Report of the RS-IAP-ICSU international workshop on science and technology developments relevant to the Biological and Toxin Weapons Convention

Summary

This workshop, held on 4 – 6 September 2006, brought together 84 leading international scientific and policy experts from 23 countries to discuss scientific and technological developments most relevant to the operation of the Biological and Toxin Weapons Convention (BTWC). The meeting aimed to inform the delegates at the Sixth Review Conference being held in Geneva in November 2006. Developments addressed included synthetic biology, post genomic technologies, immunological research, drug discovery and delivery, agricultural and environmental biotechnology, and diagnosis and surveillance of infectious diseases. These advances will undoubtedly bring positive benefits to humankind. The challenge facing the international scientific and political communities is to identify what measures can be taken to reduce the chance of misusing these developments without jeopardising the enormous potential benefits, that is to manage what is often called the 'dual use' risk.

The key points arising from the workshop were:

- The misapplication of the scientific and technological developments discussed at the workshop should be covered under BTWC Article I, which should be reaffirmed at the forthcoming Review Conference.
- The risk of misapplication can be minimised, though not completely eliminated, through States Parties implementing their international obligations into national laws and regulations. These measures must encompass the full range of BTWC prohibitions and those that go beyond the implementation of BTWC obligations must not inhibit scientific progress.
- It is essential that processes are explored by which the scientific community can regularly input into the BTWC regime, such as independent scientific advisory panels and regional scientific meetings. If they do not already do so, States Parties should seek advice from their scientific community as part of their preparation for BTWC meetings and consider including scientists in their delegations.
- The pace of scientific and technological developments is now so rapid that the implications of new scientific and technological developments need to be reviewed more frequently than allowed by the five year cycle of BTWC Review Conferences. Interim structures such as independent scientific advisory panels and regional meetings could also assist in keeping track of developments.
- Risk management processes dealing with the misuse of technologies across the full spectrum of biological threats must also be improved. There should also be further investigation of best practice in communicating the associated risks.
- Enabling technologies going beyond the classical life sciences are equally relevant to the BTWC, particularly in relation to the means of delivery of agents for hostile purposes. The convergence of these technologies with traditional and current biotechnologies should be closely monitored.
- Restricting the free flow of information about new scientific and technical advances is highly unlikely to prevent potential misuse and might even encourage misuse. All reasonable measures should be taken to facilitate the flow of information and scientists amongst the international community in both the developing and the developed world.
- National and international scientific organisations and industry should engage with those involved with scientific endeavours in academia, government and the private sector in order to educate and increase awareness of the BTWC and dual use issues, for example through codes of conduct. These measures

would promote in depth implementation of the BTWC and help to further responsible stewardship in the life sciences and to ensure vigilance when work with dual use potential is undertaken.

1 Introduction

The workshop was held at the Royal Society on 4–6 September 2006 and was jointly hosted by the Royal Society, International Council for Science (ICSU) and InterAcademy Panel on International Issues (IAP). The following scientific and technological developments and their implications on the BTWC were addressed:

- synthetic biology;
- post genomic technologies;
- immunological research;
- drug discovery and delivery;
- agricultural and environmental biotechnology;
- diagnosis and surveillance of infectious diseases.

This report outlines the dual use dilemma facing research in the life sciences and summarises the presentations made at the workshop on the above developments, as well as discussions of their associated dual use risks. Key issues that emerged are then presented followed by the workshop's conclusions. A background summary to the BTWC, the workshop programme and a list of participants are listed in appendices A, B and C, respectively. The presentations from the speakers are also available on the Royal Society website (www.royalsoc.ac.uk/policy) and are referred to in this report.

This report represents views expressed at the workshop and does necessarily represent views of the host organisations.

Our thanks go to the workshop organising committee who advised on the programme of the workshop and the contents of the report. This committee comprised of Professor Roderick Flower FRS (Queen Mary, University of London), Professor Mary Osborn (Max Planck Institute, Germany), Professor Sergio Jorge Pastrana (Cuban Academy of Sciences), Dr. Carthage Smith (International Council for Science) and Professor Pieter Steyn (Stellenbosch University, South Africa). We would like to thank the Alfred P Sloan Foundation for its generous grant for the workshop, as well as the InterAcademy Panel, International Council for Science and Wellcome Trust for their financial contributions. We would also like to thank the US National Academies staff for assisting with the organisation of the workshop.

2 The BTWC context

The BTWC will only work properly if it evolves in directions that are scientifically sound and make sense in terms of politics, sociology, law and international relations in its military and diplomatic dimensions. Care must be taken to keep the right balance of incentives and disincentives favourable to compliance, and governments need to give it more continuous attention and demonstrate more visibly that they hold it in high esteem. However, this care and attention and high esteem cannot come from government alone but must also continue to come from national academies of science, international scientific unions and the relevant professional organisations in the life sciences, as well as universities, research institutes and NGOs and other civil society organisations. Further details of BTWC obligations are given in Appendix A, as well as being outlined in detail in the presentation made by Mr Nicholas Sims.

3 Dual use dilemmas

It was stressed that 'dual use' relates to the threat of misapplying information or technologies rather than the carrying out of research itself. This highlights the extent of dual use dilemmas since many types of research may be dual use by implication. However, just because a piece of research is considered to be dual use, this does not mean that it should not be carried out. Rather, this classification serves to emphasise that special consideration may be warranted regarding how the research is carried out and how its results are communicated.

This highlights the problem of defining dual use in the life sciences. One definition is provided by the US National Science Advisory Board for Biosecurity (NSABB): 'biological research which may provide knowledge, products, or technology that can be directly misapplied with sufficient scope so as to threaten public health or other aspects of national security, such as agriculture, plants, animals, the environment and materiel' (NSABB 2006). Examples of dual use research include the 'experiments of concern' highlighted in the US National Research Council report *Biotechnology research in an age of terrorism* (US NRC 2004). These are experiments that would:

1 Demonstrate how to render a vaccine ineffective;
2 Confer resistance to therapeutically useful antibiotics or antiviral agents;
3 Enhance the virulence of a pathogen or render a non-pathogen virulent;
4 Increase transmissibility of a pathogen;
5 Alter the host range of a pathogen;
6 Enable the evasion of diagnostic/detection modalities;
7 Enable the weaponisation of a biological agent or toxin.

Participants stressed the importance of involving the wider international scientific community in the formulating of new rules and regulations.

4 Synthetic biology

Unlike systems biology, which analyses large quantities of data on the simultaneous activity of many genes and proteins, synthetic biology reduces the same systems to their simplest components by modelling patterns of gene expression as genetic circuits. Pieces of DNA are treated as fundamental black box modules that can be spliced together to construct what are effectively biochemical logic boards. Circuits are introduced into bacteria and those that perform best are selected. In this way, biological circuits are empirically refined to arrive at the best computational solutions

Like electronic circuits, live bacterial circuits perform simple computations to function as sensors and input and output devices. For example, researchers have engineered bacteria to be sensitive to their external environment so that given certain environmental conditions genes coding for fluorescent proteins are activated and the bacteria flash or glow. Synthetic biology therefore has many useful potential applications, such as designing bacteria to detect chemical and biological agents and diagnose disease. Further details were given in the presentation made by Professor Drew Endy.

Synthetic biology and attempts to synthesise simple bacterial genomes are driving the development of better ways to make larger pieces of DNA. Furthermore, synthetic biology has helped catalyse progress across biological engineering disciplines since researchers no longer need the expertise to prepare DNA relevant to their research and thereby save time and money. This technique is available commercially worldwide so it is now significantly easier to engineer more genes on increasingly larger scales, especially since genetic material can be ordered by mail and DNA synthesisers can even be bought over the internet.

4.1 Dual use risk

Synthetic biology promises to deliver extensive benefits to progress in the life sciences and humankind. However, participants felt that the potential dual use risk of synthetic biology is high. The ease with which genetic material can be synthesised deskills the process of biological engineering, and so 'backyard or garage biology' may simply be inevitable. The concern is that an eradicated or extinct biological agent may be reconstituted (the polio virus, for example, was entirely chemically synthesised in 2002) or a pathogenic agent or toxin could be generated outside of existing controlled and regulated frameworks. One way to reduce the risk of misuse of synthetic biology is through increased training and awareness raising amongst scientists about dual use issues and relevant national and international laws and regulations. This applies equally to those working in academia, government and the private sector.

5 Post genomic technologies

5.1 Genetic targeting and pharmacogenetics

The Human Genome Project has significantly expanded our knowledge of genetic polymorphisms (DNA sequences that vary between members of a species) some of which affect the susceptibility of individuals to some infections and therapeutic drugs. For example, genetic variation has a significant role in the development of AIDS. Genetic analyses have revealed genetic polymorphisms regulating HIV-1 cell entry and cytokine defences to HIV-1. Many other genes and the systems they control are still yet to be discovered. The presentation made by Professor Winston Hide discussed this issue in greater detail.

Genetic polymorphisms not only exist at the level of the individual but also at the level of the group. Stable genetic differences and similarities exist between population groups of differing geographic origin, race and ethnicity. For example, homozygosity for a mutation in the *CCR5* gene is presently considered to be the most relevant genetic factor explaining resistance to the HIV-1 virus, but only Europeans appear to have it. Studies have also highlighted significant genetic polymorphisms across African, Asian and European populations for gene families that mediate the metabolism of certain clinically useful drugs and environmental toxins. Even subpopulations show genetic variations with significant differences between White Americans and African Americans, and between Portuguese and Black Brazilians. Dr Guilherme Suarez-Kurtz's presentation outlined further details.

Pharmacogenetics therefore aims to target these differences and similarities to design more effective, personalised diagnoses and vaccines. However, this sort of research has only been possible due to powerful computational techniques of bioinformatics, which can extract biological information that would have previously been lost as background cellular noise (Royal Society 2005a). At the scientific level, previously difficult and intractable problems can now be tackled and solved in radically shorter times; and clinically these

new information techniques have given rise to user friendly diagnostic technologies that provide rapid genomic analyses of individuals.

Bioinformatics has also enabled the global management of biological information. There is a vast repository of public domain software for computational biology, and individual accounts for remote access and data processing can be opened at high-performance computer facilities and bioinformatics regional centres, including FIOCRUZ in Brazil, SANBI in South Africa, CeCalCULA in Venezuela, and ICGEB in Italy and India. In this way, digital libraries of biological research results allow the global sharing of knowledge. Biological research can be distributed over multiple laboratories so investigators can work collaboratively around the world.

Bioinformatics also requires relatively modest hardware and technical support, which helps explain in part the rapid rise of biotechnology in Africa. LINUX operating systems, for example, permit the use of personal computers as powerful workstations, and information technology training for African scientists has been available online, although this has been constrained by limited internet connectivity.

5.2 Proteomics

The aim of proteomics is to understand the expression and modification of proteins and their involvement in metabolic pathways in real time in a single (or set of) cell(s). This has only been possible due to advances in the speed, automation and availability of basic techniques. For example, new array technologies and advances in mass spectrometry provide improved resolution of protein species, whilst fluorescent probes, coated nanoparticles and Raman and fluorescent optical spectroscopies can monitor intracellular signals more effectively. One valuable application of proteomics has been the manufacture of sensitive biosensors to diagnose certain illnesses in individuals. The presentation made by Dr Andrew Pitt outlined further details.

However, a major challenge has been that seemingly simple pathways are in fact embedded in extremely complex intra- and intercellular networks. Consequently, there is a growing awareness of the usefulness of systems biology and its powerful computational techniques to analyse and integrate the complex interactions of individual molecular elements of biological systems into manageable, predictive models. For example, it is now possible to look at the effect of a particular stimulus on many different signal transduction pathways that control cellular responses to infection, and this has helped advance the understanding of pathogenesis, virus morphology and drug resistance in micro-organisms, as well as mechanisms of disease and related cellular biochemistry in humans.

5.3 Transcriptomes and metagenomics

Whereas much of a cell's DNA does not code for proteins, a cell's transcriptome (which refers to all messenger RNA molecules or transcripts produced in that cell) reflects all the protein coding genes that are being actively expressed at any given time in a cell. Transcriptome analyses are therefore valuable contributions to understanding transcriptional regulation, and have been used to investigate how cancer cells progress and how stem cells maintain their unique properties.

One new post-genomic technique that has facilitated these analyses is paired end ditagging (often known as PET), which has significantly improved the efficiency of DNA sequencing. This technology has also been used in metagenome analysis, which identifies and studies genomes recovered from environmental samples rather than from clonal cultures. This area of research has received attention especially given recent public health

concerns over SARS and avian flu. One aim has been to discover previously uncharacterised viruses that are relevant to human health. For example, one set of studies carried out in Singapore investigated microbial communities found in human-associated environments. Unexpectedly, many of the microbial communities taken from indoor air samples were of human origin, and certain genes were found to be enriched in some of the air microbes, including genes involved in resistance to desiccation and oxidative stress, and possible virulence factors. Dr Yijun Ruan outlined further details in his presentation.

5.4 Dual use risk

Given the continued presence of ethnic tensions and conflicts in the world today, the fear is that genetic polymorphisms could be used to target specific populations for non-therapeutic purposes. Some participants felt that this fear was exaggerated because inter-ethnic, and thereby genetic, admixture is becoming common or increasing at a fast pace, and so it is rare that a given polymorphism is specific to one population. Moreover, although there are a large number of polymorphisms within the human genome, the proportion of them lying in functionally important areas is small and therefore reduces the risk of selective targeting.

Others argued that targeting need not be hugely effective or completely selective. Public perception of the risk posed by bioterrorism feeds into the geopolitical response to incidents, and so even a moderate level of selectivity would be sufficient for seriously damaging societal structures. The social panic resulting from the attack would be enough to trigger effects far in excess of those from the initial attack itself.

However, targeting need not involve individual polymorphisms. For example, certain cell surface antigens have distinctive distributions that vary with geographic origin and so viruses could be used to target distinct ethnic groups with characteristic cell surface molecules without needing to identify population-specific genetic variations (Institute of Medicine and National Research Council 2005).

In addition, genomic medicine presupposes a sound understanding of the relationship between genetic differences and pathogens' mechanism of disease. For example, researchers have investigated how genes in the bacteria *Mycobacterium tuberculosis* and *Vibrio cholera* control the invasion of the bacteria into host environments. In doing so, potential drug targets have been identified, as well as novel virulence factors. Professor Winston Hide discussed further details in his presentation. The concern is that this knowledge could be misused to enhance the susceptibility of host populations to pathogen infection.

Similarly, some participants felt that knowledge of the diagnostic applications of post-genomic technologies could be misused to enable biological agents or toxins evade detection methodologies. Others also raised concerns that the problem-solving promise of systems biology could be misused to identify ways to deliberately manipulate biological systems with the intent to do harm.

6 Immunological research

6.1 Manipulating innate immunity

'Innate immunity' represents the first line of non-specific defence against pathogens and is essential for keeping an infection in check before longer lasting, specific 'acquired immunity' can be induced. Cells of the innate immune system respond to pathogen associated molecular patterns (PAMPs) on alien microbes and produce cytokines, which in moderate amounts contribute to defence processes but when overproduced can

lead to autoimmunity and even death. The severe reactions suffered by volunteers during clinical drug trials at Northwick Park Hospital in London in spring 2006 highlighted the disastrous clinical effects of agents that induce a cytokine storm.

Several recent reports in the scientific literature describe the possibilities of targeting the innate immune system for therapeutic purposes, especially using PAMPs whether in natural form or artificially designed. For example, synthetic imidazole quinolones target innate immune system receptors for the treatment of genital warts and other diseases caused by human papillomaviruses; and synthetic oligodeoxynucleotides can provide generic immunity in rodents against many different bacteria, viruses and parasites. The presentation made by Professor Kathryn Nixdorff gave further details.

6.2 Manipulating acquired immunity

Short interfering RNA (siRNA) or silencing RNA refers to a class of small RNA molecules that can act upon and interrupt RNA related pathways, most notably those controlling gene expression. For example, the introduction of siRNA complexes can silence gene expression in mammalian cells without triggering an innate immune response. This has been important for cancer treatments where immunity can be boosted by silencing immune suppressive genes. Conversely, immune responsive genes can be silenced to lower immunity, which is useful to treat allergic and autoimmune diseases, as well as graft rejection after transplants. In addition, siRNA methods are beneficial because they can inhibit specific genes that have been inaccessible to conventional drugs. Dr Wei-Ping Min discussed the applications of siRNA in his presentation.

6.3 Dual use risk

The concern is that immunity or the effectiveness of immunisation could be disrupted for non-therapeutic purposes. A worst case scenario would involve designing a tool to interfere with the signalling mechanisms within immune systems to manipulate either the innate or acquired immune systems. On the one hand, cytokine production could be over stimulated as a biological weapon. On the other hand, over-silencing immune suppressive genes too much could produce a hypo-immune response, leading to the development of cancer; whilst over-silencing immune responsive genes could trigger a hyper-immune response, leading to autoimmune disease. Manipulating the innate system is considered to be the more dangerous of the two because as a non-specific mechanism it would have more widespread effects.

The immune system does not act in isolation but interacts with other systems and bioregulators, such as the nervous and endocrine systems. Consequently, the dual use risk is raised to a whole new order of complexity. By affecting the functions of these other systems, even small manipulations to the immune system could be amplified to bring about devastating consequences.

On the whole, participants agreed that immunological research does pose a dual use risk but they felt that this potential risk should not be exaggerated, especially since current delivery systems do not allow effective targeting of human or animal immune systems.

7 Drug delivery

7.1 Gene therapy and vectorology

Nucleic acids, such as DNA, can be delivered into cells, after which they are decoded and translated into therapeutically useful proteins. This allows cells to be targeted whilst avoiding some of the toxic side effects caused by conventional drugs. There has been considerable research into 'artificial viruses'- polymer based complexes containing DNA with special molecular features to enhance the efficiency of DNA uptake into specific cells. This technique has been used in cancer treatment, for example, where DNA is released within cancer cells and translated into proteins that can kill tumour cells directly, block the cell cycle or stimulate anti-tumour immunity. In one study, local applications of synthetic double stranded RNA on different tumours in mice led to the eradication of intracranial glioblastoma; and DNA coding for cytochrome P450 isoforms directed at tumour cells activated cyclophosphamide, which helps boost acquired immunity against cancerous cells. Dr Manfred Ogris outlined further details in his presentation.

7.2 Dual use risk

This area of research is already generating benefits. However, participants felt that its potential dual use risk is high because the feasibility of delivery is central to the targeting of genes and biological systems (whether for therapeutic or non-therapeutic purposes). The concern is that vectorological research could be used to deliver harmful genes into host cells and increase the stability, transmissibility or ability to disseminate harmful biological agents or toxins. While delivery is currently problematic, research is being carried out to improve delivery, exploiting nanotechnology to enhance absorption of aerosols and liposome and lipid nanoparticle formulations of chemically modified and stabilised siRNA complexes (Royal Society - Royal Academy of Engineering 2004).

8 Agricultural and environmental biotechnology

8.1 Biopharming

The agricultural applications of biotechnology are varied and have helped farmers grow crops with larger yields that are more robust in the face of disease and drought, as well as crops with improved nutritional content and greater photosynthetic efficiency. Crops have also been genetically modified to produce and deliver vaccines and engineered plants can elicit an immune response in humans. For example, clinical trials on humans are currently underway to test vaccine produced in edible crops.

8.2 Pest control

One new application of biotechnology concerns non-chemical controls on insect pest infestations, which cause great losses especially in developing countries with agriculturally dependent economies. In Tanzania, for example, maize is a staple food and a major cash crop. Tanzania has traditionally relied on the use of persistent, non-specific chemical pesticides to combat pest outbreaks. However, this has led to great environmental damage including contamination due to residual poisons, build up of toxins in food chains and the killing of beneficial organisms. These have all been compounded by the spread of resistance in pest populations. Moreover, chemical pesticides in Africa are often very expensive, especially when these associated risks and social costs are included.

To combat these problems, Tanzania has tried to diversify its insect pest management, especially through biological controls, such as introducing naturally-occurring pest-specific predators and parasites. Programmes of sterilising males have also been tried, as well as pheromone use to control sexual behaviour. Researchers have also genetically engineered crops to be pest resistant, and investigated the ecology of pests to look at ways to interrupt pest development and reproduction. Dr Costancia Rugumamu discussed integrated pest management in further detail in her presentation.

8.3 Environmental biotechnology

Biotechnology applications also extend outside of the farm. In Pakistan, for example, the Centre for Molecular Genetics at the University of Karachi has isolated bacteria from indigenous sources and developed them for large scale industrial and medical applications. Bacteria have been used to filter and digest toxic aromatics, such as pesticides and crude oil components, and certain oil eating bacteria have even been successfully used to decontaminate beach sand after oil spills. Bacteria have also been used to produce bio-fertilizers and biodegradable plastics, which have been useful for safely destroying surgical equipment and baby and female hygiene products. Dr Nuzhat Ahmad gave further details in her presentation.

8.4 Therapeutics and vaccines

One promising security application of biotechnology is creating strategic stockpiles of therapeutics and vaccines against biological agents. In 2004, Project Bioshield was launched in the USA with a $5.6 billion budget (to spend by 2014) on strategic reserves of therapeutics and vaccines against known biological agents to be stored as the Strategic National Stockpile (MacKenzie 2006). However, strains can easily mutate and become resistant to stockpiled vaccines; long term reserves of therapeutics tend to be unstable; and large scale manufacturing of therapeutics takes one to three years using traditional techniques.

Alternative genetic engineering techniques are being explored to avoid these problems. One technique involves transient gene expression in plants where genes coding for relevant protein antigens are inserted into a plant virus, which is then introduced into plant hosts. Replication of the virus then leads to the production of the protein antigens, which can then be harvested. Another method is to convert viral RNA into a DNA sequence, insert this into a delivery vector and then introduce the vector into a plant. With each replication the RNA expressed from the DNA leads to the production of the antigen. Similarly, research has been carried out to produce countermeasures against organophosphate nerve agents, such as sarin. Organophosphate toxicity occurs by inhibiting the neurotransmitter breakdown by acetylcholinesterase (AChE), and so plants have been engineered to bio-manufacture human AChE that can be used as a molecular sponge to mop up nerve gas agents and hence decrease their toxicity.

The major appeal of this technology is that plant manufacturing facilities are cheap and can be easily and rapidly scaled up to produce large quantities of vaccines. US Army research on producing plague vaccines from plants found that 100 plants could yield a gram of purified vaccine, the equivalent of 75,000 doses, and time from the initial infection (of the vector into the plants) until harvest took only 12 days. Professor Charles Arntzen outlined further details in his presentation. The protein antigens produced were then purified for delivery by injection. This means that highly effective vaccines can be produced in a cost-effective manner for countries wishing to create on demand strategic stockpiles of threat reduction agents.

8.5 Dual use risk

Participants felt that the dual use risk of this area of biotechnology is low. However, it was noted that transgenic plants could be malevolently engineered to mass produce large quantities of non-therapeutic (toxic) proteins. Concerns were also raised that targeting crop production could have broader ramifications since by entering the human food chain biological agents and toxins could be easily delivered across large populations.

9 Diagnosis and surveillance of infectious diseases

There is little difference between preparing for, and responding to, a bioterrorist attack and a natural outbreak of disease. Both cases will require the same sort of diagnostic and surveillance infrastructure. However, given their different socio-political consequences, it is vital that a bioterrorist attack is not misinterpreted as a natural outbreak of disease, and *vice versa*.

Determining whether a bioterrorist event has taken place will be difficult. Clinical signs may not appear for days or weeks and initial symptoms may be non-specific. Likely indicators will include large numbers of causalities with unusual epidemiologies and/or multiple simultaneous outbreaks of multi-drug resistant pathogens. Guides, such as Category A, B and C lists from the US Centers for Disease Control and Prevention (CDC) website, are available to identify key diseases (CDC 2006). One problem is that these do not include non-indigenous diseases. However, given the scale of today's international trade and travel, diseases have spread across the world and so non-indigenous diseases should not be overlooked, especially in cases of unusual symptomology. It is also important that knowledge about diseases that are supposedly extinct, such as smallpox, is not lost as this would be vital for early diagnosis and response if the disease was to reappear.

The activities and responses of the health services and intelligence and law enforcement agencies must also be co-ordinated. Health and security services need to agree on what must be monitored and on the use of surveillance guidelines, including instructions on the detection of events, and the collection of appropriate laboratory specimens for forensic evidence. There also has to be a suitable laboratory service with a hierarchy of competence to conduct various types of investigation depending on the perceived level of biohazard.

9.1 Dual use risk

Some participants felt that bioterrorism had generated considerable political interest, disproportionate to the importance of the events, and that natural outbreaks of diseases (such as SARS and avian flu) are much more likely to occur than bioterrorist attacks. Loss of life has been far greater from natural diseases than from bioterrorist attacks. For example, it has been suggested that the geopolitical impact from the US anthrax letters in autumn 2001, which resulted in 22 cases and five deaths, was of a similar scale to the 2002-2003 SARS outbreak, which caused an estimated 8098 cases and 774 deaths (Royal Society-Wellcome Trust 2004). Other participants from developing countries stressed the enormous loss of life caused by naturally-occurring diseases, such as AIDS, malaria and tuberculosis, and suggested that bioterrorist threats should be viewed in this context. Even so, establishing and maintaining national and global surveillance systems for human, animal and plant disease is a key element of the defence against the misuse of scientific and technological developments.

One major challenge is that effective medical surveillance infrastructures only exist in the most well developed countries where diagnosis may take only a few hours whereas in less developed countries it may take several weeks. This significantly decreases the efficiency of responding to an outbreak of infectious disease or a bioterrorist attack. Given the increase in global travel, which has increased the spread of disease across the world, no country can afford to act in isolation. The acquisition of the necessary infrastructure, communications and skills for monitoring infectious diseases in less developed countries should therefore be of paramount concern for all countries. States Parties should cooperate with each other and international organisations (such as World Health Organisation, World Organisation for Animal Health and United Nations Food & Agricultural Organisation) to further the development and application of scientific discoveries for the detection, prevention and countering of disease, under Article X of the BTWC (Joint Science Academies 2006).

10 Key issues

10.1 Strengthening scientific input into the BTWC

Participants stressed the importance of the universal application of the BTWC. The BTWC unequivocally covers all naturally or artificially created or altered microbial or other biological agents or toxins, as well as their components, whatever their origin or method of production, that have no justification for prophylactic, protective or other peaceful purposes. Participants agreed that States Parties to the BTWC should reaffirm that the misapplication of the scientific and technological developments discussed at the workshop is covered under BTWC Article I.

Participants also emphasised States Parties' obligations under BWTC Article IV to 'prohibit and prevent' the development, production, stockpiling, acquisition, or retention of biological toxins and weapons, and to translate their international obligations into national laws and regulations of enforcement. However, this raises three major challenges to ensure:

- national legislation and regulations of enforcement encompass the full range of BTWC prohibitions whilst making scientific sense;
- measures that go beyond the implementation of BTWC obligations do not inhibit scientific progress;
- implementation of BTWC obligations into national legislation is sensitive to the particular political and scientific context of individual countries.

The scientific community can assist in addressing these challenges by regularly inputting into the BTWC regime. For example, this could be achieved through interim structures such as independent scientific advisory panels and regional scientific meetings. If they do not already do so, States Parties should also seek advice from their scientific community as part of their preparation for BTWC meetings and consider including scientists in their delegations. The pace of technological development is now so rapid that the implications need to be reviewed more frequently than allowed by the five year cycle of BTWC Review Conferences. Participants suggested that interim structures such as independent scientific advisory panels and regional meetings could also assist in keeping track of developments.

Scientific practices, infrastructure capacities and the political will to enact national BTWC related legislation and regulation vary between countries. Consequently, national academies of science, professional societies, universities and research institutes, NGOs and other civil society organisations can all play a role in their own countries by promoting the importance of the BTWC to ensure that their governments fulfil their BTWC

obligations. This sort of national input is particularly important to promote scientific progress in developing countries since, as some participants noted, there is a perception that BTWC related legislation and regulation could be used by the developed world to inhibit scientific progress in developing countries.

Concerns were also raised that the BTWC binds and refers only to states rather than individuals, and this might be undermined by the existence of terrorist groups. Although the BTWC was not primarily intended as a counter-terrorism device, a closer reading of the text shows that states' obligations to prevent and prohibit misuse on their own territory makes them responsible in this respect. Moreover, this aspect of prevention and prohibition is reinforced by other international measures against both state actors, such as the Chemical Weapons Convention, and non-state actors at the national level, such as UN Security Council Resolution 1540 on the non-proliferation of weapons of mass destruction.

10.2 Improved risk management

It was widely agreed that dual use research in the life sciences poses a potential security risk. However, the complexity of biological systems continues to make it extremely challenging to understand fully or manipulate them. It is also difficult to predict the details and application of breakthroughs given the serendipitous nature of scientific research; and it is becoming increasingly difficult to know where technological breakthroughs will occur in the world as many countries have sophisticated research facilities. Furthermore, technological developments are now also bringing processes that could feasibly be used to make and deploy biological and toxin weapons within the capability of small groups below state level because of the reduction in costs and expertise required.

Participants agreed that although misuse can be minimised, it cannot be completely eliminated; however, the scope and immediacy of the risk of misuse must not be exaggerated. Sensible policies must be guided by critical and realistic risk assessments. Therefore, risk management processes to deal with dual use technologies need to be improved. Methods are needed for undertaking assessments across the full spectrum of biological threats, ranging from the deliberate weaponisation of biological agents through the inadvertent misuse of technologies to emerging naturally-occurring diseases, and there should also be further investigation of best practice in communicating the associated risks. Risk management processes would require close interaction with scientists working at the forefront of dual use technologies, who are better equipped to predict and mitigate science based security risks.

In addition, research in the life sciences should not be considered in isolation from other scientific disciplines because the development and weaponisation of biological agents can involve techniques from fields such as mathematics, engineering, physics and computer science.

A major challenge is how to factor in the perception of risk into dual use risk analysis, particularly by the public. This is made more complicated since risk environments and risk perceptions differ around the world and the likelihood of abuse in the life sciences and the harm to public health may vary according to the perception of the risks and individual countries' efforts to reduce them. Participants felt that a shared risk methodology and terminology would be particularly useful to understand how countries perceive biosecurity threats differently. For example, a number of languages, such as Russian, Spanish and Swedish, use a single word to mean both 'biosafety' and 'biosecurity'.

10.3 Openness and transparency

Throughout the workshop it was stressed how open communication has been intrinsic to the scientific tradition, providing a forum for validating, repudiating and building upon scientific ideas necessary for intellectual and technological progress. Some participants from developing countries were especially concerned about censorship since access to training, technology and the results of research carried out elsewhere in developed countries is necessary to further the development of scientific capacities in their countries (Joint Science Academies 2005). Participants therefore stressed the importance of BTWC Article X, which promotes international cooperation in biology for prevention of disease including the free flow of information and scientists in both the developing and developed world.

Although a piece of research may be considered to be dual use, publication can still be possible. For example, the American Society for Microbiology (ASM) introduced formal processes as part of the peer review process for its eleven journals for manuscripts dealing primarily, but not exclusively, with research conducted on select agents. In 2002, 313 select agents manuscripts received special screening from a total of 13,929 manuscripts submitted. Only two of the manuscripts receiving special screening were sent to the full ASM publications board for further screening. Between January and July 2003 of the 8557 manuscripts submitted only 262 select agents manuscripts were screened and none was referred to the publications board for further review (Royal Society 2005b).

Classifying research as dual use serves to emphasise that special consideration may be warranted regarding how its results are communicated. There are a set of communication options, ranging from full and immediate publication, to delayed and/or modified publication to restricted or no publication at all. These options could be used singly or in combination on a case by case basis. In very rare cases consideration could be given to delaying publication of highly sensitive information, or releasing only some of the information into the public domain. However, in these cases there would need to be a very clear benefit in delaying publication.

Censoring research would not necessarily prevent misuse. Information is likely to be published elsewhere such as in other journals, websites or conference proceedings, or communicated informally via e-mail, telephone or face-to-face discussion. Publishing also makes others aware of unintended results. For example, the publication of the paper on the insertion of the interleukin-4 gene into mousepox made a large number of researchers aware of the discovery that the insertion of this gene enabled the virus to overcome both genetic resistance and immunisation against the disease (Royal Society–Wellcome Trust 2004). A common opinion at the workshop was that censoring the results of dual use research in order to prevent bioterrorist activity may in fact be counter-productive. Censorship would simply suffocate new research in the life sciences yet with greater scientific expertise, including knowledge of its harmful applications, it would be easier to prepare for and combat bioterrorism most effectively.

Participants also highlighted that dual use concerns are not limited to the scientific community and its academic journals but also the general public and media. Public confidence and trust in the scientific community cannot be ignored, and the media needs to be encouraged to report dual use aspects of science and technology responsibly. This is crucial since, as mentioned above, a major issue is the perception of biosecurity risks, which is determined by the level of public confidence and trust in science. The media therefore needs educating on these issues as much as scientists themselves.

10.4 Education and training

It is essential to continue to raise awareness of dual use issues within the scientific community, including scientists working in academia, government and the private sector, and thereby help responsible stewardship to be furthered in the life sciences. Academic and industrial researchers, as well as university students should be educated on the matter, perhaps by undertaking courses in ethics and responsible research practice, and should be taught about relevant international law obligations of their governments, especially relating to the BTWC. Bioethics curricula should build on local values and ethical norms. Some participants suggested post-14 year olds should also be taught about these issues at school.

Many participants supported the use of codes of conduct as a valuable educational tool. However, codes of conduct are also useful tools to lower the risks associated with using or transferring sensitive knowledge. Many participants were particularly concerned about the possibility of 'backyard' or 'garage' biology by both state and non-state actors; and some felt that codes of conduct can play a key role in developing a strong scientific culture of responsible stewardship.

The presence and level of codes of conduct and safety regulation varies between countries. Accordingly, if an international scientific culture of responsible stewardship is to be furthered in the life sciences, there need to be international strategies to harmonise, and thereby raise, the standard of national regulation and to promote adherence to codes of conduct. One example is the statement on biosecurity released by the InterAcademy Panel, which was signed by 69 national academies of science (InterAcademy Panel on International Issues 2005). The statement highlighted fundamental guiding principles for the formulating of codes of conduct in order to minimise the possibility of the misuse of scientific research.

Some participants felt that simply reaffirming codes of conduct does not provide any further illumination over important details of their scope and meaning. There still need to be more efforts to engage with scientists directly to educate them about dual use issues and the value of codes of conduct, and encourage them to input into the formulating of these codes. In this way, misperceptions within the scientific community that codes of conduct are just another level of regulation to interfere with their research can be overcome. Work has been carried in this area by sets of seminars and workshops (Dando, Rappert & Chevalier 2006).

11 Conclusions

11.1 Strengthening scientific input into the BTWC

- The BTWC unequivocally covers all naturally or artificially created or altered microbial or other biological agents or toxins, as well as their components, whatever their origin or method of production, that have no justification for prophylactic, protective or other peaceful purposes. Participants agreed that States Parties to the BTWC should reaffirm that the misapplication of the new scientific and technological developments discussed at the workshop are covered under BTWC Article I.
- BTWC Article IV obliges States Parties to 'prohibit and prevent' the development, production, stockpiling, acquisition, or retention of biological toxins and weapons, and to translate their international obligations into national laws and regulations of enforcement. However, national legislation and regulations of enforcement must encompass the full range of BTWC prohibitions whilst making scientific sense, and measures that go beyond the implementation of BTWC obligations must not inhibit scientific progress.

- The scientific community can assist in addressing these challenges. Processes need to be explored by which the scientific community can regularly input into the BTWC regime, for example, through interim structures, such as independent scientific advisory panels and regional scientific meetings. If they do not already do so, States Parties should also seek advice from their scientific community as part of their preparation for BTWC meetings and consider including scientists in their delegations.
- The pace of technological developments is now so rapid that their implications need to be reviewed more frequently than allowed by the five year cycle of BTWC Review Conferences.

11.2 Improved risk management

- The risk of misuse of 'dual use' technologies can be minimised, though not completely eliminated, through national controls and regulations and through increased awareness of the prohibitions of the BTWC.
- Risk management processes to deal with the misuse of dual use technologies need to be improved. Methods are also needed for undertaking assessments across the full spectrum of biological threats, ranging from the deliberate weaponisation of biological agents through the inadvertent misuse of dual use technologies to naturally-occurring diseases. There should also be further investigation of best practices in communicating the associated risks.
- Technological developments outside the classical life sciences are equally relevant to the BTWC, especially those involved with the delivery of agents for hostile purposes. These technologies will converge with traditional and current biotechnologies and should be closely monitored.

11.3 Openness and transparency

- Restricting the flow of information about new scientific and technical advances is highly unlikely to prevent potential misuse and might even encourage misuse. Freedom of communication and movement of scientists is fundamental to scientific progress and therefore to achieving the potential benefits for human, animal and plant health. Governments may take steps to protect their own security by occasionally restricting some information. However, they should also promote transparency and confidence building.
- BTWC Article X must be respected. Legislation and regulations of enforcement must allow the flow of information and scientists amongst the international community in both the developing and developed world.
- States Parties should also cooperate with each other and international organisations (such as World Health Organisation, World Organisation for Animal Health and United Nations Food & Agricultural Organisation) to further the development and application of scientific discoveries for the detection, prevention and countering of disease.

11.4 Education and awareness raising

- National and international scientific organisations and industry should encourage and engage with those involved with scientific endeavours, including scientists working in academia, government and the private sector, to increase awareness of the BTWC and dual use issues, especially through codes of conduct.
- University students should also be educated on dual use issues, perhaps by undertaking ethics and responsible research practice courses, and should be taught about relevant international legal obligations of their governments, especially relating to the BTWC.

- These measures would promote in depth implementation of the BTWC and help further responsible stewardship in the life sciences and ensure vigilance when work with dual use potential is undertaken.

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RS-IAP-ICSU will also be hosting a lunchtime seminar at the United Nations in Geneva at lunchtime on Tuesday 21 November 2006 during the Review Conference.

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Further information on the organisers of the international workshop is available online at:

www.royalsoc.ac.uk ***www.icsu.org*** ***www.interacademies.net***

Appendix A: Background to the Biological and Toxin Weapons Convention (BTWC)

The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction, is commonly known as the Biological Weapons Convention (BWC) or Biological and Toxin Weapons Convention (BTWC), opened for signature in 1972 and entered into force in 1975. It was the first multilateral disarmament treaty banning an entire category of weapons. It effectively prohibits the development, production, acquisition, transfer, retention, stockpiling and use of biological and toxin weapons and is a key element in the international community's efforts to address the proliferation of weapons of mass destruction.

States Parties to the Biological Weapons Convention undertake *never in any circumstances to develop, produce, stockpile or otherwise acquire or retain:*

1. *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;*
2. *weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.*

Taken from the United Nations Office at Geneva | Disarmament webpage (accessed on 26 October 2006) http://www.unog.ch/80256EE600585943/(httpHomepages)/6A03113D1857348E80256F04006755F6?OpenDocument

Summary of Obligations

Article I Never in any circumstances to develop, produce, stockpile or otherwise acquire or retain: (a) 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; (b) weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict. *[Note the 'general purpose criterion'.]*

Article II To destroy them, or divert them to peaceful purposes, not later than nine months after entry into force, with all necessary safety precautions to protect populations and the environment.

Article III Not to transfer them to any recipient whatsoever, and not in any way to assist, encourage or induce any state, group of states or international organizations to manufacture or otherwise acquire them.

Article IV To take any necessary measures, in accordance with its constitutional processes, to prohibit and prevent breaches of Article I within its territory, under its jurisdiction or under its control anywhere *[i.e. giving domestic legal and regulatory effect to international obligations and enforcing the relevant law and regulations. Note the stringency of the 'prevention criterion' and the increasing emphasis on penal legislation as central to national implementation measures under this Article*.]

Article V To consult one another and to cooperate in solving any problems that may arise, including the use of appropriate international procedures. *[Both the compliance diplomacy contingency mechanism of Consultative Meetings at expert level, so far only invoked in 1997, and the agreed programme of Confidence-Building Measures dating from 1986 and enhanced and expanded in 1991, have been developed by drawing out the implications of this Article in extended understandings, definitions and procedures.]*

Article VI To cooperate in carrying out any investigation which the UN Security Council may initiate, should it receive a complaint from any State Party that it finds another State Party to be acting in breach of obligations deriving from the BTWC. *[This complaints procedure has never been used.]*

Article VII To provide or support assistance to a State Party which the Security Council decides has been exposed to danger as a result of violation of the BTWC. *[This assistance provision has never been used.]*

Article IX To continue negotiations in good faith with a view to reaching early agreement on chemical weapons. *[NB. The Chemical Weapons Convention was negotiated 1972-1992, opened for signature in 1993 and entered into force in 1997. As of 2006 it has 178 States Parties.]*

Article X To pursue international cooperation in biology for prevention of disease, or for other peaceful purposes; and to implement the BTWC in such a way as to avoid hampering the economic or technological development of States Parties or international cooperation in the field of biology for peaceful purposes.

Article XII To review the operation of the BTWC, taking into account any new scientific and technological developments relevant to the BTWC, five years after entry into force. *[Although only one review was required by this Article, and took place in 1980, the States Parties have also held Review Conferences by their own decision in 1986, 1991, 1996 and 2001-02. The Sixth Review Conference is taking place 20 November-8 December 2006.]*

Adapted by Nicholas A. Sims from tables composed for the books *The Diplomacy of Biological Disarmament* (Macmillan/St Martin's Press, 1988) and *The Evolution of Biological Disarmament* (Oxford University Press for SIPRI, 2001)

Appendix B: Workshop programme

NB The presentations from the speakers are available on the Royal Society website - www.royalsoc.ac.uk/policy.

Day 1:	**4 September**
9:30-9:45	**Welcome and brief remarks from co-conveners** Lord Rees, President, The Royal Society Dr Carthage Smith, Deputy Executive Director, ICSU Professor Sergio Pastrana, Executive Committee Member, IAP
9:45-10:30	**Plenary overview** Chaired by Professor Mary Osborn (Professor of Biochemistry, Max Planck Institute for Biophysica Chemistry, Germany) 1) Dual Use Research: Scope, Criteria and Communication Issues Professor Paul Keim (Professor of Biology, Northern Arizona University, USA)
10:30-11:00	*Coffee break*
11:00-11:45	2) The BTWC Context Mr Nicholas Sims (Reader in International Relations, London School of Economics, UK)
11:45-12:30	**Presentation: synthetic biology & biological security** Professor Drew Endy (Assistant Professor, Biological Engineering Division, Massachusetts Institute of Technology, USA
12:30-1:30	*Lunch*
1:30-4:00	**Session 1: post genomic technologies** Chaired by Professor Huanming Yang (Director, Beijing Genomics Institute, China) *Presentations:* 1) Professor Winston Hide (Director, South African National Bioinformatics Institute, University of Western Cape, South Africa) 2) Dr Yijun Ruan (Genome Technology Senior Group Leader, Genome Institute of Singapore, Singapore) 3) Dr Andrew Pitt (Head of Proteomics, University of Glasgow, UK) Breakout discussions
4:00-4:30	*Break*
4:30-5:15	**Presentation: genetic targeting: potential for targeting specific population groups** Professor Grant Gallagher (Director for Research, Center for BioDefense, New Jersey Medical School, USA)
Day 2:	**5 September**
9:00-9:30	**Presentation: diagnosis & surveillance of infectious diseases** Dr Robert Swanepoel (Consultant, National Institute for Communicable Diseases, South Africa)
9:30-10:00	**Feedback from session 1 breakout groups** Chaired by Professor Indira Nath (Director, Blue Peter Research Centre - LEPRA Society, India)
10:00-10:30	**Session 2: Immunological research** Chaired by Dr Adel Mahmoud (President, Merck Vaccines, USA)

Presentations:
1) Professor Kathryn Nixdorff (Professor of Microbiology and Genetics, Darmstadt University of Technology, Germany)
2) Dr Wei-Ping Min (Assistant Professor of Microbiology and Immunology, University of Western Ontario, Canada)

10:30-11:00 *Break*

11:00-12:30 Breakout discussions

12:30-1:45 *Lunch*

1:45-4:15 **Session 3:** Participants choose to attend either session a) or b)

a) Drug discovery & delivery
Chaired by Professor Malcolm Dando (Professor of International Security, Department of Peace Studies, University of Bradford, UK)
Presentations:
1) Professor Charles Arntzen (Professor of Plant Biology, Arizona State University, USA)
2) Dr Guilherme Suarez-Kurtz (Head of Pharmacology, National Institute of Cancer (INCA), Brazil)
3) Dr Manfred Ogris (Vectorology Group leader, Ludwig Maximilians University, Germany)

b) Agricultural & environmental biotechnology
Chaired by Professor Sergio Pastrana (Foreign Secretary, Cuban Academy of Science, Cuba)
Presentations:
1) Dr Andrew Powell (Chief Executive Officer, Asia BioBusiness Pte. Ltd, Singapore)
2) Dr Nuzhat Ahmad (Director, Centre for Molecular Genetics, University of Karachi, Pakistan)
3) Dr Costancia Peter Rugumamu (Department of Zoology and Marine Biology, University of Dar es Salaam, Tanzania)

Breakout discussions

4:15-4:45 *Break*

4:45-5:45 **Presentations: responsible stewardship of scientific research**
Chaired by Dr Ralf Trapp (CBW arms control consultant, France)
1) Dr Brian Rappert (Department of Sociology and Philosophy, University of Exeter, UK)
2) Dr David Franz (Director, National Agricultural Biosecurity Center, Kansas State University USA)
3) Dr Rainer Wessel (President & CEO, GANYMED Pharmaceuticals AG, Germany)

15 min Q&A

Day 3: 6 September

9:00- 11:00 **Feedback from session 2&3 breakout groups**
Chaired by Professor Rod Flower FRS (Deputy Chief Executive, William Harvey Research Institute, University of London, UK)

11:00-11:30 Final discussion session

11:30-12:00 Summing up, conclusions and recommendations

12:00 Conclusion of Meeting

Appendix C: List of workshop participants

Name	Organisation
Dr Abdulhafeed Abudheir	Disease Surveillance Center, Libya
Prof Rafat Ahmad	Royal Scientific Society, Jordan
Professor Nuzhat Ahmed	University of Karachi, Pakistan
Professor Ruth Arnon	Weizmann Institute of Science, Israel
Professor Charles Arntzen	University of Arizona State, USA
Dr Volker Beck	Federal Foreign Office, Germany
Dr Katie Bowman	National Academies of Science, USA
Ms Sarah Broughton	Foreign and Commonwealth Office, UK
Mr Pierre Canonne	Pugwash/Univ. Marne-la-Vallés, Switzerland
Mr David Carr	Wellcome Trust, UK
Professor Naiyyum Choudhury	Bangladesh Academy of Sciences, Bangladesh
Dr Teresa Cornide	Institute for Sugar Cane Research, Cuba
Dr Robin Coupland	International Committee of the Red Cross, Switzerland
Professor Abdallah Daar	University of Toronto Joint Centre for Bioethics, Canada
Professor Malcolm Dando	University of Bradford, UK
Professor Ray Dixon FRS	John Innes Centre, UK
Dr Thomas Egwang	Med Biotech Laboratories, Uganda
Professor Drew Endy	Massachusetts Institute of Technology, USA
Dr Gerald Epstein	Center for Strategic & International Studies, USA
Professor John Finney	University College London, UK
Professor Roderick Flower FRS	University of London, UK
Dr David Franz	Midwest Research Institute/ Kansas State University, USA
Professor David Friedman	Tel-Aviv University, Israel
Professor Grant Gallagher	University of Medicine and Dentistry of New Jersey, USA
Professor Anfeng Guo	Beijing Institute of Microbiology & Epidemiology, China
Mr Richard Guthrie	Stockholm International Peace Research Institute, Sweden
Dr Kathryn Harris	National Institute of Health, USA
Professor Alastair Hay	University of Leeds, UK
Sir Brian Heap FRS	University of Cambridge, UK
Ms Melissa Hersh	United Nations Department for Disarmament Affairs, Switzerland
Professor Winston Hide	National Bioinformatics Institute, University of Western Cape, South Africa
Professor Robert Hinde FRS	Pugwash, UK
Professor Motonori Hoshi	Keio University, Japan
Professor Li Huang	Chinese Academy of Sciences, China
Dr Jo Husbands	National Academies of Science, USA
Dr Thomas Inch	Former Chief Executive, Royal Society of Chemistry, UK
Mr Richard Johnson	Arnold & Porter LLP, USA
Dr Venkatesh Kareenhalli	Indian Institute of Technology- Bombay, India
Professor Paul Keim	Northern Arizona University, USA
Dr Sergiy Komisarenko	Palladin Institute of Biochemistry of the Ukraine, Ukraine
Dr Gabriele Kraatz- Wadsack	UN - Weapons of Mass Destruction Branch, USA
Professor Marie-Paule Lefranc	Montpellier University, France
Dr Filippa Lentzos	London School of Economics and Political Science, UK
Dr Adel Mahmoud	Merck Vaccines, USA

Dr Abdussalam Masaud	Faculty of Pharmacy, Libya
Dr John Mbogoma	Basel Convention Regional Centre, South Africa
Dr Caitriona McLeish	University of Sussex, UK
Dr Lorna Miller	Defence Science and Technology Laboratory, Porton Down, UK
Dr Piers Millett	United Nations Department for Disarmament Affairs, Switzerland
Dr Wei-Ping Min	University of Western Ontario, Canada
Mr Michael Moodie	Private consultant, USA
Dr Amir Muhammed	National University of Computer & Emerging Sciences, Pakistan
Professor Indira Nath	LEPRA Society, India
Professor Kathryn Nixdorff	Darmstadt University of Technology, Germany
Dr Manfred Ogris	Ludwig Maximilians University, Germany
Professor Mary Osborn	Max Planck Institute for Biophysical Chemistry, Germany
Professor Sergio Pastrana	Cuban Academy of Sciences, Cuba
Dr Graham Pearson	University of Bradford, UK
Professor Charles Penn	Syntaxin Ltd, UK
Dr Anthony Phillips	University of Sussex, UK
Dr Andrew Pitt	Dept. of Proteomics, University of Glasgow, UK
Dr Andrew Powell	Asia BioBusiness Ltd, Singapore
Dr Ranjan Ramasamy	University Brunei Darussalam, Sri Lanka
Ms Pierrette Ramasiarisoa	Centre National de Recherches sur l'Environnement, Madagascar
Dr Brian Rappert	University of Exeter, UK
Mr James Revill	University of Bradford, UK
Dr Sheikh Riazuddin	University of the Punjab, Pakistan
Dr Yijun Ruan	Genome Institute of Singapore, Singapore
Dr Costancia Rugumamu	University of Dar es Salaam, Tanzania
Mr Ben Rusek	National Academy of Sciences, USA
Mr David Sawaya	OECD International Futures Programme, France
Mr Nicholas Sims	London School of Economics and Political Science, UK
Dr Carthage Smith	ICSU, France
Professor Geoffrey Smith FRS	Imperial College London, UK
Dr Ben Steyn	South Africa Military Health Service, South Africa
Professor Pieter Steyn	Stellenbosch University, South Africa
Dr Guilherme Suarez-Kurtz	Instituto Nacional de Câncer – INCA, Brazil
Sir John Sulston FRS	The Sanger Centre, UK
Dr Robert Swanepoel	National Institute for Communicable Diseases, South Africa
Mr Terence Taylor	International Council for the Life Sciences, USA
Dr Ralf Trapp	CBW arms control consultant, France
Dr Emmanuelle Tuerlings	WHO, UK
Dr Rainer Wessel	GANYMED Pharmaceuticals AG, Germany
Ms Angela Woodward	Verification Research, Training and Information Centre (VERTIC), UK
Professor Huanming Yang	Beijing Genomics Institute, China