New scientific and technological developments relevant to the Convention

Background information document submitted by the Implementation Support Unit

Summary

The Preparatory Committee decided to request the Implementation Support Unit (ISU) to prepare a background information document on new scientific and technological developments relevant to the Convention, to be compiled from information submitted by States Parties as well as from information provided by relevant international organisations (see BWC/CONF.VII/PC/2, paragraph 24). The ISU has duly prepared this document which includes an overview of developments prepared by the ISU based on submissions from States Parties and other sources, and an overview of developments prepared by IAP: the Global Network of Science Academies. For technical reasons, an annex comprising the individual submissions from States Parties will be issued separately as an addendum to this document (BWC/CONF.VII/INF.3/Add.1).

I. Overview of scientific and technological developments

Prepared by the Implementation Support Unit

1. During its efforts to prepare for meetings of the Biological Weapons Convention and through its interactions with other organizations, the Implementation Support Unit identified a number of developments in science and technology that have either come about, or developed significantly since the last comprehensive review. Full details of all the developments identified can be found in a longer document on the Unit's website[1]. The following is a summary of that document and the individual submissions on developments in science and technology received from States Parties (see the annex, issued separately as BWC/CONF.VII/INF.3/Add.1, in English only).

A. General trends

1. Convergence

2. The last five years have seen increasing convergence of different scientific disciplines. Modern life science research is becoming increasingly interdisciplinary. In many settings, it is redundant to consider individual fields of study and necessary to think about multi-skilled teams composed of numerous disciplines. Efforts to promote awareness of the Convention and the norms it enshrines, as well as efforts to inculcate safety and security consideration into best practice and the day-to-day practices of modern biology must now reach beyond microbiologists to many different scientists, technologists,

[1] http://www.unog.ch/bwc/science

managers and ancillary staff. Since the last review conference there has been distinct convergence of biology with: mathematics; engineering; chemistry; quantum mechanics (in photosynthesis; in protein folding; and explaining properties of DNA); computer science and information theory.

2. Increasing understanding of the life sciences

3. Since the last review conference there has been progress in: surveying human genetic diversity; the identification of novel pathogens; understanding horizontal gene transfer; symbiotic relationships between microbes and animals; as well as revisions to central dogma of molecular biology.

3. Trends in biotechnology

4. In recent years, the global biotechnology industry has been affected by the global economic situation. There are signs that it is beginning to recover. While publicly floated biotechnology companies still tend to be registered in developed countries, there are a host of emerging biotechnology companies to be found in developing countries. Biofuels and increasingly biomaterial production are major areas of interest. Biotechnology research and development seems to focus heavily on proteomics and small-RBA systems, with rapid growth happing recently in epigenomics and systems biology. The biotechnology industry continues to have access to dual-use technology, such as for freeze drying biological agents and compounds.

4. Global distribution of capacity

5. Capacity in the life sciences continues to grow around the world. Emerging economies such as China and India have become major players in global research and development. Other developing countries, especially in Asia, have been investing heavily in life science capacity and are beginning to benefit from it. While there are positive signs of increasing capacity in Africa, this continues to lag behind many other parts of the world.

5. Open science

6. Developments in information technology have affected how information is exchanged. New tools, such as wikis, blogs and microblogs have altered how information is gathered, handled, disseminated and accessed. There are indications that raw research data, laboratory notes and previously unpublished scientific information is becoming accessible. An increasing amount and a broader array of scientific information can also be accessed online. It is not only information that is becoming more accessible. Amateur communities, scientific outreach and educational toys have all increased access to hardware for wetwork in the life sciences.

6. Media, perceptions and society

7. Research released in recent years has confirmed the important role the media plays in shaping how the public perceives disease. There have also been interesting insights into how information provided from government sources influences public responses to health emergencies. There have also been positive examples of the successful communication of science to the general public.

B. Developments with possible negative consequences

1. Specific research and projects of interest

8. Examples of experiments that might be of interest to States Parties include: efforts to increase the virulence of influenza viruses through the reassortment of a contemporary virus with the strain responsible for the 1918 pandemic; efforts to increase the virulence of influenza viruses through the reassortment of two contemporary viruses; efforts to increase the virulence of influenza viruses through the reassortment of a variety of contemporary viruses; efforts to increase the transmissability of influenza viruses through the reassortment of the H1N1 and H5N1 strains; the development of computer simulations that model the spread of disease, which could also help optimise the impact of a deliberate release; the creation of a chimera virus from components from an influenza virus and the West Nile Virus; as well as the identification and characterization of antibiotic resistance to new antibiotics, previously held in reserve for the treatment of multi-drug resistant strains.

2. Advances with potential for weapon applications

Improved understanding of toxicity, transmission, infectivity, virulence and pathogenicity

9. The last few years have seen the production of a great deal of data connected with disease and intoxication. Dedicated research programmes have been set up to generate it. There have also been efforts to centralise access to this type of information. Research published in the last five years has advanced our understanding of: how toxins work, including the characterization of new toxins; transmission of agents, such as the creation of new modelling approaches which provide more accurate simulations of transmission; virulence, such as the role of quorum sensing in the expression of virulence factors; and pathogenicity; such as the use of sequencing techniques to identify relevant proteins.

Enhancing a biological weapon agent

10. There have been advances in: improving the efficacy of agents, such as engineered RNA-based systems to differentiate between cell states and kill a programmed type; altering host ranges, such as determining that prions are capable of crossing the species barrier; delivering biological agents, such as efficient systems for oral delivery; avoiding host immune systems, such as how influenza used glycoproteins to avoid the human immune system; the role of host factors in infection, such as the identification of mechanisms that determine whether an infection will produce symptoms or not; evading detection, such as through self-destruction mechanisms employed after an agent has completed its intended task; mechanisms that confer resistance to therapies, such as the characterization of how HIV survives treatment with retroviral drugs; and environmental stability, such as the development of silica coating techniques for living microbes. There has also been significant increase in the adoption of aerosol technologies by industry.

Producing biological weapon agents

11. There have been important advances in capabilities to produce complex bioactive compounds including: through the use of bacterial chassis; the development of synthetic ribosomes; and advances in biopharming.

Circumventing existing control mechanisms

12. There are indicators of increasing access to laboratory and production equipment, whether that be: disposable equipment, such as fermenters or bioreactors; basic laboratory equipment, such as stir plates; or more advanced equipment, such as open source versions of PCR machines. This might challenge export control regimes. Trends towards working on

parts, systems or information in minimal containment settings from pathogens that would usually require high-containment provisions, or the use of proxies, might challenge the security assurances previously provided by biosafety provisions. Advances in synthesis technology could challenge restrictions to access of certain agents provided by biosecurity provisions. While largely addressed through the implementation of screening standards for commercial synthesis, there remain outstanding challenges in dealing with in-house synthesis technology, expanding coverage to companies currently outside of existing frameworks, and in information exchange between companies.

Neurobiology

13. There have been reports by the US National Academies of Sciences[2] and the Royal Society[3] that identify security implications stemming from neurobiology. Since the last review conference, there have been advances in: understanding the role of neuroregulators; how to influence psychological states and alter physical performance; as well as linking neurobiology to disease.

C. Developments with possible beneficial consequences

1. Detection

14. Being able to detect that a disease event is occurring, to track causative agents, and start diagnostic practices prior to symptoms speeds up the timeframe in which a response can be organized. This can reduce the impact of a disease event and possibly reduce the desirability of instigating an outbreak in the first place. Recent advances in science and technology have provided a range of new capabilities in this arena, including: different approaches; research into in-building early warning and response systems; use of satellite data; the identification of pre-clinical disease indicators; the use of engineered bacteria that glow when in the presence of a biological stressor; visual sensors for tracking of pathogens and toxins; as well as improvements in environmental detection of agents.

2. Diagnostics

15. There have been a number of recent advances in the production of cheap and portable equipment for diagnosing diseases. Some devices may enable the creation of rudimentary diagnostic capabilities in parts of the world currently lacking such capabilities. The also offer interesting opportunities to move some diagnostic tools and techniques to the point of care – or at least into a regional, rather than national, context. There have also been advances in rapid diagnostic capabilities, which would also enable a faster, more efficient and tailored response, including through: new approaches to differentiate between bacterial and viral infections; genotyping pathogens and identifying reassortment events; the identification of single particles of pathogens or toxins; the real-time diagnosis of fungal pathogens; broader use of mass spectrometry; advances in microscope technology; as well as the use of sequencing capacity as a public health tool. There have also been advances in developing faster assays for toxins.

3. Prevention and prophylaxis

16. There has been progress in creating broad spectrum vaccines as well as new approaches for developing vaccines. A range of novel mechanisms to pre-empt disease are

[2] http://www.nap.edu/catalog.php?record_id=12177
[3] http://royalsociety.org/policy/projects/brain-waves/society-policy/

also being developed. There has also been progress in finding ways to improve upon our natural immune systems. Researchers also report improvements in delivery techniques for prophylactics.

4. Therapeutics

17. Developing novel antibiotic capabilities remains a priority for the fight against disease. The last few years have seen: the creation of novel classes of antibiotics; progress in their characterization; success in improving their efficacy; identifying new targets; advances in understanding how bacteria overcome antibiotics; and better discovery tools. Progress in antiviral therapy, includes: the development of a pan-viral drug; the discovery of new drugs; improvement in understanding of how viruses work; the discovery of an anti-viral virus; virucidal proteins; proteins to disrupt viral adhesion to host cells; proteins that disrupt viral replication; as well as high-affinity binding reagents that demonstrate an antiviral activity. Bioprospecting has continued to identify potential therapeutic compounds. There have also been advances made in dealing with toxins including through genetic manipulation of host mechanisms, nanoparticles to trap toxins, as well as antibody approaches to allow them to be flushed from the body.

5. Response capacity

18. There have been advances in determining whether a disease event involves cultured rather than natural pathogens, as well as statistical approaches for separating out mixed data sets, as well as the development of microbial forensic capabilities – all of which would assist in identifying if an attack has taken place and who might be responsible. Research has also demonstrated the importance of effective quarantine measures in limiting impact. Developments in decontamination technology, such as antibacterial foams and the use of nanoparticles, could facilitate a post-attack clean up.

D. Enabling advances and technologies

1. Characterizing biological systems and networks

19. Considerable progress has been made in recent years across a broad range of different -omics, such as genomics (the study of all the genetic information in an organism), transcriptomics (the study of all the RNA in an organism), proteomics (the study of all the proteins in an organism), metabolomics (the study of all the biochemical processes or metabolism of an organism), as well as how they relate to one another.

20. Genomics advances have included: genome wide analysis; progress in understanding the role of Single Nucleotide Polymorphisms in disease; progress in understanding the role of copy number variation in disease; functional genomics; and increased understanding of the evolvability of gene regulatory networks.

21. Advances in transcriptomics include: the identification of regulators; the characterization of regulators; and the implications of network structure.

22. Progress in proteomics has included: better understanding of how proteins are synthesised; better characterization of the system which ensures the premature termination of sequences that fail quality control; new tools assist in the identification and quantification of proteins; increasing standardization of data reporting; improved tools for determining the structure of proteins; enhancing understandings of protein-protein interactions, such as through mapping, regulation, cross network comparisons and studying protein signalling cascades.

23. Metabolimics advances have included: comparative studies of pathways between species; improved tools for perturbing and studying pathways; investigations of network motifs; as well as studies on fluxes within metabolic networks (fluxomics).

24. There has also been considerable progress made in integrating data from these fields, especially in terms of mapping and, to a lesser extent, modelling systems. Perhaps the best example of combining different approaches was the characterization of Mycoplasma pneumoniae which included the integration of genomic, metabolic, proteomic, structural and cellular information.

2. Manipulating biological systems and networks

25. There have been a variety of developments over the last five years that enable greater control in manipulating biological systems and networks. The two most significant advances were RNA interference technology (RNAi) and Zinc Finger Nucleases (ZFN).

3. Engineering biological systems and networks

26. Biological engineering, or synthetic biology, has advanced considerably since the last review conference. Industry is becoming increasingly interested in these approaches. There has been a significant increase in the biological complexity of the biological systems and networks that can be engineered.

27. In addition to the chemical synthesis of a genome able to control a bacterial cell (Craig Venter's artificial life) other important stepping stones include: the engineering of the metabolic pathway in yeast to produce the precursor of an anti-malarial drug; the creation of a synthetic mammalian gene circuit that revealed anti-tuberculosis compounds; a demonstration of distributed biological computation; and the engineering of an *E. coli* to sense and kill a human pathogen.

28. There has been progress in overcoming the technical hurdles identified as limiting the utility of synthetic biology, including: characterizing parts; improving wiring; addressing complexity; improved interoperability; and enhanced reliability. There have been: technical improvements; chassis improvement; and the development of new components. Significant attention has also been paid to the safety and security implications of these advances.

4. Gathering and manipulating biological information

29. Advances in bioinformatics and computational biology have greatly aided the gathering, processing and utility of biological data, including: the creation of new languages; advances in data mining; improvements in modelling and simulation, including the creation of whole-cell simulations; online tools and software for visualising complex biological information, analysing gene sequence data, protein analysis; as well as designing tools. Advances in bioinformatics have been combined with progress in characterization technology, high-throughput approaches and robotics to create a fully automated researcher. A computer controlled artificial intelligence develops hypotheses, tests them in an automated laboratory and feeds the results back into the system, to design a new round of experiments. Not only do robot scientists promise to take much of the drudgery out of basic research but they might also help to address the current bottlenecks in characterizing parts, identifying function and interpreting raw data.

5. Converting biological information to digital data and back

30. If biology is becoming an information science then in part it is because of the ability to convert biological data into digital data and back again. Gene sequencing (reading the genetic code) enables us to move in one direction and gene synthesis (writing the genetic

code) the other. Capabilities to read and write genetic code are not new but capabilities in these areas have changed dramatically since the last review conference.

31. Since the last review conference second and then third generation sequencers have become available. This has led to a dramatic increase in raw sequencing power. Modern machines can sequence a bacterial genome in around two hours. The cost of sequencing has also fallen roughly four orders of magnitude in the last five years. This has enabled new types of project to be attempted and different types of data collected. At the Sixth Review Conference only two human genomes had been sequenced. At the time of writing over 13,000 human genomes have been sequenced. It is expected over 30,000 will have been sequenced by the end of 2011. There has also been progress in the ability to understand and use sequence data.

32. Trends in synthesis capacity mirror those for sequencing. There have been technical improvements in the ability to produce longer strands of genetic material. New assembly techniques make is easier and faster to combine short fragments into long sequences. The cost of having gene length fragments commercially synthesized also continues to fall. The quality of sequenced material seems to be increasing. This has led to more sophisticated projects being attempted. Since the last review conference, synthesis of genetic material has moved from viral settings, through bacterial settings, and mammalian organelles, to partial synthesis of a chromosome from a eukaryote.

6. Generic enabling technologies

33. Underpinning many of the advances discussed throughout this paper are a range of technologies that make it easier, cheaper, faster or more reliable to do many of the basic procedures and practices involved in expanding the limits of our understanding and creating new applications. Other advances have allowed scientists to do things that were previously unattainable. There has been a broad range of new enabling technologies developed since the last review conference.

II. Life sciences and related fields: trends relevant to the Biological Weapons Convention

Prepared by IAP–the Global Network of Science Academies

A. Introduction

34. Over the last decade, national and international scientific organizations have become increasingly engaged in considering how to respond to the biosecurity implications of developments in the life sciences and in assessing trends in science and technology (S&T) relevant to biological and chemical weapons nonproliferation. The latest example is an international workshop, Trends in Science and Technology Relevant to the Biological Weapons Convention, held October 31–November 3, 2010 at the Institute of Biophysics of the Chinese Academy of Sciences in Beijing. The workshop and the subsequent final report were intended to be independent contributions from the international scientific community to the Seventh Review Conference.

35. The workshop was planned by an international committee appointed by the National Research Council (NRC) of the National Academy of Sciences and convened in cooperation with IAP–the Global Network of Science Academies, the International Union of Biochemistry and Molecular Biology (IUBMB), the International Union of Microbiological Societies (IUMS), and the Chinese Academy of Sciences.

36. The workshop provided an opportunity for the scientific community to discuss the implications of recent developments in S&T for multiple aspects of the BWC. For example, a continuing question for the treaty's review conferences is whether scientific developments yield new or novel types of agents or materials that are not captured by Article I, which defines the scope of the treaty's prohibitions as "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." More broadly, however, developments in S&T also affect the other key articles of the Convention that provide for its operation, such as the adequacy of national implementation of the convention through national policies and regulatory systems (Article IV), the capabilities to carry out investigations of alleged use of biological weapons (Article VI), and the design of international cooperation to ensure that all States Parties have access to the benefits of peaceful applications of biology (Article X).

37. The meeting benefited from being able to draw on the diverse perspectives and active engagement of the participants through both plenary and breakout discussion sessions. Almost 80 scientists and policy makers from 28 countries and several international organizations took part in the workshop, with a mix of scientists and engineers currently engaged in research and technical experts from government and nongovernmental organizations, many of whom are also practicing scientists, who could help draw out potential implications for the BWC. The speakers for the S&T sessions were asked to focus on the "state of the science" with regard to their topics; in a few cases they also offered additional comments on the implications and applications for the BWC. The subsequent plenary discussions, and particularly the breakout sessions, further explored the implications. The workshop participants also discussed ways in which the BWC and its States Parties could continue to follow trends in S&T, including potential mechanisms for more systematic engagement with the scientific community.

38. Given the immense diversity of current research and development, the report is only able to provide an overview of the areas of science and technology the committee believes are potentially relevant to the future of the BWC, although there is an effort to identify areas that seemed particularly ripe for further exploration and analysis. The report offers findings and conclusions organized around three fundamental and frequently cited trends in S&T that affect the scope and operation of the convention:

(a) The rapid pace of change in the life sciences and related fields;

(b) The increasing diffusion of life sciences research capacity and its applications, both internationally and beyond traditional research institutions; and

(c) The extent to which additional scientific and technical disciplines beyond biology are increasingly involved in life sciences research.

39. The report does not make recommendations about policy options to respond to the implications of the identified trends. The choice of such responses rests with the 164 States Parties to the Convention, who must take into account multiple factors beyond the project's focus on the state of the science.

B. Pace of scientific and technological developments

40. Continued progress is being made in a wide variety of S&T areas, although the committee did not identify any game-changing advances since 2006 that fundamentally alter the nature of life sciences research. Life sciences research continues to advance rapidly and is expected to do so for the foreseeable future. Key advances achieved in one field may also combine with developments in others to achieve new opportunities and new applications. One example is the interaction of research in fields such as immunology,

neuroscience, and systems biology with developments in "omics" technologies such as genomics and proteomics, which undertake holistic analyses of a set of biological information to achieve a comprehensive understanding of its structure, function, interactions, and other properties. The results are providing scientists with information to better understand biological processes, helping to support a more complete understanding of human, animal, and plant variability and its relationship to disease, and identifying and characterizing new microbes and their roles in multiple environments. Scientists actively seek to integrate information at multiple levels in order to support rational engineering and design. Although advances in S&T are increasing the overall understanding of biological systems, the extraordinary complexity of biology and the challenges this complexity presents to the effective understanding and design of biological systems remain significant barriers; this complexity is likely to remain a defining feature of the biological sciences for the foreseeable future. Developments in S&T are also changing the nature of biological production, advancing delivery systems, and underpinning the ongoing development of biosensors and detectors.

41. There has been particularly rapid progress in both the availability and power of enabling technologies that underpin life sciences research, including computational resources, communication resources, and high-throughput laboratory technologies. The computational power available to researchers continues to increase, through specialized stand-alone computers and through distributed computing networks. The use of high-throughput sample handling and analysis methods has become widespread, and these tools increase the speed with which researchers can conduct studies as well as the volume of data they can obtain. At the same time, new methods of communication and information sharing enhance scientific collaboration and support research progress.

C. Diffusion of research and capacity

42. The increasingly widespread access and ease of use of communications technologies, combined with growing availability of resources to support research, are helping to support the continuing expansion of global research capacity and an ever larger number of international collaborations in science and technology. The workshop highlighted that international S&T collaborations are occurring not only among researchers in scientifically developed countries and between researchers in developed and developing countries, but among regional networks and increasingly among scientists within developing countries. It also underscored that a growing number of "developing" countries already have impressive scientific sectors. Advanced S&T capacity is far from evenly distributed worldwide, and researchers in developing countries may still face problems in gaining access to resources and knowledge, but these trends are expected to continue and accelerate.

43. The continuing, rapid diffusion of research capacity and knowledge makes the commitments of States Parties in Article III to restrict access to knowledge, materials, and technologies for anything other than purposes permitted by the Convention more challenging. Given that there is little hope of reversing this trend—and multiple reasons beyond the commitments in Article X to see the diffusion as positive and beneficial—this argues for at least two important findings. First, it suggests the importance of continuing attention to monitoring and assessing the diffusion to try to anticipate any potential negative consequences and to strengthening the capacity of States Parties to address them, for example through their Article IV commitments to national implementation. Second, it underscores the potential for a much larger number of States Parties to contribute to the implementation of the Convention, for example by expanding global public health and disease surveillance capabilities, or playing leadership roles in capacity-building in their regions. Two examples, one current—global disease surveillance—and one potential—

developing scientific capacity in microbial forensics—illustrate the positive aspects of diffusion.

44. There is also another important form of diffusion: the increasing ability to do life sciences research outside traditional research institutions. In some cases these are trained researchers taking advantage of commercial kits and services, as well as the availability of secondhand equipment, to build their own laboratories and conduct experiments. In others it enables less trained practitioners to perform experiments without having the detailed biological or mechanistic understanding previously required in the life sciences. This is exemplified by innovative approaches to engaging students in hands-on research early in their studies and the expanding interest in what is frequently called “amateur,” “garage,” or “do-it-yourself” (DIY) biology. There are encouraging examples of initiatives from within and outside these communities to foster cultures of safety, security, and ethics**,** but it underscores the need to understand how training and know-how are propagated and cultures of safety are developed in such non-institutional environments.

45. However, although commercial life science kits and services and other advances such as standardized DNA parts provide efficiencies and ease of use, successful achievement of experimental goals generally relies on more than these products. Valuable knowledge and skills are also acquired through experience, and the importance of having these additional levels of knowledge increases with the complexity of the research projects undertaken.

D. Integration of life sciences with other disciplines

46. Life sciences research draws on the expertise not only of biologists, but also increasingly of scientists from engineering, physics, mathematics, computer science, chemistry, materials science, and many other disciplines. The multidisciplinary and integrative nature of modern life sciences research and the diversity of fields relevant to the future of the BWC were reflected in the Beijing workshop. The convergence of disciplines, particularly between biology and chemistry, may pose challenges to the operation of regimes like the BWC and the Chemical Weapons Convention (CWC). New scientific developments might alter or expand the types of agents that could be of concern as biological or chemical weapons or might alter or expand the definitions of which molecules fall under the purview of both treaties. As science continues to advance, the convergence of multiple disciplines, including the life, chemical, physical, mathematical, computational and engineering sciences, will continue and the developments that this convergence enables will be relevant to the BWC. The science community could play a role in exploring the technical understanding of converging S&T areas to help inform further policy discussions. The monitoring of scientific developments that integrate these fields and the assessment of their implications will need to draw on expertise from a range of disciplines.

E. Drivers and roadblocks

47. Engaging a range of expertise within the scientific community, from academia, industry, and government, can contribute to efforts both to monitor the state of science and technology and to assess the implications of developments for the scope and operations of the BWC. In addition to tracking advances across diverse fields, the science community can contribute to a better appreciation of both the drivers and the roadblocks that broadly affect how S&T actually develops. Examples include the differential distribution of commercial markets for research products and the current challenge of developing mathematical models able to successfully capture the complexity of biological systems. Tracking and analyzing the impact of these forces should also be considered areas of potential interest for future

monitoring of S&T trends. The report notes a number of current examples, and also suggests that an area for future in-depth analysis is the changing nature of tacit knowledge, of which intangible technology is a subset, as kits and other resources make it easier for less skilled individuals to carry out work that once required significant training.

F. Looking ahead: future approaches to monitoring S&T trends for the BWC

48. The preparations for the Seventh Review Conference have highlighted the potential for adopting a more systematic process to monitor and assess developments in S&T. Whatever sort of mechanism is selected should depend on how the States Parties define their objectives in reviewing areas of S&T and the desired outcomes of the process. These decisions will impact both the types of activities that are undertaken and the timing of activities in order to most effectively meet these objectives. International scientific organizations are one potential resource for gaining access to a wide range of expertise to assist in understanding the "state of the science" and in assessing its implications.

Findings

49. The committee did not identify any discoveries that fundamentally altered the nature of life sciences research since 2006. However, advances in S&T on many fronts have increased our overall understanding and exploitation of biological systems, despite their daunting complexity.

50. There has been particularly rapid progress in the power of, and access to, enabling technologies, especially those depending upon increased computing power. These include high-throughput laboratory technologies, computational and communication resources. This has the following consequences:

(a) Collaborations between individual investigators, global networks of researchers and the formation of "virtual laboratories" are growing trends in the life sciences.

(b) Increasing access to sophisticated reagents such as standardized DNA "parts" and easy-to-use commercial kits and services has placed some hitherto advanced technologies within the reach of less highly trained practitioners, and has expanded the global spread of life sciences research and its industrial applications.

(c) Although first class research continues to rely heavily upon tacit knowledge, the availability of web-based technologies is facilitating the transfer of tacit knowledge through the creation of worldwide formal or informal learning communities or partnerships.

(d) These technologies reduce the barriers to the spread of S&T knowledge for responsible, educational purposes, thus creating more favorable conditions for international cooperation in the peaceful application of the life sciences.

(e) At the same time, we must recognize that these same barriers also serve as impediments to misuse. This is an area that would benefit from more in-depth analysis to gain a more nuanced understanding of the developments and trends and their impact on the norm against biological weapons.

51. Multiple disciplines, including the life, chemical, physical, mathematical, computational, and engineering sciences, are converging. This trend will continue and is relevant to the BWC as well as the CWC. The impact of this convergence on the existing arms control system must be better understood in order to draw conclusions about whether

adaptations in the application of the existing regimes may be required, and if so, what they should be.

52. The field of bioreactor research and the use of transgenic organisms to produce commercially or medically important proteins have seen impressive advances. These have reduced the time needed to produce proteins and have the potential to affect the scale of the facilities required. This has obvious implications for the BWC, for example with regard to the measures States Parties need to take to implement the BWC and to prevent the use of biological or toxin agents for hostile purposes.

53. The development of microbial forensics illustrates one way through which life sciences research from around the world can support the BWC and create better tools to investigate and discriminate between natural and deliberate disease outbreaks.

54. Notable technical advances have been made at the level of individual-use biosensor detector systems although there are limitations to what can be achieved given that sensor development must balance factors such as specificity, sensitivity, range of target molecules analyzed, and type of use.

55. The combination of approaches including improved biosensors, epidemiological monitoring, vaccine research, forensics, and other laboratory investigations can contribute to effective disease detection, investigation, and response systems worldwide.

56. These advances underscore the potential for more States Parties to contribute to the implementation of the BWC, for example by expanding their global public health and disease surveillance capabilities, or by playing leadership roles in capacity building in their regions.

57. Certain scientific and technical roadblocks (e.g., drug delivery technologies) impede future progress, but once overcome, would presage a phase of rapid development. The international scientific community can play a useful role in tracking trends and developments in S&T. Its continued engagement with the BWC is essential to identifying these key scientific hurdles and when they have been overcome.

G. Conclusions

58. Many of the committee’s individual findings about particular developments in S&T will not surprise those who follow trends in research that are potentially relevant to the BWC. Taken together, they represent the S&T reality in which the convention is now operating and the challenges and opportunities this reality poses for the Seventh Review Conference. They also lead the committee to four general conclusions:

Conclusion 1

59. None of the trends surveyed for this report currently falls outside the scope of Article I. The language of the treaty, as reinforced by the common understandings reached in prior review conferences, provides a degree of flexibility that has so far allowed it to adapt to progress in the life sciences and related scientific fields. The committee recognizes, however, that as new developments arise, including in fields of research that this report did not assess in depth, there may be surprise discoveries; hence, continued monitoring of advances in the life sciences and evaluation of their relevance for the BWC will be important.

Conclusion 2

60. Beyond the question of whether these trends pose fundamental challenges to the scope of the treaty, every major article of the treaty will be affected by the developments

surveyed. The trends may pose challenges to the implementation of some aspects, but they also offer important opportunities to support the operation of the convention.

Conclusion 3

61. The three broad trends that provided the organization of the report—the increasing pace, diffusion, and convergence of S&T—will continue for the foreseeable future. The diversity of the fields potentially relevant to the BWC and the potential for surprise discoveries make efforts to predict developments problematic. Within these trends, however, particular fields will be affected in important ways by factors such as commercial interests that drive developments at different rates, as well as roadblocks that impede progress. Gaining a deeper understanding of the drivers and roadblocks would provide a more meaningful picture of how and when continuing S&T developments are likely to affect the convention.

Conclusion 4

62. There are potential roles for the scientific community in helping to monitor trends in S&T and to assess their implications for the BWC, and there are a number of mechanisms by which input and advice could be provided. The most effective starting point for the Seventh Review Conference, therefore, would be to address the functions that such advice and analysis will serve for the future operation of the convention, including increasing the capacity of States Parties to participate fully in its implementation.