enough. Other significant overlap areas include the micro-encapsulation of enzymes for possible enzyme replacement therapies [1065–1066], the many other pharmaceutical applications, and such oddities as the use of encapsulated live bacteria in cosmic dosimeters [1067]. Most of the information on the preparation of microcapsules is contained in the patent literature, which has been reviewed by a number of authors [1067–1068].

Novel chemical agents

An enormous number of substances have been examined as potential CW agents: the US Army alone screened about 100 000 different ones during 1963–67 [1069]. Such activities form a central part of the search for new chemical weapons, for areas where improved defences may be needed, and the "prevention of technological surprise". In recent years the focus has been on incapacitating chemicals, at least for the USA and certain of its allies. Rather sophisticated preliminary screening procedures have been elaborated which can be applied by relatively unskilled workers, including laboratory technicians [1070–1071].

The pharmacological properties that a candidate CW agent must possess are stringent, no less than the chemical and physical properties. Attractive candidate agents are therefore rare, despite the enormous number examined. The agent must be able to cross one of the barriers between the exterior and the interior of the body—the skin, the mucous membranes of the nose, mouth, trachea or bronchi, or the alveolar membrane of the deep parts of the lung. Once it has done this, it must be able to get into and out of the bloodstream easily enough to latch onto its target in the body and, at the same time, it must resist renal filtration: the kidneys automatically filter off from the blood all small molecules and ions, and then process the filtrate to re-absorb as much as possible of anything worth conserving. Within limits, this means that the agent should ideally exist in the blood plasma in combination with proteins or lipids. The combination must be a loose one, for as the blood circulates through the minute vessels of other organs, free toxic agent must be able to pass out of the vessels into the fluid in the tissue spaces, and from there it must find its way into the cells with whose function it is to interfere. It will not be a very effective toxic agent if it can easily get into all the cells of the body since a large fraction of the dose may then be employed in affecting the functioning of cells whose activities are not crucial for the desired outcome: powerful poisons produce *characteristic* signs and symptoms, indicating a distinct localization of action. It follows that powerful poisons must possess two properties in unusual degree: a capacity to get into a particular kind of cell unusually easily; and a high capacity to bind to, and interfere with, some essential functional element of this cell. Other things being equal, the fewer the number of kinds of cell in the body that a poison can enter, other than its target cell type, the more toxic it will be. [1072]

The ability to pass some kinds of biological barrier and the inability to pass others, and the ability to bind to some kinds of body element

and not to others, depend on chemical and physical factors concerning which knowledge is still elementary. This is not surprising because the properties can scarcely ever be observed in isolation. Long and laborious attempts have been made to bring order into knowledge in this field, but, as one authority has put it, it remains a field in which there are well-tilled plots of cultivated empiricism surrounded by wide expanses of barren ground [1072].

This topic is merely a subdivision of the larger one of relations between chemical structure and pharmacological action, and work in this field is strongly motivated in many parts of the world: this is where the drug firms look for efficient development of new products. It is as much the case now as it ever was that powerful new drugs appear by chance, and that their development is largely concerned with the moderation of side-effects or with modest improvements in efficacy and convenience of use [1072]. Much the same applies to CW agents.

Be that as it may, publicists among the searchers for new CW agents have in the past described confident methodologies for their work [1045–1046, 1073]. They have distinguished three different approaches: chemical, physiological and natural-product. The first of these, sometimes called the "Beilstein-Edisonian" approach, involves monitoring the rapidly expanding chemical and pharmacological literature for new compounds possessing physiological activity, or screening novel compounds encountered during academic, industrial or in-house chemical synthesis. Candidate agents may thus be revealed, or leads for further programmes of synthesis may be obtained. Relationships between chemical structure and physiological activity will be sought, and exploited to the full if discovered. Most of the major CW agents have been found by this method.

The physiological approach starts from biochemical studies of physiological function, particularly enzyme-mediated ones. There are many biochemical processes taking place in the body that are profoundly disturbed by minute amounts of extraneous chemicals, and since these processes may be essential for continued life or well-being, such chemicals may be candidate CW agents. By close examination of the biochemistry involved it may be possible to predict hitherto unencountered chemical structures to which the processes are still more sensitive. For example, should the structure of the active site of a crucial enzyme become known, it may be possible to design molecules likely to inhibit it. One at least of the pharmacological requirements set out above might then be satisfied.

The natural-product approach involves study of the active principles of poisons that occur in nature. Occasionally these poisons are themselves candidate CW agents, but the main aim is to discover toxic structures

Table 4.2. Relative lethalities of selected natural and synthetic poisons: order-of-magnitude groupings relative to sarin

Synthetic poisons[a]	Relative lethality[b] (sarin = 1 000)	Natural poisons[c] Name	Source
Homocholine Tammelin-ester[1] Dioxin[2] 33 SN+ [3]	10^{-4} to 10^{-3}	Botulinal toxin type A, α-fraction[31]	Botulinal toxin type A
		Botulinal toxin type A, crystalline[32]	*Clostridium botulinum* bacteria
		Tetanal toxin, crystalline[33]	*Clostridium tetani* bacteria
Ethylthioethyl-metasystox+ [4] Seleno-VE[5] HC-3[6] VX[7] Ro 3-0422[8] TL 1236[9] Gd-42[10] DCMQ[11] Phospholine[12] 3152 CT[13] Soman[14] (−)-Sarin[15]	10^{-3} to 10^{-2}	Botulinal toxin type A, amorphous[34]	*Clostridium botulinum* bacteria
		Palytoxin[35]	*Palythoa* zoanthid coelenterates
	10^{-2} to 10^{-1}	Batrachotoxin[36]	Kokói arrow poison
		Ricin, crystalline[37]	Castor beans, the seeds of *Ricinis communis*
		C-alkaloid E[38]	Calabash-curare arrow poison
		Saxitoxin[39]	*Gonyaulax catanella* dinoflagellate marine algae
	10^{-1} to 1	Tetrodotoxin[40]	Puffer-fishes and certain salamanders
		Atelopidtoxin[41]	*Atelopus zeteki*, a Panamanian arrow-poison frog
		Abrin, crystalline[42]	Jequirity beans, the seeds of *Abrus precatorius*
	1 to 10	Indian Cobra neurotoxin[43]	Indian Cobra venom
		BWSV-toxin[44]	Black Widow Spider venom
Sarin[16]	10 to 10^2	Ricin, amorphous[45]	Castor beans, the seeds of *Ricinis communis*
		Kokói arrow-poison[46]	*Phyllobates aurotaenia*, a Columbian frog
		Russell's Viper venom[47]	*Vipera russelli*
Tabun[17] Armin[18] Gd-7[19] Methyl fluoroacetate[20]		Israeli scorpion venom[48]	*Leiurus quinquestriatus*
		α-Aminitin[49]	The Death-Cap mushroom, *Amanita phalloides*
	10^2 to 10^3	Indian Cobra venom[50]	*Naja naja*
		Brown Widow Spider venom[51]	*Latrodectus geometricus*
	1 000	*d*-Tubocurarine[52]	Tube-curare arrow poison
Hydrogen cyanide[21] *Cadmium oxide*[22] Mustard gas[23] Parathion[24] Lewisite[25] *Phosgene*[26] *Arsine*[27]	10^3 to 10^4	Aconitine[53]	Roots of Monk's-Hood, *Aconitum napellus*
		Physostigmine[54]	Calabar beans, the seeds of *Physostigma venenosum*
		North American scorpion venom[55]	*Centruroides sculpturatus*
		Strychnine[56]	*Strychnos nuxvomica* bark or seeds
	10^4 to 10^5	Black Widow Spider venom[57]	*Latrodectus mactans mactans*
		Ouabain[58]	*Strophanthus gratus* seeds
Cyanogen chloride[28] *Chlorine*[29] *White arsenic*[30]	10^5 to 10^6	Nicotine[59]	*Nicotiana* tobacco plants
		Western Diamondback rattlesnake venom[60]	*Crotalus atrox*

[a] *Homocholine Tammelin-ester* is 3-trimethylammoniopropyl methylphosphonofluoridate iodide; *Dioxin* is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin; *33SN*$^+$ is O-ethyl S-2-trimethylammonioethyl methylphosphonothiolate iodide; *Ethylthioethyl-metasystox*$^+$ is OO-dimethyl S-2-(S′-ethyl-S′-ethylthioethylsulphonio)ethyl phosphorothiolate bromide; *Seleno-VE* is O-ethyl Se-2-diethylaminoethyl ethylphosphonoselenolate; *HC-3* is 4,4′-*bis*(NN-dimethyl-N-2-hydroxyethylammonioacetyl)biphenyl dibromide; *VX* is O-ethyl S-2-diisopropylaminoethyl methylphosphonothiolate; *Ro 3-0422* is 3-(diethylphosphoryl)-1-methylquinolinium methosulphate; *TL 1236* is 2-methyl-5-trimethylammoniophenyl N-methylcarbamate chloride; *Gd-42* is O-ethyl S-2-(S′S′-methylethylsulphonio)ethyl methylphosphonothiolate methosulphate; *DCMQ* is 5-NN-dimethylcarbamoyl-1-methylquinolinium bromide; *Phospholine* is OO-diethyl S-2-trimethylammonioethyl phosphorothiolate iodide; *3152 CT* is 1-(3′-trimethylammoniophenoxy)-3-(3′-trimethylammoniophenoxy-5′-NN-dimethylcarbamoyl)propane diiodide; *Soman* is 1,2,2-trimethylpropyl methylphosphonofluoridate; *Sarin* is isopropyl methylphosphonofluoridate; *Tabun* is ethyl NN-dimethylphosphoroamidocyanidate; *Armin* is O-ethyl O-4-nitrophenyl ethylphosphonate; *Gd-7* is O-ethyl S-2-ethylthioethyl methylphosphonothiolate; *Mustard gas* is *bis*(2-chloroethyl) sulphide; *Parathion* is OO-diethyl O-4-nitrophenyl phosphorothionate; *Lewisite* is 2-chlorovinyldichloroarsine. For structural formulae, see table 1.4 and page 23.

[b] The "relative lethality" was determined as follows. Reported LD50 figures for the following combinations of experimental animal and route of administration were assembled from the cited literature: iv/mouse, ip/mouse, sc/mouse, iv/rat, sc/rat, iv/guinea-pig, iv/cat, iv/rabbit. Within each animal/administration-route set, each agent LD50 was converted into a lethality-index relative to sarin, assigning a reference value of 1000 to the sarin LD50 concerned. For example, the sc/mouse index for batrachotoxin is taken as 10 because its sc/mouse LD50 and that of sarin were around 0.002 and 0.2 mg/kg respectively. In this table, the agents are ranked according to their lowest lethality-index. Only in the case of the italicized synthetic poisons were animal parenteral LD50s unavailable. In these cases, respiratory LCt50s were used instead, except for white arsenic, where an oral LD50 was used. The respiratory LD50 of sarin in man is estimated to be about 1000 micrograms.

[c] The venoms of *Vipera russelli*, *Leiurus quinquestriatus* and *Latrodectus geometricus* appear to be the most poisonous snake, scorpion and spider venoms known.

Sources:

[1] [1406] [2] [1099] [3] [1420] [4] [1416] [5] [1425] [6] [1104, 1498–1503] [7] [1504] [8] [966, 1411–1412] [9] [1427] [10] [551, 977, 979, 1401] [11] [1401] [12] [1401, 1414, 1420] [13] [1429] [14] [975, 979, 1375, 1378, 1383–1385, 1389, 1398, 1400–1402, 1505] [15] [1506] [16] [979, 1184, 1365, 1371–1372, 1377–1379, 1386, 1388, 1401, 1404, 1406–1407, 1420, 1506–1509] [17] [979, 1004, 1375, 1383, 1388, 1390, 1400, 1404, 1407] [18] [504, 979, 1510] [19] [551, 979] [20] [1511–1512] [21] [62] [22] [240] [23] [1513–1514] [24] [918, 1399, 1401, 1515] [25] [1516] [26] [54, 56, 62, 1517] [27] [1516] [28] [62] [29] [1518] [30] [1397] [31] [1519–1520] [32] [87–88, 106] [33] [1521] [34] [91] [35] [1111] [36] [1522–1526] [37] [1527] [38] [1110] [39] [1528–1530] [40] [1499, 1525, 1529, 1531–1534] [41] [1535] [42] [1536] [43] [1537] [44] [1538] [45] [1116, 1527] [46] [1523] [47] [113, 1539–1543] [48] [1541, 1544] [49] [1545] [50] [113, 1537, 1541, 1546–1547] [51] [1548] [52] [1499, 1525, 1532, 1549–1550] [53] [1551] [54] [1390, 1401, 1426–1427, 1552] [55] [1553–1556] [56] [1499, 1525] [57] [1538, 1548] [58] [1551, 1557] [59] [1558–1560] [60] [113, 1554, 1561] [61] [1562]

that can be replicated in synthesizable chemicals. The potential fruitfulness of this approach is growing fast. In recent years analytical techniques have improved vastly, so much so that the complex mixtures of chemicals occurring in newly encountered toxic natural products can be analysed in a matter of hours or days, rather than weeks, months or years, as hitherto. Especially noteworthy in this connection is the computerized gas-chromatography/mass-spectrometry technique developed at the Department of Toxicology of the Karolinska Institute in Sweden [1074]. Moreover, the accelerating search for new sources of food has brought great ranges of hitherto unexplored natural products under detailed scrutiny. In recent years, the tremendous harvestable-protein potential of the oceans has become apparent, for instance, and many nations are rapidly expanding their fishing operations, penetrating further into unexploited marine areas, and making use of a greater variety of marine organisms, including invertebrate animals and seaweeds. A number of these contain highly active poisons, and more will undoubtedly be discovered [1075]. The spectrum of natural-product and CW agent toxicity exemplified in table 4.2 shows how remarkably far the CW chemists have already come in mimicking the potency of natural poisons; but it also shows the scope there is for further advance.

The manner in which the search has been put into practice is illustrated by the following excerpts from the project descriptions or progress reports of US Army contractees engaged to search for new CW agents. They have been selected to give an idea of the scope of the search and of the effort put into it.

(1) The screening of extracts from the cultures of several hundred strains of microorganisms was continued and resulted in the selection of 30 strains worth further investigation. Large-scale fermentation runs were conducted with these strains. Ten of these produced toxins at levels high enough for further interest. The isolation of the toxins is being pursued. Work on the isolation of *Physalia* toxin was discontinued because of the inherent instability of the proteinaceous toxin. Since the fractionation of various snake venoms did not yield any toxic oligopeptide fraction, this approach to synthesizable, low molecular-weight, toxic peptide models was not pursued further. The venom of *Conus* (cone shell) was shown to be a high molecular-weight peptide; further investigation was, therefore, discontinued. Several toxic sponge species were found and are being processed for the isolation of the toxin(s). A highly vesicant intermediate of the synthesis of oenanthotoxin was prepared in amounts sufficient for toxicity screening. An additional series of organonitrofluorine compounds was synthesized by the subcontractor ... and screened. The inherent instability and low toxicity of these compounds led to the discontinuation of further work in this area, which was replaced by the synthesis of possible anticholinesterases of the sulfonyl fluoride type. [1076]

(2) A three-man expedition to the rain forests of Peru and Equador collected samples of 2 500 plants, which are similar to plants collected in previous years and contained biologically active materials. Extracts are being prepared from these plants and screened for biological activity. [1077]
(3) A total of 3.4 g of pure puffer poison has been isolated during the year and has been made available to the current effort on structure determination.[13] Ten thousand pounds of the 15 000 pounds of puffer viscera obtained in FY 1960 have been processed. [1078]
(4) *Approach:* Mechanism of incapacitation and/or of lethality by selected compounds will be studied, including physicochemical events involved in brain function, the action of respiratory centers, enzymatic processes and electrical phenomena occurring during heart action. *Statement of work assigned:* ... Study the inhibition of muscle relaxation by ryanodine,[14] and the inhibition of myokinase and trans-phosphorylase by unknown components of crude ryanodine extracts. ... [1079]
(5) The object of the investigation is to obtain information on the biochemical mode of action of toxic and incapacitating compounds, and on the fundamental mechanism of ATP synthesis in mitochondria. The specificity of interaction of compounds including benzimidazoles, butyrophenones, phenylhydrazones and phenothiazines with submitochondrial particulates and mitochondrial membranes are to be studied. The effects of dicyclohexyl carbodiimide, rutamycin, DIO-9 and tributyltin chloride on oxidative phosphorylation coupling factors have been determined. [1080]
(6) *Purpose:* To provide basic information in the field of allergy with a view to its possible utilization in incapacitation; and to study a plant toxin [ricin]. [1081]
(7) *Statement of work assigned:* Determine the fundamental nature of the skin barrier; elucidate the principles governing alteration of the penetrability of this barrier; and concurrently apply the knowledge acquired to the development of optimal materials and techniques for increasing or decreasing the penetration of skin by biologically active materials. [1082]

Skin-transferral agents

Excerpt (7) above relates to one of many similar projects. The search for substances that modify the permeability of skin and other tissue towards extraneous chemicals has long been pursued, both as regards finding "skin-transferral agents" for increasing the permeability, and permeability-lower-

[13] This was a large US Chemical Corps programme [1053] which began in 1950 and culminated some 13 years later in R. B. Woodward's structure determination at Harvard University [1054]. Puffer poison occurs in certain newts of the genus *Taricha* and in a variety of tetraodontoid fishes besides the Japanese Fugu or puffer-fish [1053, 1055–1057]. Its active principle has variously been called Tarichatoxin, Tetrodotoxin and Fugutoxin. Tetrodotoxism is one of the most violent forms of fish poisoning known, and occurs frequently in Japan where the Fugu is considered a delicacy. The toxin is described in appendix 2.
[14] Ryanodine is the alkaloidal active principle of *Ryania speciosa*, a genus of small shrub and tree occurring in tropical America, from the ground stemwood of which is made ryania, used as an insecticide.

ing agents for use in barrier creams and other protective ointments. An example of a skin-transferral agent is dimethylsulphoxide (DMSO). Until its possibly harmful side-effects were appreciated, this substance held out great promise for use as an ingredient in topically-applied medicaments and in other drug preparations where an enhanced penetrability through the lining of vascular or reticuloendothelial vessels was called for [1396]. This is a typical civil/military and offence/defence spin-off area of research, for just as DMSO might be used to improve, say, cortisone treatments [51] or oxime nerve-gas therapy [1088–1089], it can also be used to increase and accelerate percutaneous toxicity [1090]. Thus, studies in Canadian CB defence laboratories have shown that the lethal dosage through the skin of guinea pigs of a 50 per cent solution of soman in DMSO is six times smaller than the lethal dosage of pure soman [1091]. Likewise, at Edgewood Arsenal, it has been shown that the time to death of rabbits can be halved if droplets of VX/DMSO mixture, rather than pure VX, are placed on their skin [1092]. DMSO is certainly not unique in these respects; in this particular Edgewood study, for example, a range of dimethylamides was examined, of which NN-dimethylpalmitamide was as effective as DMSO. By 1961, Edgewood had studied about 200 possible skin-transfer adjuvants for VX [1093].

The mode of action of DMSO and related skin-transferral agents is still not entirely clear, but will presumably become explicable in terms of physical chemistry. For different classes of agent, quite different mechanisms can be envisaged. For instance, enzymes might be used that are capable of degrading skin tissue. In this connection, the ability of the enzyme hyaluronidase to break down connective tissue (by depolymerising a mucopolysaccharide occurring in it) may be mentioned. The time taken to paralyse goats given intramuscular injections of succinylcholine chloride can be significantly shortened by including this enzyme in the innoculum [1094].

Skin penetrability is one of the most sought-after features in CW agents intended for battlefield use. Adjuvants may make it possible to confer this property onto CW agents that possess other militarily attractive features. Percutaneous incapacitating agents, for example, might be developed in this fashion, as is noted in chapter 1 (page 47).

Lethal agents

Given the existing state of knowledge, novel lethal agents seem more likely to appear by accident than by design. Of the three search techniques mentioned earlier, the Beilstein-Edisonian approach therefore seems the most promising, but its successes, if there are to be any, cannot be pre-

dicted. In recent years, the literature has contained reports of several new synthetic poisons of great toxicity, but the interest which they have aroused in CW laboratories is not known. The case of *2,3,7,8-tetrachlorodibenzo-p-dioxin* may be mentioned as an example. This compound was shown in 1965 to be the substance mainly responsible for the toxic hazard occurring during certain manufacturing operations involving 2,4,5-trichlorophenol; it may appear, for instance, as a contaminant of the widely used herbicide 2,4,5-T [1095]. As a pollutant, its dangers are primarily those of chronic toxicity: it is a potent teratogen, for example, and plant workers exposed to it have suffered extremely unpleasant long-term effects. These have included severe and persistent acne, sometimes over the entire body; muscular weakness; and a variety of psychological effects such as weakened memory and power of concentration, and alcohol intolerance [1096–1098]. Upon closer study the substance was also found to possess an astonishingly high acute toxicity, the lethal dose in guinea pigs being about fifty times smaller than that of the nerve gas sarin [1099]. The open literature does not reveal whether this toxicity came as a surprise to CW laboratories.[15]

Too little is yet known about the interaction of the different factors that contribute to drug action for the physiological approach in the search for new CW agents to be anything more than a subdivision of the chemical approach. In years to come, its importance may grow as molecular pharmacology gains in predictiveness. For the present, all that can be done is to keep track of the various biochemical processes that have proved susceptible to poisons. As an example, the work on the blockade of neuromuscular transmission may be noted. Such studies have substantial practical civil importance, and in recent years understanding of the molecular basis of the transmission has been expanding rapidly [1100]. Neuromuscular blocking drugs, such as the muscle relaxants, have many applications in diagnosis, therapy and surgery [1101–1102], and others are valuable tools in fundamental pharmacological research. The nerve gases are the prime examples that have CW importance. As noted in chapter 1, nerve gases work by inhibiting acetylcholinesterase: this leads to accumulation of the chemical transmitter substance acetylcholine at neuromuscular junctions (and anywhere else in the cholinergic nervous system reached by nerve gas), thus prolonging depolarization of the end-plates of muscle fibre and soon rendering them inexcitable. Blockades having correspondingly damaging consequences can be caused by several other mechanisms

[15] A number of dioxane derivatives were certainly being examined by US Army Chemical Corps contractees in the mid-1950s [1103].

[1101]. The synthesis or the release of the acetylcholine itself can be blocked; or cholinomimetic drugs can be introduced which depolarize the end-plates in the same fashion as acetylcholine but which are not destroyed by acetylcholinesterase; or the depolarizing action of acetylcholine can be inhibited by the use of "antidepolarizing agents", for example, drugs that compete successfully with acetylcholine for occupation of its end-plate receptor sites but without depolarizing them. Blocking agents often exhibit more than one of these actions, and may produce comparable effects elsewhere in the cholinergic nervous system. Examples of highly toxic neuromuscular blocking agents include the hemicholinium compound HC-3, which appears to interfere with the transport of choline to the site of acetylcholine synthesis [1104]; botulinal toxin, which is thought to prevent release of acetylcholine from terminal nerve endings [1105]; succinylcholine, carbolonium and decamethonium, which are cholinomimetics used in medicine as muscle relaxants; *d*-tubocurarine, the classical antidepolarizing agent and active principle of some forms of curare, the well-known South American arrow poison;[16] and α-bungarotoxin, another antidepolarizing agent [1106–1107], obtained from the venom of the Taiwan krait, *Bungarus multicinctus.*

As regards acetylcholinesterase inhibitors, the currently standardized nerve gases are thought to be near the upper limit of toxicity that can be expected. More toxic ones are certainly known, for example the so-called Tammelin esters (ω-trialkylammonioalkyl methylphosphonofluoridate salts) and carbamates such as the French 3113 CT and 3152 CT, but these have physical and chemical properties that make them unsuited to CW. Other, more amenable classes of inhibitor may be discovered, however, for there are several potent anticholinesterases that are neither organophosphorus compounds nor carbamates [1108].

In the natural-product approach, the main interest attaches to natural poisons that are nonproteins, particularly ones of low molecular weight, for it is these that hold out the greatest promise as models for new programmes of candidate agent synthesis. Examples that display exceptional toxicity include saxitoxin (see above, pp. 61–62), batrachotoxin (the active ingredient of another South American arrow poison, Kokói, obtained from the skin of certain *Phyllobates* frogs), and tetrodotoxin—all of which are neuromuscular blocking agents. More toxic still, but with a rather

[16] Curare preparations, which comprise complex mixtures of alkaloids obtained from the bark of various species of *Strychnos* and *Chondodendron*, are designated "tube" (whence "tubocurarine"), "pot" or "calabash" according to the type of container. Calabash curare is the rarest and most toxic form: included among its active principles is the most active neuromuscular blocking-agent yet described, calabash-alkaloid E [1109–1110].

high molecular weight, is palytoxin, said to be the most poisonous non-protein known [1111]. These are described in appendix 2. Only in the case of tetrodotoxin are there yet published reports of attempts (unsuccessful) to reproduce the toxicity in easily synthesizable chemical analogues [1112]. The work on the scorpamines in the French CW laboratory [1113] may have been more successful in this respect.

Protein poisons, unless they are oligopeptides, are less promising because of the size and complexity of their molecules. This means difficulty in the accurate determination of their structures and especially in their chemical synthesis. But in both these respects, the capabilities of organic chemists are expanding rapidly. On the one hand, there are the increasingly successful attempts to concentrate the toxicity of protein toxins into fragments of much lower molecular weight. In the case of botulinal toxin type A, the most poisonous substance known, a fraction with about one-seventh of the molecular weight has recently been isolated that retains most of the toxicity: not only does it represent a three- to five-fold increase in toxicity on a weight-for-weight basis, but it also brings the poison somewhat nearer chemical synthesis [1114–1115].[17] Similar results are being obtained with several other protein toxins, for example ricin [1116–1118] and components of certain elapid snake venoms [1119]. Then, on the other hand, there are the newly developing techniques for protein synthesis. The Merrifield solid-phase technique, for instance, has been used to prepare proteins containing as many as 55 amino acid residues [1120–1121]. While this certainly falls short of, say, the botulinal toxin fraction just mentioned, it opens the way towards synthetic analogues of such things as the pituitary hormones, which produce profound physiological changes in amazingly small quantities.[18] The scaling-up of existing laboratory methods for making this type of substance is not inconceivable, although their application on the scale that would be needed for a chemical-weapon programme is harder to visualise. Nonetheless, in some quarters

[17] Moreover, another group of workers also studying type A botulinal toxin have reported isolating a fraction with a molecular weight of about one-sixtieth of the original toxin, but with much the same specific activity [1123–1124]. But it has been suggested that this fraction does not constitute a sub-unit of the toxin, but is instead an enzymatic breakdown product [1125].

[18] For man, the polypeptide known as Substance P, isolable from human tissue, is a powerful spasmogenic and vasodilator in doses lower than a microgram [1126]; a man's blood pressure can be raised with 0.5 microgram of angiotensin, given intravenously; and a synthetic nonapeptide has been made that can lower the blood pressure of many laboratory animals at dosages of around 0.3 μg/kg [1127–1128]. Scotophobin may be mentioned as an example of the more bizarre effects that oligopeptides can have. It is a pentadekapeptide that has now been synthesized but which was originally isolated from the brains of rats that had been made to fear the dark. Injected into mice or goldfish, it can make them fear the dark also [1129].

the synthetic peptides are considered to represent one of the areas most likely to generate new CW agents [1122]. Civilian interests in advancing peptide studies are substantial, particularly in connection with enzyme chemistry and technology. It would be surprising if further major advances did not result from, for instance, the recent heavy injection of funds into this area by the British Science Research Council—notably to the enzyme research groups at Oxford and London universities and at the BW defence establishment at Porton Down [1130].

Little is known about which, if any, of the classes of poison referred to above have been seriously studied as CW agents. In the US chemical-weapon programme, a number of novel lethal agents seem to have reached an advanced stage of development, but their chemical identities have not been openly disclosed. Field tests were conducted at Dugway during 1969 with 20 kg of one of them, code-named EA 1356[19] [1131]. Another one, code-named XR, has apparently been standardized [1131]; it is a botulinal toxin preparation. The symbol WA [1132] also designates a classified material which may be a new CW agent, although possibly an incapacitating one.

Incapacitating agents

The objective of research on incapacitating agents is to find substances capable of reducing military effectiveness for lengthy periods without endangering life or causing permanent injury, and to do so at dosages comparable with the effective dosages of existing CW agents. In the US Army's current screening programme for incapacitating agents, anything with an MED50[20] of less than 1 mg/kg in mice, and an LD50/MED50 ratio exceeding 10, is given further study [1071], but for the compound to become a serious candidate agent the requirements are a good deal more stringent: militarily significant incapacitation at submilligram dosages (i.e., an ID50 of less than 0.01 mg/kg or an ICt50 of less than 100 mg-min/m^3 [1070]), with the incapacitating dose being at least a hundred, preferably a thousand or more, times lower than the lethal dose [1].

In the early days of the US incapacitating-agent programme, there seemed to be many mechanisms of incapacitation which new CW agents might be developed to exploit. The US Army Chemical Corps drew attention to at least a dozen of them during its propagation of the Industrial

[19] I.e., the 1356th compound, or experimental agent, studied by Edgewood Arsenal since it began applying this system of coding to newly encountered chemicals of interest (sometime after World War II). Its study there must have commenced sometime before 1955, since that was a year in which a report on EA 1476—a synthetic tetrahydrocannabinol—was written [1141].

[20] The minimum ED50: the smallest dose having a 50 per cent chance of producing an observable effect in experimental animals.

Liaison Program and its soliciting during the late 1950s of Congressional support [274, 362, 441, 443, 1046, 1073, 1134–1135]. Hypotension was one such mechanism, for at that time the drug firms were starting to have impressive success in finding new therapeutics for hypertension [1136–1138]. In healthy people, fainting is an early effect of suddenly lowered blood pressure, particularly if the subject is standing up. Potent antihypertensive drugs which can cause severe postural hypotension in normal subjects include guanethidine, bretylium and the hydrazine-derived monoamineoxidase inhibitors, such as iproniazid and Ro 4-1038. One of the earliest families of candidate agents in this category was a series of synthetic homologues of tetrahydrocannabinol, the active principle of *Cannabis sativa,* for example EA 1476[21] [1139–1140].

Emesis was a second example, for a retching and vomiting soldier would clearly not be an effective one. Besides the harassing vomiting agents such as adamsite, a great many emetics are known, notably apomorphine and the staphylococcal enterotoxins. The latter are the more potent, but aerosols of the former have been shown to produce emesis at dosages within the effective range of VX nerve gas [1070]. As noted in chapter 1, staphylococcal enterotoxin B eventually entered the US CB weapon stockpile (agent PG). On human volunteers, apomorphine has been tested with experimental dart guns, whose use by police forces to capture criminals, and even to control riots, has been advocated in the USA.[22] [1142–1144]. Similar devices have long been used in the capture of wild animals.

The disturbance of body temperature was a third example of something that an incapacitating agent might cause. A raised temperature can lead to incapacitating heat stroke and heat exhaustion. Milligram quantities of triiodothyronine can increase heat production in man [1070], and atropine, the standard nerve-gas antidote, can produce heat exhaustion by interfering with heat loss [1145–1148]. Several bacterial endotoxins are amazingly potent fever-inducers in man, effective at submicrogram dosages [1149–1152], in addition to producing other incapacitating effects, such as pain [408], vomiting and sensitization to other materials [1070].[23] A low-

[21] EA 1476 is the compound sometimes referred to as DMHP—dimethylheptylpyran—in the cannabinol literature. It was said of it in 1955 that "from the standpoint of the ratio of the LD50 to the effective dose, EA 1476 has one of the greatest margins of safety of any drug known when administered intravenously to dogs" [1141].

[22] They have occasionally been used for this sort of purpose, for instance in the case of an apparently psychotic jailbreaker in a Georgia prison who was shot with a dart charged with sodium amytal [1143].

[23] The polyriboinosinic-polyribocytidylic acid complex, poly I.polyC, a synthetic double-stranded RNA, has bacterial endotoxin-like properties, including a powerful pyrogenicity in rabbits [1157].

ered body temperature can lead to prolonged sedation or unconsciousness, and a variety of drugs are known—cannabinols, oxazolines, imidazolines, and others—that can induce "artificial hibernation" [1070, 1153–1154].

Further examples included inhibition of the labyrinthine reflexes resulting in loss of the sense of balance; muscular hypotonia, leading to paralysis;[24] temporary blindness,[25] uncontrollable muscular tremors, such as those caused by oxotremorine, a drug used to mimic Parkinson's disease; and the many different psychotropic effects [1155–1156] produced by tranquillizers, sedatives, anti-depressants and psychotomimetics.

The CW possibilities of these different mechanisms of incapacitation, although initially described by US commentators, were soon echoed in other NATO countries [1162–1163], particularly France [589, 794, 1164–1165]. The open literature on the subject from Warsaw Pact countries was largely confined to reviews of the Western publications.[26]

The crucial drawback with most of the potential agents described is that the margin of safety between the incapacitating and the lethal dose exceeds the range of dosages likely to occur when the agents are used in the field. The number of people exposed who would be likely to die

[24] Some of the neuromuscular blocking agents referred to above come within this category, for example succinylcholine. So do certain butyrophenones [589]. A US Congressional committee enquiring into CBW in 1959 was given a live demonstration of the effects in animals of two muscle relaxants. In the first demonstration, dogs were exposed for 1 minute to an aerosol generated from a 0.1 per cent solution of the agent. Half a minute later they began to relax, and within 1 minute after that they had become immobile. An antidote was then quickly applied to restore the animals. Spontaneous recovery was possible from the second agent, which was given intravenously to the dogs, but about fifty times the dose was needed to produce the paralysis; in man, the effective airborne dosage was reckoned to be something around 1 000 mg-min/m³. It was said to have been extensively tested in volunteers, and to produce effects lasting from one-half to 2 hours or more [274]. At about the same time, Edgewood Arsenal released brief details of the effects in volunteers of an agent causing ascending spinal paralysis [362].

[25] An agent first encountered during World War II that produces temporary blindness is dimethyldiglycollate. About 20 minutes after exposure to it, the cornea becomes clouded and vision fades. The wartime search for more potent and faster acting analogues was unsuccessful [1158]. The nerve gases, of course, also interfere with vision, miosis being one of the earliest consequences of their parasympathomimetic action. The pupil of the eye may become too constricted to admit enough light to the retina, and this and related effects on lens control may lead to a substantial impairment of dark or dim-light vision [81–82, 1159]. Anticholinergic agents, such as atropine, BZ and many other glycollates, have the opposite effect—mydriasis rather than miosis—the pupillary enlargement interfering with daytime vision [1145, 1160–1161].

[26] A major East German article on the subject [47] was remarkable in that it contained the first published data on the potency of agent BZ (see above, page 47). Moreover, it purported to describe three other US Army psychochemicals: *alpha*, having a "disquieting, irritant effect" at 20 mg-min/m³ after a half-hour delay; *beta*, a lysergic-acid derivative producing confusion, physical weakness, and temporary deafness and blindness at 200 mg-min/m³; and *sigma*, producing 8-hour incapacity at 2 000 mg-min/m³.

or suffer serious injury would therefore probably exceed 1–2 per cent, the statistic that, in United States parlance, distinguishes incapacitating agents from other casualty agents.[27] This is perhaps not very surprising, for what is being sought is an agent that can selectively gain access to cells in the body which subserve important functions that would lead to incapacitation if disturbed without also entering cells that subserve vital functions. For instance, one might plan to incapacitate by weakening the limbs with a muscle relaxant. But there is little or no difference between the cells of the leg muscles and those of the muscles of the rib cage. Thus, if one interferes with the capacity to stand or move, which in physiological terms is not vital, one may easily overshoot the mark and interfere with the function of respiration, which is vital [1072]. Apomorphine may induce nothing more than vomiting in small doses, but in larger ones it may induce convulsions and severe depression of the central nervous system, including the respiratory centres.

The psychotomimetics (for recent reviews, see [1166–1176]) in fact seem to be one of the very few classes of incapacitating drug which have sufficient selectivity to give a wide enough margin of safety. Some of them are sufficiently potent for CW purposes. LSD was the first to be tested on human volunteers performing simulated combat duties, during 1954–55 [1177], but it was subsequently rejected, apparently on the grounds of its cost [36] and "in view of deleterious side effects, including possible genetic effects"[28] [45]. Other potent families of psychotomimetic include the anticholinergic glycollates [48–49, 510–512, 1178–1182, 1186–1198], such as Ditran, Benactyzine and agent BZ (see page 46); the tryptamines such as psilocin, bufotenine, DMT and their synthetic congeners [1199–1202]; and the phenethylamines, such as STP[29] and the other mescaline-amphetamine synthetics [1203–1209]. Insofar as the open literature is a guide, none of these have effects at dosages as low as LSD, which is comparable in potency with VX; dosewise, they compare more with mustard gas (or tabun in the case of BZ). But the open literature does not reflect the full extent of the work that has been done with these compounds.

Currently attractive candidate incapacitating agents may include other psychotropic drugs than the psychotomimetics. This is suggested by a 1968 US Army manual [37], which contains the following passage:

[27] See p. 123.

[28] A matter of considerable current controversy [1210].

[29] STP is the popular name given to the experimental drug DOM (2,5-dimethoxy-4-methylamphetamine). When it first entered the drug scene, there were widespread rumours that supplies originated from the US Army Chemical Corps [1211–1213].

Generally speaking, an incapacitating agent is any compound which can interfere with the performance of military duties. In actual usage, however, the term has come to refer primarily to those agents which—(1) Are highly potent and logistically feasible. (2) Produce their effects mainly by altering or disrupting the higher regulatory activity of the central nervous system. (3) Have a duration of action of hours or days, rather than momentary or fleeting action. (4) Do not seriously endanger life except at doses exceeding many fold the effective dose, and produce no permanent injury.

Incapacitating agents would not be considered to include the following: (1) Lethal agents which are incapacitating at sublethal doses such as the nerve agents. (2) Substances which cause permanent or long-lasting injury such as blister agents, choking gases, and those causing eye injury. (3) Common pharmacological substances with strong central nervous system actions such as the barbiturates, belladonna alkaloids, tranquilizers, and many of the hallucinogens. These drugs, although effective and relatively safe, are logistically infeasible for large-scale use because of the high doses required. (4) Agents of transient effectiveness which produce reflex responses interfering with performance of duty. These include skin and eye irritants causing pain or itching (vesicants [*sic*]), vomiting or cough-producing agents (sternutators), and tear agents (lacrimators). (5) Agents which disrupt basic life-sustaining systems of the body and thus prevent the carrying out of physical activity. Examples might include agents which lower blood pressure, paralyzing agents such as curare, fever-producing agents, respiratory depressants, and blood poisons. Although theoretically effective, such agents almost invariably have a low margin of safety between the effective and possible lethal doses and, thus, defeat the basic purpose of an incapacitating agent which is to reduce military effectiveness without endangering life.

In spite of the restrictions imposed by the above definition, a great variety of mechanisms remain by which central nervous system regulation and maintenance of performance could theoretically be disrupted. In reality, however, only two general types of chemical agents are likely to be encountered in military use. (1) *CNS depressants.* These are compounds which have the predominant effect of depressing or blocking the activity of the central nervous system, often by interfering with the transmission of information across synapses. An example of this type of agent is BZ. ... Cannabinols and phenothiazine type compounds are other potential incapacitating agents which seem to act basically as CNS depressants. The primary effects of these agents, however, are to sedate and destroy motivation rather than to disrupt the ability to think.[30] (2) *CNS stimulants.* These agents cause excessive nervous activity, often by "boosting"

[30] About the most potent phenothiazine major-tranquillizer in current use is fluphenazine dihydrochloride [1214]. The butyrophenones, however, include several much more potent major-tranquillizers, notably spiroperidol and droperidol, said to be the "most potent neuroloptic drugs know to date" [1215]. In one dog-behavioural study, both agents showed a subcutaneous ED50 of 0.005 mg/kg, the corresponding ED50 for fluphenazine being 0.06 mg/kg [1216]. Spiroperidol "regularly" induces Parkinson-like side effects [1217]. Apart from EA 1476, and its congeners EA 1465, EA 1507, EA 1542-5 and EA 2233 [1139, 1218–1219], further and more potent cannabinols that have been synthesized recently during the US CBW agent programme are Arthur D. Little's azatetrahydrocannabinols [1220–1221].

or facilitating transmission of impulses which might otherwise be insufficient to cross certain synapses. The effect is to "flood" the cortex and other higher regulatory centers with too much information, making concentration difficult and causing indecisiveness and inability to act in a sustained, purposeful manner. A well-known drug which appears to act in this manner is d-lysergic acid diethylamide [LSD]; similar effects are sometimes produced by large doses of the amphetamines.

At the present time, the confidence expressed here in the military utility of psychochemicals seems somewhat excessive. It is surely the case that much more has to be known than is now known about the working of the mind, and about the fundamental nature of the action of psychochemicals upon it, before it can ever be concluded that the abnormalities produced by such agents would necessarily impair the military functioning of men intoxicated with them (see above, pp. 47–48). What is known about these agents relates almost entirely to persons who lack motivation or who suffer from abnormalities of motivation. What could or would happen in states of military stress is unpredictable, and will probably remain so [1072]. Attempts to correlate "personality" and reactivity to psychochemicals continue in military laboratories [1604–1608].

The effects of physiochemical incapacitators—that is to say, agents which do not depend for their incapacitating effects solely upon action on the central nervous system (CNS)—on military performance are more predictable than those of the psychochemicals. If and when a potent physiochemical appears which has the same sort of selectivity manifested by some of the psychochemicals, it could very well have substantial military attractions. Its discovery, if it happens, is likely to be accidental, and could as well occur in a university or pharmaceutical laboratory as in a CW one. There is not yet enough fundamental knowledge to predict the kind of intracellular elements it will attack or the sort of biochemical transformation with which it will interfere [1072].

By 1969, the US Army was looking for potential incapacitating chemicals among four (so far unspecified) classes of compound [45] and, as noted earlier, there were at that time two new candidate incapacitating agents in advanced development.[31] The 1972 incapacitating-agent explora-

[31] Potential incapacitating agents known only by US Army code name, and which have an MED50 in mice of 0.01 mg/kg (i.v.) or less, include EA 3548, EA 3848 and EA 3990 [1071]. EA 2277, apparently a percutaneous incapacitant and possibly identical with BZ, was being intensively evaluated during 1961 [1093, 1223–1224]. Prophylactics against EA 3148 were being sought alongside BZ prophylactics during 1963–66 [1225]. A published reference exists to the interchangeability of agents BZ and TK in certain US Army chemical munitions [1226]. According to a press report, the US Air Force employed an "experimental immobilizing gas" in April 1972, during an operation in Viet-Nam [1227]. The subsequent official denial apparently referred only to the use of nerve gas [1228].

Table 4.3. Activities of selected incapacitating chemicals

Agent[a]	Incapacitating potency in man (I)				
	Dose (oral, unless otherwise indicated)[d e]			Time to peak effects (hours)	Duration of effects (hours)
	D^c (mg/kg)	14 000 D^d	Effect		
Salmonella enteritides endotoxin	*0.00002* (iv)	0.3	Hyperthermia	..	..
Staphylococcal enterotoxin B	0.00004	0.6	Vomiting and diarrhoea	2–5	1–12
(+)-NN-diethyllysergamide (LSD)	0.002	30	Hallucinations	1–3	1/2–6
1-Methyl-LSD (MLD)	0.006	80	Hallucinations	..	..
3-Quinuclidinyl benzilate (BZ)	0.03 (ih)	400	BZ effects (see p. 47)	1/2–1	48–96
ADL 226169[b]	*0.03*	400	Hypotension and somnolence	..	..
Spiroperidol	0.03	400	Major tranquillization	..	..
Scopolamine	0.03	400	Hallucinations	..	..
Decamethonium	0.04 (iv)	600	Paralysis	0.1	1/3
Ditran	0.04	600	BZ effects (see p. 47)	1	12–24
Oxotremorine	*0.05* (iv)	700	Muscular tremors	*seconds*	*1/2–1*
Dimethylheptylpyran (EA1476)	0.06	800	Hypotension and somnolence	3–8	4–48
2,5-Dimethoxy-4-methylamphetamine (STP)	0.07	1 000	Hallucinations	3–5	3–7
Apomorphine	0.08 (im)	1 000	Vomiting	<0.1	..
Atropine	0.1	1 000	Hallucinations	..	..
Fluphenazine	0.1	1 000	Major tranquillization	..	..
Psilocin	0.1	1 000	Hallucinations	1–2	3–5
Guanethidine	0.1	1 000	Hypotension	4–6	24–48
Bufotenine	0.2 (iv)	3 000	Hallucinations	minutes	*1/2–2*
Phencyclidine	0.2 (iv)	3 000	Hallucinations and hypnosis	<0.1	..
α-Methyltryptamine	0.3	4 000	Hallucinations	1–3	..
Ro 4-1038	0.4	6 000	Hypotension	..	..
Δ^1-tetrahydrocannabinol	0.5	7 000	Hallucinations	1–2	2–3
Benactyzine	0.6	8 000	Hallucinations	3–4	12
Picrotoxin	*0.8* (iv)	10 000	Convulsions	*1/4–1/2*	..
NN-dimethyltryptamine	0.9 (im)	10 000	Hallucinations	0.1	3/4–1
NN-diethyltryptamine	0.9 (im)	10 000	Hallucinations	1/2–1	3
Mescaline	5	70 000	Hallucinations	3–6	5–12
Pentobarbital	6 (iv)	80 000	Hypnosis	..	..

Notes:

[a] For the chemical structure of the synthetic chemicals listed here, see pp. 22–25.

[b] ADL 226169, a candidate incapacitating agent, is an azatetrahydrocannabinol chemically and pharmacologically related to EA 1476.

[c] Except for the italicized entries, these are doses reported in the literature to have produced the indicated effects in man. They do not necessarily represent either MEDs or ED50s. In some cases, smaller or larger doses are reported, as well as those given here. The selection of data reflects an attempt to indicate the relative potencies of the agents, insofar as this can be gauged. Italicized entries are estimates based on animal data.

[d] The purpose of this column is to indicate how potent the agents might be by aerosol administration. If D mg/kg is the respiratory ID50 of an agent, then the ICt50 of the aerosolized agent would be around 14 000 D mg-min/m^3 for a 70 kg man breathing 10 litres of air per minute, assuming he absorbs 50 per cent of the inhaled agent. But it must be noted that the respiratory ID50s of the agents do not necessarily correspond to the oral or parenteral dose-levels given in the previous column.

[e] Routes of administration are indicated by *ih*, *iv*, *sc*, *im* and *ip*: respectively, inhalation, intravenous, subcutaneous, intramuscular and intraperitoneal.

Lethal toxicity (LD50)[e]				
(II)	(III) Mouse	(IV)	(V) Rabbit	
Man(est) (mg/kg)	iv (mg/kg)	ip (mg/kg)	iv (mg/kg)	Authorities consulted
..	..	30	..	I, IV [1563]
..	..	>3	0.005	I [95, 118] IV [1564] V [122]
0.2	46	..	0.5	I [52] II [1565] III, V [1167]
..	..	..	5.4	I [1169] V [1566]
..	23.5	110	..	I [45] III, IV [49]
..	47	..	..	I, III [1220]
..	29	..	..	I [1217] III [1566]
0.15	..	..	..	I [1191] II [1567]
0.05	..	..	..	I, II [1101]
..	..	60	12	I [1169, 1190] IV, V [1566]
..	1.4	..	..	I [1373, 1568–1569] III [1569]
..	63	14	..	I [1139–1140] III [1220] IV [1133]
..	..	..	..	I [1207]
..	..	..	..	I [1070, 1570]
0.15	..	206	..	I [1571] II [1567] IV [1499]
..	60	89	..	I [1215] III, IV [1566]
..	75	..	7.0	I [47] III, V [1566]
..	..	..	..	I [1136, 1570]
0.23	..	..	..	I [1572] II [47]
..	..	..	..	I [1167, 1169, 1570]
..	..	38	..	I [1574] IV [1575]
..	1000	..	..	I [1576] III [1566]
..	..	..	..	I [1577]
..	23	<100	15	I [1573–1578] III [1566] IV [1579] V [1580]
..	..	11.4	..	I [1581] IV [1499]
..	43	..	..	I [1170, 1582] III [1583]
..	32	..	..	I [1169, 1582] III [1582]
..	157	261	..	I [1584] III [1585] IV [1208]
14	..	114	..	I [1586] II [1567] IV [1499]

tory development projects were directed towards "agents with higher potency, improved margin of safety, and greater preponderance of physical (as opposed to mental) symptoms of incapacitation than obtained with agents presently known" [1599]. A French authority has stated that the principal classes of chemical that are of interest in the search for new incapacitating agents include derivatives of benzofuran and pyrimidine; organotin compounds; indole derivatives; and ethoxyfluoro-compounds [589].

Table 4.3 provides data on the more potent substances described in the open literature that have powerful incapacitating effects.

The search for novel irritant agents continues in several countries. In the UK, a substance that is more aggressive but less toxic than CS is said to be under development. In the USA, three types of agent are being sought: one that would be as quick-acting as CS, but with longer-lasting effects; one that would be effective in vapour form, and would not require sought: one that would be as quick-acting as CS, but with longer-lasting which were nearly all volatile liquids); and one that would produce its effects upon contact with the skin, rather than the eyes or upon inhalation. As of 1972, a volatile irritant code-named EA 4923 was being closely studied. [1599]

Binary chemical weapons

A review of recent developments in agent-dissemination technology is included in chapter 1 (pages 72–90). In addition to the munitions concepts described there, a further category has recently come to the forefront of CB weapon technology, more specifically nerve-gas weapon technology. These munitions employ the so-called "binary concept". Instead of being loaded with actual CW agent, the munition is filled with two nontoxic chemicals that are allowed to mix and react only when the munition is being delivered to its target, the reaction product being a CW agent.

This concept has been studied sporadically since before World War II, for at least three different reasons. One reason was to provide a weapon that could generate a cloud of CW agent rather slowly and for a prolonged period. In an experimental World War II aircraft bomb, a forward compartment of the bomb contained magnesium arsenide, with sulphuric acid in a rear compartment. A plunger shattered the diaphragm separating the compartments as the bomb struck the ground, thus allowing the two chemicals to react and produce arsine, a blood gas [1229].

A second reason was to provide a means for exploiting toxic chemicals that were too unstable to be stored for any length of time. One such chemical is methyl N-(2-chloroethyl)-N-nitrosocarbamate, a potent vesicant studied during World War II.[32] There is no available information on whether binary munitions were actually developed for this or related substances, but the suggestion was certainly made [1230]. Methyl N-(2-chloroethyl)-carbamate would have been one component of the binary system, with a nitrosating agent as the other. There would be little interest in this particular combination today, but several intensely toxic substances

[32] This compound was code-named *KB-16* in the USA. For a brief account of it and of its congeners, see Volume I of this study, p. 79.

have been found since World War II that were rejected as CW agents because of their instability. The new concept could restore their candidacy: a binary weapon that disseminates a Tammelin ester, for example, can be envisaged.

A third reason was to decrease the hazards of manufacturing, storing and handling toxic munitions. Particularly relevant here are the dangers of storing chemical munitions on board ship, for even small leakages of toxic (or infective) substances might well put a ship completely out of action.[33] One safety precaution which naval CB weapon designers have studied is the inclusion of decontaminant within the actual weapon. Enough of it is present to destroy any agent that might leak from its location within the weapon [1231]. The drawbacks of such a system are obvious enough, and it is not known whether it has actually been put into practice. On paper, at any rate, the binary system seems a better proposition.

Apart from reducing storage hazards, the binary concept would also increase the availability of nerve-gas weapons from a country's chemical industry. Normally the payloads for nerve-gas weapons can be manufactured only within special factories equipped with safety measures that far exceed normal industrial practice.[34] Because the fillings for binary nerve-gas weapons are much less toxic than nerve gas, they can be produced in normal civilian chemical plants.

The advantages of applying the binary concept to nerve-gas weapons have been publicized since 1969 by US Army spokesmen [45, 1232], some of whom anticipate that the entire US stockpile of nerve-gas weapons will be converted to the binary system. In terms of actual hardware, the concept is still in the development stage. Development is proceeding rapidly, however; in the 1972/73 US defence budget, the funds sought by the Army for binary weapon R&D would have supported the entire CB defence R&D programmes of West Germany, Sweden and the Netherlands combined.

In February 1969, the US Navy sought bids for an R&D contract on "a chemical cluster weapon capable of mixing and reacting two nontoxic chemicals to generate toxic agent within the cluster payloads". The weapon was to be based on a G-agent nerve gas, and to be suitable for delivery onto surface targets from the external mountings of supersonic aircraft [1233]. Four years earlier, the Navy had filed patent applications on a binary-chemical bomb design in which one of the two chemical reactants was a liquid, the other a solid [1610]. The US Army apparently has several other designs of binary munition in advanced development,

[33] See the discussion of naval chemical weapons and shipboard decontamination in Volume I of this study, pp. 96–98.
[34] See Volume V of this study, pp. 166–70.

including missile warheads, aerial munitions (e.g., an air-to-ground rocket) and artillery projectiles of various sizes [1599, 1609]. As of 1972, only one of these had reached engineering development, namely the XM687 projectile for 155 mm artillery. This has been described as follows:

> [T]wo nonhazardous constituents are stored separately in polymeric containers encased in steel canisters and are inserted into the basic artillery shell just before firing. When fired, the set-back forces and spin-up of the projectile provide the mixing action necessary to produce a lethal agent. [1234]

Details of the "nonhazardous constituents" have not yet been released, but it is reported that several G- and V-agent precursors have potentialities. The current prototype generates sarin [1609], but the main emphasis is on constituents that react to form a nerve gas whose volatility is intermediate between that of sarin and that of VX [1235]. In the case of the intermediate-volatility agent soman, for example, it might be supposed that one constituent would be pinacolyl alcohol and the other methylphosphonyl difluoride (or "di-di", the equimolar mixture of this with methylphosphonyl dichloride).[35]

Binary nerve-gas weapons are unlikely to be as effective as normal ones. In the first place, they introduce an additional system into the weapon, thus increasing the chances of malfunction. In the second place, the constituents require time to react, and although this may be short, it might still preclude use of the weapons against close-in targets. Thirdly, the reaction of the two constituents will never be 100 per cent efficient, and will generate a byproduct. This will mean that the effective payload of a binary munition will be smaller than that of a normal nerve-gas munition of equal size. It will also mean a decrease in the chances of the agent cloud disseminated by the weapon remaining undetected by the unaided human senses, which is one of the many military assets claimed for the nerve gases. The dihalide precursors mentioned above are strong sensory irritants (so is the byproduct halide), whose presence might immediately warn anyone in the target area.

Novel biological agents

In this section we describe approaches towards more potent payloads for biological weapons. We consider three different areas: the possibilities of little known or newly encountered pathogens as BW agents; physicochemical methods for modifying existing agents; and techniques of genetic

[35] It may not be irrelevant to note that the US Army has recently published a detailed toxicological study of methylphosphonyl difluoride [1236], a substance which is not normally of much toxicological interest.

manipulation that might lead to "synthetic" BW agents. Since there is virtually no information in the open literature on the nature of existing biological-weapon fills, several of these possibilities may already, for all we know, have been put into practice; one or two certainly have.

"New" diseases

If what is known of the contents of the US biological-weapons arsenal is any guide, currently standardized BW agents are based on well-known species of pathogenic microbe. The natural forms of the diseases they cause have long been studied in medical and public health laboratories around the world in areas where the diseases are endemic. But it is conceivable that future biological weapons might create what appear to be entirely novel diseases. From the attacker's point of view, the medical countermeasures against such weapons would be advantageously difficult.

There are several ways in which biological weapons might cause unusual clinical syndromes. A disease which is normally initiated by, say, the bite of an infected mosquito may appear very different when caused by inhalation of the pathogen [1237]. The natural defences of man towards respiratory infection can be impaired by exposure to lung-irritant chemicals [1238], so that the dissemination of a mixed chemical-biological aerosol might lead to signs and symptoms not normally associated with the pathogen used. Similar confusion may result from simultaneous infection by two or more different pathogens, which may in addition have a synergetic effect upon one another.[36] Irradiation may increase susceptibility towards pathogens such as *Bacillus anthracis* [1239]. These topics are discussed further in appendix 1.

Further possibilities are presented by the growing battery of "genetic engineering" techniques. It is possible, for example, to breed strains of well known pathogens that have increased antibiotic resistance or altered biochemical and immunological characteristics; and in some cases the symptomatology can be influenced by selection techniques. Stretched far enough, it is conceivable that such methods might, in the distant future, lead to a strain of pathogen so different from its parent as to be classifiable as a new disease agent.

Nature is still a source of diseases which, because they occur only in

[36] In a section omitted from subsequent editions, the 1962 edition of the unclassified US Army manual on biological-weapon employment [420] refers to the advantages of employing more than one agent in the attack of a target. Pathogen combinations studied in laboratory animals at Fort Detrick include *Francisella tularensis*/staphylococcal enterotoxin B [119], *Francisella tularensis*/*Coxiella burnetii* [153], and several others. Some pathogen combinations have a mutually inhibitory effect rather than a synergetic one [e.g., 1240].

remote areas, were previously unknown, and some of them could have BW potential. Many of these turn out to have been caused by arboviruses, a group of pathogens from which BW agents have already been selected, and from which yet others may be chosen. One indication of their candidacy in this respect is their propensity for causing accidental laboratory infections. When the Rockefeller Foundation reviewed its public health programme in 1964, it mentioned 160 arboviruses, almost half of which had originated in the Amazon Valley [1241]. The Foundation's laboratory at Belem, at the mouth of the Amazon, had by then come up with some sixty new viruses in the nine years of its operation. The Foundation could also report arbovirus discoveries in several other parts of the world, for instance the Oropouche virus from Trinidad and Kyasanur virus from India. Several of these new viruses have engaged the attention of military microbiologists, for instance the Rio Bravo virus, which was originally isolated from Texas bats and which has caused many laboratory-acquired human infections [1243]. A simple and effective method for preparing non-infectious antigens from this and from other arboviruses has been developed [1244]. The World Health Organization (WHO) has recently published a general review of the complexity and ecology of the arbovirus group [1245].

Similar discoveries of bacteria have not occurred for many years, but cases of very rare bacterial diseases are occasionally reported. An example is the disease caused by *Chromobacterium violaceum* which, in 1970, killed two US military personnel in Viet-Nam [1246]. This disease was first observed in Malaya in 1927, and is said to have been mentioned in the medical literature only 16 times since then.

In contrast to the bacteria, the viruses are still contributing entirely new clinical entities, as in the case of the peculiar "green monkey disease" caused by what is now called the Marburg agent. This resembles the rabies/vesicular-stomatitis group of viruses in morphology, but also has some similarities with the *Leptospira* [1247]. In 1967 the agent attacked 23 people, killing five of them, most of whom were engaged in handling green monkeys or their organs at a vaccine and serum production plant in Marburg, West Germany [1248]. After an incubation period of 5–7 days, it caused headache, drowsiness, myalgia, vomiting, diarrhoea, swollen lymph nodes and reddening of the skin and mucous membranes. Samples of the agent were sent to MRE Porton Down (the BW defence laboratories in the UK), where the disease was reproduced in monkeys; they could be infected by an infected liver suspension diluted by a factor of as much as 10^{10}. The agent appeared to be effective via the aerosol route [1249].

An even more lethal agent may be the Lassa virus which in 1969 was noted in three nurses in Nigeria, and infected two workers at the Yale Arbovirus Research Unit. Two of the nurses and one of the laboratory workers died from the infection. In morphology, the agent resembled lymphocytic choriomeningitis virus, with which it also had a low-profile relationship as judged by complement fixation. Large-scale complement-fixation tests, as well as haemagglutination-inhibition and plaque-reduction neutralization tests, however, showed that Lassa virus differed from more than 200 viruses, including most known arboviruses [1250].

Ferocious though some of these newly-encountered pathogens may be, they still have to fulfil the basic stability and other requirements made of existing agents. It is worth recapitulating these here with the following quotation from a US Army BW manual [97]:

REQUISITES OF BIOLOGICAL AGENTS

(a) *General.* Certain requirements must be met by organisms or substances if they are to be effective biological agents. Additional characteristics that will enhance their value under varied conditions of use are desirable. The selection of a particular biological agent will be governed not only by the effect desired but also by the agent's characteristics and its ability to withstand environmental conditions. All these conditions cannot usually be fulfilled by any one agent; therefore, in making a selection, some compromise may have to be made between characteristics ranging from optimal to minimal desirability.
(b) *Requirements.* The agent should meet certain requirements for use against personnel, domestic food and draft animals, or plants. It should: (1) Consistently produce a given effect (death, disability, or plant damage). (2) Be manufacturable on a large scale. (3) Be stable under production and storage conditions, in munitions, and during transportation. (4) Be capable of efficient dissemination. (5) Be stable after dissemination.
(c) *Desirable characteristics.* Additional agent characteristics that are desirable but not required are as follows: (1) Possible for the using forces to protect against. (2) Difficult for a potential enemy to detect or protect against. (3) A short and predictable incubation period. (4) A short and predictable persistency if the contaminated area is to be promptly occupied by friendly troops. (5) Capable of: (a) Infecting more than one kind of target (for example, man and animals) through more than one portal of entry. (b) Being disseminated by various means. (c) Producing desired psychological effects.

Apart from the pathogens noted above, there are several other rare or peculiar pathogens whose properties may fit in with at least some of the above requirements or desirable characteristics. As an example, one may note the strange ability of scrapie and other slow viruses to withstand formalin, ultraviolet radiation and temperatures up to 90°C [1251].

Physico-chemical modification of existing agents

Much can be done to increase the performance of a biological weapon by modifying the physical characteristics of its payload, or by including special adjuvants within the agent formulation. Three principal types of improvement may result: enhancement of the ability of the agent to withstand aerosolization and post-aerosolization stresses; a masking of those characteristics of the agent which could trigger the defender's warning devices; and an increase in the infectivity of the disseminated particles.

The first and last of these possibilities are related, for a lowered viability-decay rate after dissemination may effectively amount to an increase in infectivity. What is perhaps the simplest way of increasing the latter is to increase the purity of the agent payload. The number of microbes infesting each disseminated aerosol particle may then increase. The concentration and purification of microbial cultures is a subject of considerable peacetime importance, notably in connection with the production of vaccines, and in such other fields as biological pest control. As regards the latter, the US Atomic Energy Commission has recently announced a major advance in the concentration of a viral insecticide (being developed in a US Department of Agriculture programme) by zonal centrifugation; and not only was the product highly concentrated, but because its constituent particles had become micro-encapsulated within residual culture tissue, it also had substantially increased resistance to weather extremes [663]. Civilian requirements are therefore stimulating work in this area. On the military side, significant progress in purification techniques is indicated by a series of recent publications from Fort Detrick: a chemical-extraction/centrifugation technique for removing more than 99 per cent of the extraneous yolk-sac components from chick-embryo yolk-sac cultures of *Chlamydia psittaci* [1252]; ultrafiltration for tissue cultures of Rift Valley fever (RVF) virus [1253]; hundred-fold concentration of RVF and Chikungunya virus cultures by a precipitation method [1254]; and chromatographic purification of Eastern and Venezuelan Equine Encephalitis viruses [1255–1256].

Techniques for decreasing aerobiological decay rates include the incorporation of certain spray additives in the weapon payload. Among the many different adjuvants that have been studied, certain sugars, polyhydric alcohols and glycerol-thiourea mixtures have a marked ability to sustain aerosolized microbes against the stresses of adverse relative humidity and oxygen toxicity. Inositol has proved particularly effective for some species. Spent growth-medium can afford protection, even though it may contain sodium chloride which can have a lethal effect on microbes [126, 1257–1260]. It may also be noted that aerosols disseminated from the wet

and the dry states are often not equivalent in their ability to survive. For some agents (such as *Francisella tularensis*) under some weather conditions, a markedly more potent aerosol may be obtained from a dry-powder payload than from a liquid slurry [125, 1261]. This puts a high premium on the development of existing drying [145, 1262–1266] and milling [205] techniques for converting microbial cultures into viable dry-agent powders.

The micro-encapsulation methods referred to earlier in this chapter provide another possible way for increasing aerobiological stability. In addition to the ultraviolet shielding possibilities considered there, more complex developments can be envisaged. For instance, with double-wall micro-encapsulation, it is conceivable that an outer impermeable membrane which would melt away at the temperature of the depths of the lungs might be used to seal a permeable pathogen-microcapsule. Advances of this sort could completely alter the BW threat. Agents which earlier were disregarded because of their great fragility, such as the infectious nucleic acids described below, or because of extreme aerobiological instability, as in the case of many respiratory viruses, might be made into formidable weapons. And because these techniques would block surface antigens, and because they could mobilize unsuspected pathogens, several current biological-alarm concepts could become outmoded even before they had been fully developed.

A specific blocking of antigens on the surface of viruses without inactivating the latter is also theoretically possible by means of monovalent antibodies which prevent neutralization by divalent antibodies [1267–1268]. And the fact may also be exploited that a number of viruses become covered by a host membrane when they escape from the cell in which they are cultivated. Such a coating has been demonstrated for a number of animal viruses, including herpes simplex [1269], members of the myxovirus group [1270–1272], and apparently also for the viral insecticide referred to above.

"Synthetic" BW agents and the genetic modification of existing agents

The possibilities of genetic engineering methods producing a novel type of disease have already been alluded to. Whether a "synthetic" pathogen suitable for BW purposes could in fact be produced is, of course, a highly speculative matter. In some quarters it is apparently felt that such a development might be less than a decade away. For example, in 1969 a US Department of Defense spokesman provided a Congressional committee with the following information:

The dramatic progress being made in the field of molecular biology led us to investigate the relevance of this field of science to biological warfare. A small group of experts considered this matter and provided the following observations:

1. All biological agents up to the present time are representatives of naturally occurring disease, and are thus known by scientists throughout the world. They are easily available to qualified scientists for research, either for offensive or defensive purposes.

2. Within the next 5 to 10 years, it would probably be possible to make a new infective microorganism which could differ in certain important aspects from any known disease-causing organisms. Most important of these is that it might be refractory to the immunological and therapeutic processes upon which we depend to maintain our relative freedom from infectious disease.

3. A research programme to explore the feasibility of this could be completed in approximately 5 years at a total cost of $10 million.

4. It would be very difficult to establish such a program. Molecular biology is a relatively new science. There are not many highly competent scientists in the field, almost all are in university laboratories, and they are generally adequately supported from sources other than DOD. However, it was considered possible to initiate an adequate program through the National Academy of Sciences-National Research Council (NAS-NRC).

The matter was discussed with the NAS-NRC, and tentative plans were made to initiate the program. However, decreasing funds in CB, growing criticism of the CB program, and our reluctance to involve the NAS-NRC in such controversial endeavor have led us to postpone it for the past 2 years.

It is a highly controversial issue, and there are many who believe such research should not be undertaken lest it lead to yet another method of massive killing of large populations. On the other hand, without the sure scientific knowledge that such a weapon is possible, and an understanding of the ways it could be done, there is little that can be done to devise defensive measures. Should an enemy develop it there is little doubt that this is an important area of potential military technological inferiority in which there is no adequate research program. [45]

This quotation reflects the mounting hostility within the USA towards the US biological weapon programme at that time and the constraining effect upon the programme of the reluctance of key microbiologists to get involved.

The traditional techniques for developing new strains of microbe involve the selection of mutants from microbial cultures grown under varying conditions. For example, antibiotic-resistant strains may be accessible by successive selection and re-culturing of micro-organisms growing in antibiotic-containing media; and chemical mutagens have been used to obtain mutant arboviruses [1273]. Relatively recently, three powerful new methods have become available for modifying the genetic structure of microbes: cross-breeding, through what is essentially sexual reproduction; inserting new genes carried by a virus, a process called "transduc-

tion"; and direct manipulation of DNA as a chemical substance prior to reintroducing it into microbial cells [1274]. These are further discussed later in this chapter.

Studies of microbial genetics may lead to far-reaching improvements in BW agents, even though a synthetic agent may not materialize. For example, just as antibiotic resistance can be bred into microbes, so can such other characteristics as increased virulence, greater resistance to aerosolization and post-aerosolization stresses, and less demanding nutritional requirements during production. The problem is to find mutants that also meet the basic requirements of a BW agent. What tends to happen is that the accentuation of one offensive characteristic in a microbial strain is accompanied by the attenuation of others. The possibilities afforded by microbial genetics for developments both in biological weaponry and in BW defences are illustrated in the following extract from US Department of Defense Congressional testimony during 1962:

At the US Army Biological Laboratories, genetic studies of microorganisms—bacteria, viruses, rickettsia and fungi—are receiving ever-increasing attention. Attention is devoted to basic studies in genetics to understand the mechanisms involved, evolve new concepts, and increase the body of knowledge in general. Approximately 40 scientists, several of them nationally and internationally recognized, devote full efforts to genetics research. Many others appreciate the implications of genetics for their work and, therefore, devote considerable attention to the applications of genetics techniques and methodology to their own research.

The objectives stated above are currently being implemented in part by (1) attempting to obtain combination, recombination, or transformation with intact viral particles and/or their nucleic acid fractions, (2) studying population genetics which includes the development of methods for inducing mutations and selecting such populations, (3) studying genetic changes occurring in cells and viruses in "chronically infected" tissue-culture systems, (4) isolating and attempting to recombine the ribonucleic (RNA) acids from different viruses into a "new" virus, (5) studying the genetic compatibility between bacterial species of interest to biological operations by measuring the similarity in "melting points" of their specific deoxyribonucleic acid (DNA), (6) attempting to isolate or adapt bacteria and viruses to growth at elevated temperatures (50 centigrade) to improve resistance to thermal and aerosol stresses, (7) attempting to isolate mutants of bacteria which are inherently more resistant to aerosolization effects than parent strains, (8) studying the transduction of desired characteristics from one species of microorganism to another such as toxin-forming ability and antibiotic resistance, (9) studying gene transfer systems including antibiotic resistance transfer, (10) conducting basic studies on L-cells and protoplasts of biological agents, (11) conducting basic biochemical investigations designed to measure changes or differences between parent and mutant cells, (12) applying genetic techniques for isolating mutants of pathogens which may be used for live vaccine preparations.

In other areas of the program the genetics of insects and plants are being investigated. Mutants of insect species are examined for increased resistance to insecticides and cold temperatures. Genetics of population changes, gene competition, radiation effects on survival, and propagation of insects and development of desired characteristics are studied intensively.

This in-house effort, particularly in microbial genetics, is supplemented by grants with universities, frequent consultations and correspondence with other experts in the science, and attendance of research personnel at scientific meetings.

Although the Biological Laboratories conducts a vigorous and dynamic program in many areas of basic and applied genetics, it is certain that the effort, of necessity, will expand in the near future. It is not unlikely that the major contributions to biological weaponry and defense will result from research and a better understanding of the sciences of genetics. [611]

Molecular biology

In this section we discuss more closely certain of the possible BW applications of molecular biology. We begin by outlining some of the basic theory, and then go on to describe ways in which it might conceivably find both beneficial peacetime applications and offensive BW ones.

Almost two decades have elapsed since the double-helix shape of the molecule that carries the genetic code was demonstrated. It resembles a spiral staircase in which the banisters are fashioned of long chains of sugars and phosphates, and each step comprises two of four possible bases joined by weak hydrogen bonds. The order of the bases attached to each banister may vary indefinitely, but each one can only be paired with its opposite number in a particular fashion: the base adenine can pair only with thymine, and cytosine only with guanine. The structure of this particular molecule, desoxyribonucleic acid (DNA), suggested how hereditary information might be propagated: a process involving separation of the complementary single strands (which are nucleotide molecules) so that they could each serve as a mould for a supplementary strand.

The far-reaching consequences of this notion promoted the science of molecular biology. This advanced rapidly, and by 1956 an enzyme, DNA-polymerase, was found that was able to pick up complementary nucleotides from a mixture to form a complete double-helix out of an incomplete molecule. A few years later the process whereby the genetic code is translated into functional proteins began to be understood. A further type of nucleic acid, ribonucleic acid (RNA), which appeared in three forms, was found to play a critical role. First, a messenger (m-RNA) is formed on an uncoiled strip of DNA in the nucleus of the cell. This becomes imprinted with the particular message exposed and then travels to globular

RNA bodies in the cytoplasm—the ribosomes. These are active centres of protein synthesis, and assemble proper polypeptide chains from amino acids which have been provided with "handles" made of the third form of RNA—transfer RNA. There are some 20 amino acids available, each called up by a few of the available 64 three-letter code words (the three-base codons), which also include words acting as punctuation to mark the start or completion of a message to order the production of a particular protein, and so on.

One of the most remarkable facts about this code is that it is universal. The same genetic code words are used in all living things. Their genetic make-up varies, however, in the amount of DNA available to the cell, both to store unique information and to provide identical copies as a means for achieving intensive protein synthesis or for protecting against loss of vital information. In addition, the more advanced forms of life have developed complex regulatory mechanisms: hormone triggers on cell membranes, for instance, and histones—kinds of protein that seem to keep large segments of the genetic information switched off. This permits the various cells of the body to differentiate and to specialize in spite of the fact that they all carry the information for making a complete organism. But even microbes have a rather complex regulatory system for their genetic information. Repressor molecules prevent the transfer of coded information to m-RNA, and there are inducers that can unlock the repressors and turn the genes back on. The repressors and inducers may be subject to control by further molecules that require still other factors to recognise the appropriate genes.

These concepts have led to a remarkably rapid growth in the understanding of fundamental life processes; but they also permit new insight into the ways in which life can be distorted or destroyed.

Genetic and ethnic weapons and related possibilities

It is now possible to envisage several ways in which conceivable CB weapons might be used to inflict genetic damage on an enemy, or in which more direct forms of damage may be inflicted by genetic manipulation at the molecular level. Chemical mutagens, for example, might one day be made into long-term genetic weapons, although for the present it is not possible to control the type of mutation they produce. However, the possibility of effecting controlled mutation by coupling mutagens with certain proteins, repressors for example, is under active study [1275].

It is by looking at the molecular basis of genetics that other, more subtle, methods can be envisaged. Take for example the phenomenon of transduction—the modification of genetic information by subjecting cells

to virus infection. Viruses are essentially DNA or RNA molecules surrounded by a coat which protects their genetic information from the nucleases in host tissue, provides them with affinity for certain cells, and helps them to introduce their nucleic acid into host cells. Once inside, the virus nucleic acid may force its own genetic code onto the metabolic machinery of the host cell, thereby securing its replication. But sometimes the virus nucleic acid may attach itself to the cell chromosomes, thereby propagating itself in step with the cell. In this dormant state, some of its genes may express themselves in the form of enzymes which are normally absent from the cell. This forms the basis for experiments in "genetic surgery" or "genetic intervention" [1276], as when attempts are made to help children suffering from hereditary inability to produce the enzyme arginase by inoculating them with Shope papilloma virus, a virus which contains DNA capable of triggering arginase synthesis [1277–1278]. Likewise, the SV-40 virus of monkeys, which seems to be harmless in man, has the ability to leave copies of its DNA sequences in the chromosomes of tissue-culture cells. Synthetic viruses based on this agent might eventually be used for the modification of genetic defects [1279]. It may one day not even be necessary to use metazoan viruses in such experiments. Instead, one might be able to draw genes from the almost infinitely varied array of the microbial world, where transduction is a well established phenomenon. This possibility has recently been demonstrated in work with cultivated human fibroblasts taken from a patient suffering from galactosemia [1280]. This is a hereditary defect arising from lack of the enzyme which controls galactose metabolism. A bacterial virus, λ-phage, which has the ability to transduce the galactose gene between *Escherichia coli* strains, or DNA preparations from this virus, were used to infect the tissue cultures. In both cases the viral DNA was transcribed into cellular RNA, and enzyme activity appeared in the cultures. (Of particular interest is the observation that the DNA preparations were more effective than the virus itself, but the compatibility between the latter and the cell was small in this case.) Between bacteria, transduction can be accomplished with a synthetic virus made by enzymatic attachment of a desired bit of DNA to a special carrier virus. Analogous techniques might become applicable to metazoan viruses with a proven ability to penetrate certain target cells—perhaps even the C-type RNA viruses that are now associated with cancer. With the aid of a special enzyme, the latter viruses apparently use their m-RNA to direct the synthesis of double-helix DNA, and this triggers cell division.

The foregoing developments must certainly have aroused the interest of military biologists. If critical control molecules in the cell are chosen as

the target, an enormous leverage should be possible, and selective organ effects feasible. The latter might range from sterilization (here one may note the testis affinity of the parotitis and Marburg agents [1282]) to permanent disablement or lethal loss of function. Alternatively, the goal might conceivably be an ethnic weapon exploiting biochemical differences between races. Many of these are known, ranging from the inability of Brazilian Indians to taste certain bitter substances, and the lactose intolerance among some Southeastern Asian populations, to the high proportion of slow isoniazid inactivators among Europeans [1282]. Again, the offensive possibilities residing in the ability of viruses to home on specific organs might be enhanced by using passage techniques to incorporate toxigenic genes carried by the virus. Such genes might perhaps be obtained from *Corynebacterium diphtheriae,* whose toxin production is associated with a lysogenic state induced by a bacterial virus that appears to carry the instruction for toxin synthesis [1283]. Even if toxin production could not be induced in the cells of the attacked organ, the technique might be used to develop a toxigenic strain of bacterium capable of synthesizing a toxin whose properties were tailored to military requirements. Such a bacterium might then form the basis of a large-scale toxin manufacturing programme. Here one may note, on the one hand, that relatively simple chemical techniques have been developed for mapping the chromosomes of bacteria [1284–1285], perhaps permitting location of the genetic regions that control toxigenicity, and, on the other hand, the possibilities of direct chemical manipulation of DNA prior to re-introduction into microbial cells. The latter technique has already been used by US military biologists to achieve streptomycin resistance and simplified nutritional requirements in *Pasteurella* species [1286]. And then there are the portentous implications of the recent success of Khorana's team in synthesizing a gene *de novo* [1287].

Infectious nucleic acids

The free nucleic acids of all types of virus are infectious. As they are neither antigenic nor neutralizable by antisera generated in the course of a previous vaccination, they could present immense problems to a BW defence if they could be harnessed in biological weapons. It is in relation to these infectious nucleic acids that predictions of the development of synthetic BW agents are mostly made. Table 4.4 indicates other characteristics of obvious BW relevance. The broad host range in particular might add a new dimension to biological weapons; but it would of course also increase the chances of heavy ecological repercussions.

The ability of a phage DNA to infect human cells was mentioned in the

Table 4.4. Comparison of viruses and their nucleic acids

Property	Virus	Virus nucleic acid
Infectivity	++++	++
Infectivity after mixing with viral antisera	0	++
Infectivity after phenol extraction	++	++
Infectivity after heating to 60°C	0	++
Infectivity after adding 1 per cent formalin	0	++
Infectivity after adding iodine	0	++
Infectivity after specific nucleases	++++	0
Antigenicity	+++	0
Host range	narrow	broad

Source: Herriott, R. M. Implications of infectious nucleic acids in disease. *Progress in medical virology II.* Karger: New York, 1969.

preceding section. Human cells have also been infected with nucleic acid taken from the virus causing polyhedral disease in silkworms [1288]. Likewise, while polio virus infects only a very few species of animals, polio RNA has caused infection in all warm-blooded animals studied [1289].

Since communication between cells by means of nucleic acids is likely, physiological protection mechanisms may suggest ways in which infectious nucleic acids intended for use as BW agents can be shielded from the destructive enzymes which they will encounter on their way from the lungs to their target cells. In this connection, it may be noted that RNA-DNA hybrids are resistant to digestion by pancreatic RNAase and DNAase enzymes [1290], and that the double-stranded RNA which appears to be the replicative form of single-stranded RNA viruses is relatively resistant to RNAase [1291]. Likewise, single-stranded viral RNA can be rendered resistant to enzymatic breakdown with basic proteins [1292], with lipids [1293], with polyamines [1294], with methylated serum albumin [1295] and with polylysine [1296]. The infectivity of virus nucleic acids may also be enhanced or protected by the addition of one of a variety of substances: hypertonic salt [1297], protamine [1298], basic proteins [1299], magnesium sulphate [1300], alkalinity [1301], polycations [1302] dimethylsulphoxide [1303] or DEAE-dextran [1304].

It is the fact that so many substances are already available for protecting nucleic acids and enhancing their infectivity that suggests the feasibility of synthetic BW agents of this type. Micro-encapsulation techniques might be used to protect the nucleic acid from the aerosolization stresses that might lead to its inactivation if used as a BW agent. The microcapsules might also incorporate known nuclease inhibitors [e.g., 1305]. The retained infectivity of RNA and DNA extracted from aerosolized MS-2 and φX-174 phages [1306] indicates that properly coated nucleic acids are not so easily

damaged as laboratory experience in handling these macromolecules might suggest; moreover, aerosols of poly I.poly C, a synthetic double-stranded RNA being studied as an interferon inducer (see below), have proved stable enough to maintain their activity in protecting mice from viral infection [1307].

Related to the infectious nucleic acids are the so-called viroids. These are small, naked fragments of RNA having a molecular weight of around 50 000 (i.e., about one-thousandth of that of the smallest known virus). There is evidence to suggest that potato spindle tuber disease is caused by a viroid [1308]. Although similar aetiologies for other diseases have not been reported, this finding could well have wider significance.

Detection and identification of pathogens

The pressure of the needs of public health laboratories for rapid diagnostic methods requiring the minimum of labour is stimulating the development of new instruments geared to automation. Detection and identification studies are therefore an area where civil/military overlaps may greatly aid BW defences. Since this area is thoroughly discussed in Volume VI of this study in relation to BW alarms and warning techniques,[37] we mention here only selected immunological approaches that reflect its dynamic character.

Besides the fluorescent antibody technique, several other immunological assays have been developed for detecting low concentrations of protein antigens. Several of them could assume importance in BW defence. The most widely used method, and one which also permits the quantitation of proteins, is radio-immunoassay [1309]. This has been used to determine proteins at as low as 0.01–0.1 nanograms/ml [1310–1311]. A method based on measuring the inhibition of the lysis of protein-erythrocyte conjugates has also been reported to permit the detection of antigen in amounts as low as 0.1–1 nanograms [1312]. An immunoelectroadsorption technique can detect antigen in the 1 nanogram/ml range [1313]. A microcomplement fixation assay permits antigen detection down to 1–10 picograms in microlitre volumes of antigen solution. One of the most promising techniques, however, is based on the inhibition of inactivation of protein-bacteriophage conjugates. This technique has been used to detect insulin in serum at a concentration of 0.3 nanograms/ml [1314]. Many other proteins have been attached covalently to bacteriophage to yield viable preparations that are specifically inactivated by antibodies against the

[37] See Volume VI, chapter 3.

antigenic determinants of the proteins. They could thus provide sensitive methods for detecting antibodies [1315–1316]; and since antigens inhibit the inactivation of the antigen-coated bacteriophage preparations by antibodies, a sensitive method for the detection and quantitation of protein antigens is also available [1317].

Immunoprophylaxis and therapy of disease

Studies in immunoprophylaxis and therapy are another area where civil/military overlaps may greatly benefit CB protection R&D. It is a rapidly advancing area, and we note here some of the more recent progress that may aid defences against viral BW attack.

With regard first to the specific medical countermeasures against BW, the continuing development of viral vaccines is of primary significance. Here two factors are important: the rapid advances in the large-scale production and control of human diploid cells; and the better understanding and control of the attenuation and inactivation processes that are essential to the development of safe vaccines.

The mass cultivation of mammalian cells *in vitro* under controlled and standardized conditions has been an established technique for many years [1318]. Human embryonic cells are of particular interest for the military virologist because they constitute a good substrate for a wide range of viruses that might have offensive potential, and for which vaccines might be required. Moreover, they may also be used as a basis for the production of interferon, a nonspecific antiviral agent discussed below. Because they may also be valuable in the production of hormones, enzymes and antibodies, it is not surprising that the technical problems related to their use have been the subject of many investigations [1319–1320]. Since they are "normal" cells containing the diploid number of chromosomes, they must be cultivated on solid surfaces; they may grow on these for 50 or 60 generations before becoming senescent and dying. In this regard they are different from cancer cells which can be grown in suspension culture handled by normal fermentation techniques. Since cancer cells can furthermore be cultivated indefinitely, they would be the first choice as a tissue-culture medium for the large-scale production of viruses intended for biological-weapons use. In view of the risk of cancer viruses being present in such cultures, they could not be used for vaccine production except in an emergency. Diploid cells do not entail this risk, and since their use cuts down on the need for primates, they now attract much attention as vaccine substrates. In this connection, the type of surface on which they grow, and its pretreatment, has been demonstrated to be of great im-

portance [1322–1326]. Methodological improvements like coating the surface with collagen [1327], conditioning it by prior growth [1328], and perfusing the culture [1329–1330], have permitted significant improvement. In addition, a range of new cultivation devices using rotating titanium discs [1328], multiple glass flasks [1331] or stacked glass discs [1332] have been described that permit large-scale handling. New developments are constantly appearing, and the day may rapidly approach when even diploid cells can be cultivated by regular fermentation methods. In fact a quasi-suspension technique, in which the cells grow on the surface of minute Sephadex beads, has already been developed [1333–1334], and the knowledge about optimal media is increasing fast. Rapid progress thus seems likely, particularly since the initial hesitation on the part of the regulatory agencies with regard to the safety of diploid-cell vaccines has evaporated in many countries.

Much progress has also been made in recent years in the field of viral attenuation and inactivation. New passage routines involving both new types of virus and new physical and chemical stresses have appeared, and genetic techniques have also provided new approaches. Inactivation has been diversified beyond the classical chemical methods. In the Dutch biological defence laboratories, for example, it has been shown that ultraviolet irradiation will inactivate encephalomyocarditis virus, a small RNA virus that is virulent for mice, without affecting the haemagglutinin activity [1335]. Of more direct BW interest is the inactivation at Fort Detrick of purified VEE virus by gamma irradiation [1336]. The immunogenicity was good, and the protection afforded to guinea pigs against VEE aerosol challenge was excellent [1337]. Other promising approaches are too numerous to note here.

With regard to the chemoprophylaxis and therapy of viral infections, this field is intermediate between the specific and the nonspecific defence approaches. Many potential antiviral agents have a rather broad spectrum, as in the case of 9-*d*-D-arabinofuranosyladenine (ARA-A), a nucleoside that is virucidal against a number of DNA-viruses such as herpes simplex and vaccinia. Several drug firms are working on substances that are active against infections of the upper respiratory tract; Smith, Kline and French of Philadelphia, for example, have obtained promising results in chimpanzees with 3-(hydroxy-3-methylbutylamino)-5-methyltriazinoindole (SKF-B). The substances used in experiments with influenza act at different levels in the cell. For example, an isoquinoline derivative (UK2371) tried by the Common Cold Research Unit in the UK seems to inhibit neuramidase, a virus enzyme which may be important for the escape of the virus particles from infected cells. Others, like 1-adamantanamine

hydrochloride (amantadine), seem to prevent penetration of the cell by the virus. These possibilities for attacking the virus at different metabolic levels suggest that synergetic effects may be possible, and that some of the toxicity may be avoidable, particularly that associated with interference at the DNA level. Also to be noted is the therapeutic activity of 5-iodo-2-deoxyuridine (idoxuridine) on experimental keratitis caused by herpes simplex. One of the most promising drugs acting at this level is rifampicin, a semisynthetic antibiotic derived from rifamycin produced by *Streptomyces mediterranei,* which acts by inhibiting DNA-dependent RNA-polymerase. This enzyme, which is responsible for transcribing the genetic message from DNA into RNA, is different enough in animal and bacterial cells for that of the latter to be attacked selectively. The antibiotic is also active on those viruses which carry their own RNA-polymerase, but the effect here is more obscure since it seems to be the maturation of the particles that is affected [1338]. The fact that the antiviral activity is due to a synthetic side chain, and the massive follow-up efforts under way in the search for semi-synthetic antitumour agents active on the "reverse" enzyme, RNA-dependent DNA-polymerase, can be expected to generate many new antiviral agents.

The development of nonspecific medical countermeasures is potentially of greater value to BW defence than that of disease-specific ones. The growing understanding of the body's integrated system of defence is very important here since it provides a basis for therapeutic interference with the whole interaction of virus and target cell. In this connection, Lwoff's theory about the release of lysosomal nucleases into the cytoplasm, where they degrade virus nucleic acid, is helpful [1339]. Since the release is accelerated at elevated temperatures, it explains why the highly virulent viruses are those that have a higher optimum temperature and a faster working replicase—i.e., viruses which can complete their reproductive process before the nuclease appears. However, the cell also has another defence, one that is activated by double-stranded RNA or by stable helical molecules having 2′-hydroxyl groups on sugar moieties. Normally the trigger molecules must either be present at very low concentrations or be compartmentalized within the cell. When introduced from the outside, or released in the cell, they induce formation of the protein interferon. This exhibits antiviral activity only when assayed on cells from the same species, and may well function by activating the cell genome to produce a m-RNA which is translated into an antiviral protein. This blocks viral-dependent protein synthesis. The species specificity of interferon makes it necessary to use human interferon in clinical practice. This can be produced in embryonic diploid cells or in white blood cells; the

latter have been extensively used for experimental prophylaxis against influenza [1340]. For the present, the use of interferon-inducers attracts greater attention (for a recent major review, see [1341]), and several of these may come to have therapeutic or prophylactic clinical use. From the BW point of view, it is particularly interesting to note that workers at Fort Detrick have shown that aerosols of the interferon-inducer poly I.poly C can protect mice against aerosol infection with influenza (A_2/Taiwan/64) and parainfluenza type 1 (Sendai) viruses [1307].

V. *Control of CB research and development*

At the outset of this chapter, CB weapons were portrayed as unconventional weapons that were on the verge of becoming assimilated by the military. It was suggested that further progress towards conventionality depended primarily upon technological improvements in the weapons, and that incentives towards this end were being created by changes in the traditional patterns and modes of conflict. Current R&D programmes in CB technology were thus seen to have crucial importance for the future status of CBW, and therefore also for the prospects and stability of future CB disarmament agreements.

Certain recent events support this analysis. The heavy use of chemical irritants and antiplant agents in the Viet-Nam War[38] indicates at least some measure of assimilation of some forms of CB weapons by the armed services of a major power (although, as is discussed in Volume V of this study,[39] this may have been counteracted by the backlash of opinion against the war in general and the use of these agents in particular). So also do the reports—if they are true—that Portugese forces are using similar weapons in their African colonies.[40] Then there is the fact that in recent years the military authorities of the major NATO countries have been paying a good deal more attention to CB defence than they did during the 1950s, particularly the anti-chemical protection of their combat troops stationed in mainland Europe. Of course this does not necessarily mean that NATO forces are becoming attracted to CB weapons; what it does mean is that the authorities concerned have become much more impressed by the potentialities of CB weapons in the hands of their putative enemies. So far as can be judged—and it must be said that this is not very far (see above, pages 173–184)—NATO authorities have no *confirmed and in-*

[38] See Volume I, pp. 162–210.
[39] See Volume V, pp. 39–40, 57 and 73.
[40] See Volume I, pp. 210–211. See also p. 198 above.

disputable intelligence that Warsaw Pact forces either possess enough chemical weapons for militarily significant results on a European battlefield, or would embark upon first-use CW if they had them. But increased NATO antichemical protection makes sense only if just such an appraisal of Warsaw Pact CW capabilities and intentions is accepted.[41] What seems to have happened is that nerve gas has been judged a weapon of sufficient military utility for the appraisal to be accepted without question. It is a significant fact that, in a recent major British study of the Soviet armed forces [521], frequent reference is made to the manner in which Warsaw Pact combat units would use nerve gas in a European war but there is no discussion of whether they actually possess nerve gas, or of the significance of the adherence by Warsaw Pact countries to the Geneva Protocol. This is said, not in criticism of the study, but as an illustration of current perceptions of the military value of nerve gas. The illustration would be still more pertinent if Warsaw Pact countries were indeed as interested in CB weapons as they are made out to be in the West. And just as there is, or seems to be, no information to confirm the appraisal, neither is there any to refute it.

Finally, there are certain indications that, in the USA at least, initiatives for CB-weapon development programmes have increasingly been coming from the higher levels of the military establishment rather than from the CB weapon technologists themselves. An example is an extract from Congressional testimony given in 1969 by General A. W. Betts, Chief of US Army Research and Development:

> In accordance with the instructions contained in the Secretary of Defense Decision/Guidance A-4-040, "Toxic chemical munitions", dated September 11, 1964, the Army directed the US Army Combat Developments Command to conduct a comprehensive study of tactical chemical and biological operations. The study was to develop the rationale and concepts of employment of chemical and biological systems and to determine qualitative and quantitative requirements for chemical and biological materiel supported by cost effectiveness data. Because the study did not provide an adequate basis for approving qualitative and quantitative materiel requirements or the realinement of the R.D.T.&E. program an addendum study to Project Mandrake Root (ASPMR) was conducted by the Combat Developments Command and contract organizations. This project was the most comprehensive study ever made to assess the potential value of chemical and biological weapons in support of land combat and to establish definite requirements for weapons and protective equipment.
>
> By Chief of Staff Memorandum 67-380, dated September 26, 1967, the Army Chief of Staff approved the addendum study, Project Mandrake Root (ASPMR).

[41] An alternative explanation is that NATO forces themselves intend to initiate battlefield CW in the event of a European war; but this would be directly against the declared CBW policy of the USA, the UK, France, the Netherlands and the FRG (see above, chapter 3).

This memorandum delineated the responsibilities of the Army staff agencies for follow-on actions developed as a result of the approval of the ASPMR. Among these responsibilities I was to "make alterations to the R&D program consistent with the approved Mandrake Root and addendum study findings based upon relative requirements and priorities". An extensive R&D program reorientation was initiated in 1968 and should be completed this year. [1342]

More often than not in the past, the military options provided by technical development in CB weaponry have neither been solicited nor appreciated by their intended users. Project Mandrake Root[42] can perhaps be seen as a turning point, and in the future CB weapon R&D may become increasingly subservient to explicit military requirements: CB weapons may, in other words, become accepted. And as regards particular technical developments, many of those outlined earlier in this chapter may in fact have taken place already, and others may be removed from realization only by a thin film of funding considerations.

It goes without saying that the conclusion of an international CB disarmament treaty would provide a substantial barricade against further assimilation (even though, as discussed below, it may not be quite so substantial as appears at first sight). The evident reluctance or hesitation, as of late 1972, of the superpowers to advance the chemical disarmament negotiations is perhaps another measure of the extent to which chemical weapons have already become assimilated, just as the rapid progress made with biological disarmament illustrates the present unacceptability of biological weapons. The value of the BW convention has however been questioned:[43] since several major countries, including the USA, had already renounced biological weapons unilaterally, the convention in effect merely formalized what had already happened, and was not itself the disarmament step it was claimed to be [1344–1345]. Its supporters point to the dangers of the future, however; although biological weapons may not make very much military sense today, they might in years to come. This could well be true. At the present time, biological weapons are certainly not the weapons of assured mass destruction which they were sometimes claimed to be during the 1960s; but the technical descriptions given earlier in this chapter indicate the comparatively small scientific advances that might make them become so in, say, the 1990s. Yet the convention includes very little in the way of positive measures for preventing the realization of these advances. If such 1990s-type biological weapons already

[42] Further information about the methodology and preoccupations of Project Mandrake Root is contained in the publicity brochure of one of the contractees involved [1343].

[43] See Volume IV, pp. 317–20; Volume V, pp. 120–24.

existed in 1972, the BW convention would surely not have been signed then; and just as there might have been strong military pressure in 1972 against accepting biological disarmament under such circumstances, so may there be strong military pressure in the 1990s to abrogate the 1972 convention. Concerning biological weapon R&D, parties to the convention undertake

> never in any circumstances to develop ... microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes; weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.

But the fact of the matter is that even if biological-weapon R&D programmes were discontinued in accordance with this undertaking—and the convention makes no provisions for verification other than a complaints procedure of dubious efficacy—the scientific advances needed to create a 1990s-type weapon might easily occur during a "prophylactic, protective or other peaceful" R&D programme.

In the absence of positive controls, perhaps the greatest defect in the BW convention is that it permits military scientists to study candidate BW agents and delivery vehicles for purposes of developing protection against weapons that should no longer exist. It can certainly be argued that if impregnable protection were developed, the threat of BW would disappear. But in BW, and probably also in CW, the attack is simpler to execute than the defence against it [1346]: offensive developments are thus likely to proceed faster than defensive ones if both are pursued with equal vigour, and the defence/offence spin-off possibilities exemplified earlier in this chapter are numerous. The situation is exacerbated by the fact that no country yet seems willing entirely to relax the security measures surrounding parts of their BW defence work. Protection R&D may thus continue to be misperceived as weapon R&D. One possibility which has often been voiced,[44] but not yet followed up in the disarmament negotiations, is that this research work on CB protection should be internationalized—for example, that unrestricted international exchange programmes of scientists should be instituted at BW defence establishments, or even that biological defence research (from which there have been many valuable spin-offs into the civilian sector) should be confined to establishments under international control. This at least would remove some of the grounds for suspicion that might lead a country to resume biological-weapon R&D.

[44] See Volume IV, pp. 401-402.

If this were done, the dangers of continued BW-protection R&D would be reduced to the same proportions as those of *bona fide* academic, medical or industrial R&D in areas that happen to be relevant to CBW. This is certainly not to say that the dangers would then become insignificant. Far from it; the major inputs that pest control, public health, pollution control and other such peaceful programmes can provide to CB technology have already been illustrated. These are areas to which formal disarmament or arms-control measures are clearly inapplicable.

What this seems to imply is that the conclusion of international CB disarmament treaties might not in fact be quite such an assured means of preventing CBW as at first appears. The effect might merely be to delay assimilation of CB weapons and not to prevent it altogether. Moreover, the possibility of CB armament taking place also has to be accepted as well as the possibility of CBW being waged, in circumstances where international treaties would not apply. For example, CBW commentators have often dwelt on the havoc which might be created by individuals or groups armed with small amounts of CBW agent.[45] The countermeasures here are in theory the responsibility of police and internal security forces; but it is difficult to visualise their successful application to, for example, laboratories from which supplies of CBW agent might originate. Moreover, the polarization of society into antagonistic, and sometimes violently militant, groups seems to be increasing in many parts of the world. This situation has its counterpart at the international level, both in the case of closed societies isolated from the world community, and in the hypothetical case of countries which accede to a CB disarmament treaty but which nonetheless pursue a clandestine CB weapon R&D programme.

This is the sort of background against which proposals have been made for informal verification activities by nongovernmental organizations, particularly scientific bodies. The proposals, most of which stem from the Pugwash organization, range from the institution of programmes of international cooperation in research areas that have CBW ramifications, to the formalization and enforcement by professional bodies of codes of professional behaviour for workers in CBW related disciplines. The main objectives are to identify, isolate and stigmatise CB weapon researchers, and to ensure the publicity that might lead to formal controls on new discoveries having CB weapon applications.

What is being suggested here is, of course, *vigilante* activity by groups

[45] In January 1972, two youths were arrested in Chicago on charges of having conspired to contaminate the city's water supplies with stocks of *Salmonella typhosa* allegedly found in their possession and cultured by one of them in a college laboratory [1348]. They were released on bail of $250 000 each, but subsequently fled to Cuba.

of concerned scientists. As such, the proposals are open to all the criticism that attaches to minority group watch committees. But it may be argued that the risks of CB weapons for mankind—the terrible extent to which they could magnify the consequences of irresponsible behaviour—is reason enough for this sort of action. And in CBW, where the frontiers of knowledge are perhaps closer to the battlefield than in any other area of military technology, scientists occupy a peculiarly influential position. CBW operations exploit technologies in which there is much fundamental scientific ignorance, and the professional soldier is rarely trained to distinguish scientific fact from the sort of scientific opinion in which all manner of bias, professional prejudice and vested interest may be embedded. The soldier is thus heavily dependent on the scientist, so that the continuance or withdrawal of the scientist's support could have a great effect on the future status of CBW.

The attitude of scientists towards CBW certainly depends in most cases on the context in which their judgement is sought. If they are told that CB weapons might be used against their own country, and that their country is defenceless unless they participate in defence planning most of them will probably offer their services. But thereafter, by small and perhaps imperceptible stages, individual scientists or research laboratories may drift over from defensive activities into offensive ones, even though they were not originally recruited for that purpose (e.g., from prophylactic medicine and physical defence measures into tests with nonpathogenic simulants and animal pathophysiology with potential weapons, and from there to weapons development to delineate the possibilities open to potential enemies and so on). This process may be particularly easy in large military establishments where it involves so many people that identification with a group comes easily. The prestige which well-known scientists, great resources and advanced achievements in preventive medicine can bring to such a group may accelerate the process.

Here one may note as an illustration the interplay between the US community of microbiologists and the US Army BW laboratories at Fort Detrick. In the late 1940s the latter establishment "acquired a status—at the annual meetings of the Society of American Bacteriologists (SAB), for example—more or less equivalent to that of a great university. ... It came to have a reputation as a training area for young scientists and as a continuing source of significant basic research publications" [1349]. To a large extent those who participated directly in the activities did so because they felt that their country was in a crisis that was expected to pass in a limited time, with a return to normal. When this did not happen, qualms of conscience began to set in: could there be such a thing as an

indefinitely-sustained crisis, and was continued biological-weapon R&D morally permissible [1349]? A crux was reached in 1955 when the SAB (now the American Society of Microbiologists) established a special advisory committee for Fort Detrick. The objectives of this committee, which usually met once a year, came under two broad headings: scientific advice and professional advice:

> The former, which represents by far its major function, consists of critically reviewing selected portions of Fort Detrick's research and development program, and thereafter providing the technical director of Fort Detrick with an evaluation of the planning, execution, analysis and interpretation of these scientific projects. In addition, recommendations are made regarding scientific activities to be conducted in the future. The professional advice rendered by the committee refers to such problems of Fort Detrick scientists as attendance at scientific meetings, review procedures for scientific publications, contractual relationships between Fort Detrick and the universities, recruitment of professional personnel, etc. The committee has no responsibilities regarding the moral, political or military aspects of BW. [1350]

During 1967, when misgivings about the US BW programme were becoming widespread, the Society discussed the future of this committee at length. Some felt that the Society might refer its BW advisory function to the National Academy of Sciences/National Research Council—a scientific society with federal charter whose function is to advise government agencies upon request. At a meeting in November, Joshua Lederberg argued

> that civilian review should be performed by the scientific community as a whole with the exception perhaps to be made only upon proof by the military of the need for secrecy. Small communities operating within the strictures of secrecy are limited not only by the particular competence of their members but also by the very narrow realm of criticism considered appropriate by the military. [1351]

Eventually, the committee was dissolved.

Fuller discussion than is possible here of the tensions affecting individual CB R&D workers which may arise from the interaction of professional codes of behaviour and the nature of their occupation can be found in other publications [1352–1353]. The tension is most marked in the case of medically qualified personnel working on offensive CBW matters, for these run directly contrary to the Hippocratic Oath, a clear-cut formulation of professional responsibilities that is unique among scientific disciplines. In recent years it has been suggested in some quarters that similar codes of behaviour are needed in other disciplines in order to alleviate not only the CBW threat, but also the many other hazardous side-effects of the

increasing dependence of society upon technology. Ways and means for reinforcing professional ethics could, so it is argued, serve as a basis for nongovernmental controls on CB R&D, for the further internationalization of medical and scientific research, and for similar beneficial and cooperative activities.

Efforts of this type cannot be considered in isolation from the much larger complex of questions that relate to the social responsibility of the scientist [1354–1362]; but these fall outside the scope of the present study. Moreover, the development of new codes of behaviour certainly requires a more general awareness of the need for rules in a whole range of professions, of which natural science is only one. One may point, for example, to the work of information scientists and their clients, for the growing use of computerized networks of data banks, in which detailed information on the public and private life of individuals is stored, is yet another case where the interests of the individual and those of society may stand in opposition. There is no particular reason for supposing that the responsibility of natural scientists differs in kind from that of any other group of citizens, or of any human being. Discussing this question, Karl Popper has remarked that everybody has a special responsibility in the field in which he has special power: "Just as in former times *noblesse oblige,* so now *sagesse oblige:* it is the potential access to knowledge which creates the obligation" [1363]. In the context of CBW, however, the onus lies firmly on the natural scientists.

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