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IMPLICATIONS OF BIOSCIENCE AND TECHNOLOGY ADVANCES FOR THE BTWC

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I. INTRODUCTION

Implementing the obligations of the 1972 Biological and Toxin Weapons Convention (BTWC) is a complex process that can be affected both positively and negatively by the geopolitical context and socio-technical environment in which the treaty resides. Both have changed drastically over the past 15 years. For example, new sources of risk have become more salient (e.g. terrorism and organized crime); the pace of scientific and technological developments which might be relevant for the convention appears to have quickened; and the understanding of what is 'relevant' science and technology is expanding because of life science convergence with other scientific disciplines. In order for the BTWC to remain relevant, it is particularly important for the BTWC's states parties to stay informed about the intimate relationship between biological weapons, and defences against them, and developments in the life sciences and associated technologies.

The provision for states parties to review science and technology of relevance to the convention is found in Article XII.[1] Here states parties are instructed to hold, five years after entry into force, a conference to review the operation of the convention to ensure that the purposes of the preamble and the provisions of the convention are being realized. States parties are told that such a review 'shall take into account any developments in science and technology relevant to the Convention'.[2] Strictly speaking, the legal obligation to review the operation of the convention,

[1] Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, opened for signature on 10 Apr. 1972, entered into force on 26 Mar. 1975, <http://www.opbw.org/convention/conv.html>, Article XII.

[2] BTWC (note 1).

SUMMARY

Reviewing the implications of developments in areas of science and technology relevant to the Biological and Toxin Weapons Convention is an essential task for states parties wishing to ensure that this convention remains relevant and robust. This paper examines the current method by which states parties collectively review advances in science and technology, and discusses two important changes in the practice of science—its increasing complexity and global distribution—which are requiring states parties to consider changing the current process. The paper highlights key findings from a project conducted by the Harvard Sussex Program on future options for science and technology reviews and provides three suggestions concerning more regular and holistic examination of science and technology that states parties may wish to bear in mind during their deliberations at the upcoming Seventh Review Conference.

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including taking into account any new scientific and technological developments, was fulfilled in 1980. However, in practice what has happened is that in all six review conferences (1980, 1986, 1991, 1996, 2001–2002 and 2006) states parties have considered developments in science and technology.

However, especially in the past few years, concerns have been raised as to the adequacy of the current method by which science and technology is taken into account. At the Meeting of States Parties in 2010 for example, United Nations Secretary-General Ban Ki-moon told states parties: 'With the pace of advances in biological science and technology growing ever quicker, there is a pressing need for a structured and regular means of monitoring developments and assessing their implications.'[3] Indeed, there appears to be consensus forming among states parties that something needs to be done.[4] It is therefore expected that at the Seventh Review Conference in December 2011 states parties will consider proposals to have the issue of advances in science and technology made part of a third intersessional process. Proposals thus far made by states parties include science and technology being an agenda item for the annual meetings, as proposed by India; and for it to be a dedicated work stream for a newly created task group, as proposed by the United Kingdom; a working group, as proposed by Australia, Japan and New Zealand; or an open-ended committee, as proposed by South Africa.[5]

This paper begins by describing the current practice for taking into account science and technology developments that has emerged over successive review conferences before putting forward some views as to why it is important for the BTWC's states parties to consider advances in science and technology. Two important developments in the life sciences are then examined: convergence with other academic disciplines and global distribution. The paper then provides an overview of findings from a project conducted at the Harvard Sussex Program on Chemical and Biological Weapons on the future options for reviewing science and technology in the BTWC before concluding with three main proposals for possible consideration by the BTWC's states parties for maintaining and strengthening science and technology reviews.

II. PAST PRACTICE OF TAKING INTO ACCOUNT SCIENCE AND TECHNOLOGY DEVELOPMENT

Article XII of the BTWC does not contain explicit instructions as to how states parties should be taking into account new developments for science and technology. The few explicit instructions that are given are issued by the Preparatory Committee (PrepCom) which precedes a review conference. These instructions have evolved over time especially in relation to who is responsible for conducting the reviews.

The report of the first PrepCom in July 1979, for example, requested that the depositary governments (the Soviet Union, the UK and the United States) prepare a joint background paper on new scientific and technological developments and provide this paper to all states parties before the review conference. The Secretary of the Committee would then invite other states parties to comment on the joint paper.[6] For subsequent review conferences, the PrepComs did not ask depositary governments to co-author a paper. The PrepComs for the second, fourth and fifth review conferences invited any state party that so wished to submit its own reviews on science and technology developments and suggested that such papers should contain information which covered 'the applications being made of new scientific and technological developments and their relevance to various aspects

[3] UN Secretary-General, Office of the Spokesperson, , 'Secretary-General's message to Meeting of the States Parties to the Biological Weapons Convention (BWC)', Geneva, 6 Dec. 2010, <http://www.un.org/apps/sg/sgstats.asp?nid=4978>.

[4] See also McLeish, C. and Revill, J., 'Reviewing science and technology in the context of the Biological Weapons Convention', Discussion paper presented at the 31st Workshop of the Pugwash Study Group on Implementation of the CBW Conventions Getting Ready for the Seventh BWC Review Conference in 2011, Geneva, 4–5 Dec. 2010.

[5] India, 'Proposal for structured and systematic review of science and technology developments under the Convention', <http://www.unog.ch/80256EDD006B8954/(httpAssets)/371042419B89F4D6C125791700370D2C/$file/S&T+working+paper+India+FINAL.pdf>; UK, 'Illustrative model intersessional work programme: a proposal for task group structure and agenda items', <http://www.unog.ch/80256EDD006B8954/(httpAssets)/1C3C3AEAAF19FB15C12578F7004B84D6/$file/UK+-+NEW+ISP+FINAL-0420711.pdf>; Australia, Japan and New Zealand, 'Proposal for the annual review of advances in science and technology relevant to the Biological Weapons Convention', <http://www.unog.ch/80256EDD006B8954/(httpAssets)/35B5C15F0F09EFDEC125792D00377CEB/$file/Australia+Japan+NZ+working+group+on+S&T.pdf>; and South Africa, 'Proposal for the intersessional process', <http://www.unog.ch/80256EDD006B8954/(httpAssets)/7C4F28568314206DC125793300365AD2/$file/South+Africa+new+ISP.pdf>.

[6] 'Background document on compliance by states parties with all their obligations under the BTWC', BWC/CONF.I/3, 13 Sep. 2001.

of the Convention'.[7] For the Sixth Review Conference, it was decided that the Conference Secretariat should 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'.[8] The same wording was used by the PrepCom for the Seventh Review Conference.[9]

Each PrepCom issued instruction for science and technology review papers (national or Conference Secretariat) to be submitted and made available prior to the review conference. Such reports that have been prepared have tended to follow one of three styles: the first, and by far the dominant style, is to list scientific advances and technological developments under major technical headings. No apparent hierarchical structure is discernable from the listings. The second style reports on national level or national-sector level (e.g. biodefence) scientific and technical activities since the last review conference and the third style of report have been a nil submission, that is, nothing to report. The science and technology report to the Sixth Review Conference was different in that it was a document prepared by the Conference Secretariat, primarily based on the national reports submitted by states parties. However, it was organized along the lines of the dominant style of reporting (i.e. organizing their review of scientific and technological developments under major technical headings).

During the review conferences no specific time appears to have been allocated for discussion of these documents. According to participants in the Harvard Sussex Program's project on reviewing science and technology in the BTWC context that have attended past review conferences, the only time in which advances in science and technology were discussed was in relation to the scope of the prohibitions contained in Article 1 of the convention.[10]

III. WHY CONSIDER ADVANCES IN SCIENCE AND TECHNOLOGY?

Of the many reasons that can be put forward, three basic reasons are presented here. First, the simplest of definitions of biological weapon—the means whereby disease-causing agents (certain microorganisms as well as toxins) can be deliberately released to cause disease among humans, animals, or plants—shows a necessarily dependent relationship between biological weapons and what is known and understood about disease-causing or infection mechanisms; how disease-causing agents can be transmitted and how the host reacts to disease. Any attempt to produce or defend against these weapons (e.g. through vaccine development and stockpiling) uses this knowledge. While there is a perception of being vulnerable to biological weapons there is a basic need to understand the implications for the regime of developments in various relevant science and technology fields.

A second reason for reviewing science and technology is 'dual use' which implies that technologies, including science, can be exploited for more than one purpose, in this case hostile and benign purposes.[11] The historical record shows that there is a close link between advances made in understandings of disease and biological weapon development. Commentators such as Mark Wheelis have illustrated how insights into bacteriology gained in the late 19th century found their way into the sabotage programmes of World War I and how advances in virology and aerobiology in the middle of the 20th century were incorporated into the offensive biological weapon programmes of states such as the Soviet Union, the UK and the USA.[12] This historical relationship has

[7] Preparatory Committee, 'Draft report of the Preparatory Committee for the Second Review Conference of the Parties to the BTWC', BWC/CONF.II/PC/CRP.1, 2 May 1986; 'Report of the Preparatory Committee for the Fourth Review Conference of the Parties to the BTWC', BWC/CONF.IV/PC/2, 12 Apr. 1996; and 'Report of the Preparatory Committee for the Fifth Review Conference of the Parties to the BTWC', BWC/CONF.V/PC/1, I May 2001. No request for background documents on developments in science and technology was reported by the PrepCom to the Third Review Conference.

[8] Preparatory Committee, 'Report of the Preparatory Committee', BWC/CONF.VI/PC/2, 3 May 2006.

[9] Preparatory Committee, 'Report of the Preparatory Committee', BWC/CONF.VII/PC/2, 26 Apr. 2011.

[10] This project is being funded by the UK's Economic and Social Research Council and is part of the Research Councils UK (RCUK) Global Uncertainties Programme. See Harvard Sussex Program on Chemical and Biological Weapons, 'Project overview', <http://hsp.sussex.ac.uk/sandtreviews>.

[11] For more on dual use see McLeish, C., 'The problem of dual use knowledge', eds B. Rappert and C. McLeish, *A Web of Prevention: Biological Weapons, Life Sciences and the Governance of Research* (Earthscan: London, 2007), pp. 189–208. For a case study see McLeish, C. and Balmer, B., 'The discovery of the V-series nerve agents', ed. J. Tucker, *Governance of Emerging Dual-Use Technologies* (MIT Press: Cambridge, MA, forthcoming 2012).

[12] Wheelis, M., 'Biological sabotage in World War I', eds E. Geissler and J. E. van Courtland Moon, *Biological and Toxin Weapons: Research,*

led some to raise the idea that current life science advances might also be put towards biological weapon development. Matthew Meselson, for example, wrote: 'Every major technology—metallurgy, explosives, internal combustion, aviation, electronics, nuclear energy—has been intensively exploited, not only for peaceful purposes but also for hostile ones. Must this also happen with biotechnology, certain to be a dominant technology of the twenty-first century?'[13]

A final reason, and the often overlooked reasoning for taking into account any new scientific and technological developments, is to assist in reviewing *the operation* of the convention with a view to assuring that the purposes of the preamble and provisions of the convention are being realized. Although traditionally science and technology reviews have been focused on Article 1 of the convention and examination of whether the scope of the BTWC is broad enough to embrace science and technology advances, consideration of science and technology advances is a necessary element for examination of other operational elements, such as national implementation and international cooperation.

In addition to these primary reasons there are other reasons including that biological warfare and defence require procedures and equipment for agent detection, outbreak surveillance, diagnosis, physical protection, medical countermeasures and decontamination. New discoveries in science and technology may also alter assumptions that states parties have about the manner in which the BTWC's requirements are applied in practice. For example, developments in science and technology might influence perceptions regarding the verifiability of the convention. Such scientific and technological developments might pose new challenges to states parties but also offer them more sophisticated tools for the investigation of violations. In this respect, advances being made in microbial forensics are important.[14]

Although not an exhaustive list, these reasons for taking into account advances in science and technology and their potential consequences for the implementation of the BTWC were also shared by the participants in the Harvard Sussex Program on the future of the science and technology reviewing process in the BTWC. In both interview and questionnaire participants answered the question 'Why bother reviewing science and technology?' and responses included:

> The purpose is to identify S&T developments requiring collective action with a view to strengthening the convention's regime banning BW.[15]

> In order to maintain confidence and a level playing field it is important to keep an eye on what is going on so capability can be better assessed.[16]

> We don't want to do anything stupid and must protect the treaty from doing anything dumb.[17]

> The fact is that the convention is written in such a broad way that it is difficult to consider any science on the outside. Not the scope of the convention so much, but are there things that change in terms of the implementation—changes in risks (e.g. non state actors) come into the science and technology reviews because the technology is more accessible.[18]

> Because of the potential that [science and technology advances] will significantly change the situation and serve as a game changer . . . We need [science and technology] reviews as a warning of challenges to the regime. Science and technology is also a good way to enter into the debate around contested areas and enter into science diplomacy.[19]

What these responses illustrate is a view that science and technology advances should be considered by states

Development and Use from the Middle Ages to 1945, SIPRI Chemical & Biological Warfare Studies no. 18 (Oxford University Press: Oxford, 1999), pp. 35–62; and Wheelis, M., Rozsa, L. and Dando, M. (eds), *Deadly Cultures: Biological Weapons since 1945* (Harvard University Press: Cambridge, MA, 2006). See also Dando, M., 'The impact of the development of modern biology and medicine on the evolution of modern biological warfare programmes in the twentieth century', *Defense Analysis*, vol. 15, no. 1 (1999), pp. 51–65.

[13] Meselson, M., 'Averting the hostile application of biotechnology', *CBW Conventions Bulletin*, no. 48 (June 2000), p. 16; and Petro, J., Plasse, T. and McNulty, J., 'Biotechnology: impact on biological warfare and biodefense', *Biosecurity and Bioterrorism: Biodefense, Strategy, Practice, and Science*, vol. 1, no. 3(2003), pp. 161–68.

[14] McLeish, C. and Trapp, R., 'The life sciences revolution and the BWC: reconsidering the science and technology review process in a post-proliferation world', *Nonproliferation Review*, vol. 18, no. 3 (Nov. 2011), pp. 527–43.

[15] Participant 9, 1 June 2011.

[16] Participant 22, 9 July 2011.

[17] Participant 43, 13 July 2011.

[18] Participants 56 and 57, 15 July 2011.

[19] Participant 63, 1 Sep. 2011.

parties so that they may check whether they remain 'better off' within the BTWC than outside of it. When asked what they thought had been major advances in the life sciences since the review conference in 2006, two themes emerged in the respondents' answers: the changing nature of the sciences relevant to the BTWC due to convergence with other scientific disciplines and the increasing global diffusion of science.

IV. THE CHANGING NATURE OF THE BIOLOGY

Biology today is of a different character than when the BTWC entered into force in 1975—this is true both in terms of the breadth of science, which is now considered of relevance to the operation of the convention and who is engaging in biological research. In its recent report, *A New Biology for the 21st Century*, the US National Research Council viewed biological research as being 'in the midst of a revolutionary change due to the integration of powerful technologies along with new concepts and methods derived from inclusion of physical sciences, mathematics, computational sciences, and engineering'.[20] Such changes are also altering the profile of who is engaging in life science research. As the authors of the report go on to note, not all those engaged in the life sciences are now, or will in the future be, biologists:

> The physicists who study how the laws of physics play out in the crowded and decidedly non-equilibrium environment of the cell, or the mathematicians who derive new equations to describe the complex network interactions that characterize living systems are New Biologists as well as being physicists or mathematicians. In fact, the New Biology includes any scientist, mathematician, or engineer striving to apply his or her expertise to the understanding and application of living systems.[21]

The integration of knowledge and techniques from other scientific disciplines with life science research, sometimes referred to by the term 'convergence', is creating value in terms of advancing basic understandings of biological systems and in the development of new tools and methodologies. Recent and continuing advances in genomics, for example, have been assisted by techniques and concepts from fields such as engineering, robotics, computer science, mathematics, statistics and chemistry; declining costs of genome sequencing are being made possible through convergence with engineering, robotics, chemistry and biochemistry; and the ability to analyse raw genomic data is being assisted by the application of mathematics and statistics and facilitated by advances in computing sciences.[22]

Two examples of converging science have attracted particular attention from the BTWC's states parties: synthetic biology and systems biology. According to the British Royal Society, synthetic biology is a field that integrates concepts, tools and techniques from several scientific disciplines including biology, chemistry, physics and engineering.[23] Information and communication technology (ICT) facilitates their research and scientific understanding.[24]

Typical of an emerging field, synthetic biology lacks a coherent and agreed definition. For some commentators synthetic biology is 'an approach rather a discrete set of activities with defined boundaries',[25] while for other commentators synthetic biology reflects an 'explosion in our ability to genetically engineer increasingly complex systems'.[26] Others prefer to define the term as the design and construction of new biological parts, devices and systems, and the redesign of existing, natural biological systems for useful purposes.[27] Yet another set of commentators, including at least one project participant, regarded the term synthetic biology as having no meaning at all.[28]

The Royal Society chose to describe synthetic biology through its aims: 'the (re)design and (re)assembly of biological systems'.[29] They went on: 'In short the synthetic biologist seeks to build a bespoke system

[20] National Research Council, *A New Biology for the 21st Century* (National Academies Press: Washington, DC, 2009), p. vii.
[21] National Research Council (note 20), p. 20.

[22] National Research Council (note 20), p. 42.
[23] For an account of the field of synthetic biology see Campos, L., 'That was the synthetic biology that was', eds M. Schmidt et al., *Synthetic Biology: The Technoscience and Its Societal Consequences* (Springer: Dordrecht, 2009), pp. 5–23.
[24] British Royal Society, 'Synthetic biology: scientific discussion meeting summary', 2–3 June 2008, <http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2008/7928.pdf>, p. 2.
[25] Biotechnology and Biological Sciences Research Council (BBSRC), 'Synthetic biology', July 2008, <http://www.bbsrc.ac.uk/publications/corporate/corporate-synthetic-biology.aspx>.
[26] 'Synthetic biology: what's in a name?', *Nature Biotechnology*, vol. 27, no. 12 (2009), pp. 1071–73.
[27] See OpenWetWare, 'Synthetic biology', <http://openwetware.org/wiki/Synthetic_Biology>.
[28] Participant 42, 12 July 2011.
[29] British Royal Society (note 24), p. 2.

(such as an organism) by re-designing an existing system or constructing one from scratch using parts taken from nature or specially designed.'[30]

This description encompasses what the US National Science Advisory Board for Biosecurity (NSABB) refers to as synthetic biology's 'two disparate experimental approaches . . . "top down" and "bottom up"'. The top-down approach relates to classical recombinant DNA approaches and involves the re-engineering of existing organisms or genomes for a defined purpose, while the bottom-up approach entails the assembly of biological components in a variety of novel ways. This approach attempts to assemble systems (both living and non-living) that perform desired functions in a predictable manner.[31]

As well as a lacking a coherent definition, synthetic biology is typical also of an emerging field in that its promises and potential applications are diffuse in nature. Proponents argue that potential applications of synthetic biology can help to address key global challenges, including: food security, for example, through engineering or optimizing crops; sustainable energy, for example, through developing new pathways for producing fuel; and health challenges, for example, through developing biosensors, optimizing drug production and delivery, and developing smart therapeutics. Synthetic biology is also said to have potential applications in the production of new materials, for example silks, and in environmental challenges such as bioremediation.[32] With such wide-ranging and socially beneficial potentiality synthetic biology has received considerable amounts of funding. One report on funding indicated that the USA spent around $430 million on research relating to synthetic biology between 2005 and 2010, while Germany, the Netherlands and the UK spent approximately $160 million during the same period.[33]

As the NSABB noted, whether employing the top-down or bottom-up method, one of the aims of the synthetic biologist is to 'understand the form and function of living organisms or their products (e.g. metabolites, enzymes, toxins) and utilize them in a predictable and controlled manner'.[34] Such predictability relies on a sound understanding of how sequence, structure and biological context contribute to biological properties. Here then advances in the related field of systems biology are important. Systems biology views an organism's form and function as being derived from an integrated and interacting network of genes, proteins and biochemical reactions. So, for example, a systems biologist would view the body's responses to infections and diseases as resulting from interactions of numerous genes, proteins, mechanisms and the organism's external environment. By studying the immune system response as an interactive system, proponents of systems biology believe it has the potential to 'personalize' medical treatment by customizing the treatment of disease, including preventative treatment, to each individual's genetic make-up.[35] Describing how systems biology works in practice, the UK's Biotechnology and Biological Sciences Research Council said:

> Researchers use mathematical models and current data to develop ideas and hypotheses, which they test experimentally. They then use the results of the experiments to refine and expand the models, making them as encompassing and systems-wide as possible. The refined models are then tested by further rounds of experiments, each time being developed further. In its fullest expression, systems biology integrates information across different levels of organisation to explain biological function at all levels: from molecules and cells to whole organisms and populations.

[30] British Royal Society (note 24), p. 2.

[31] US National Science Advisory Board for Biosecurity (NSABB), 'Addressing biosecurity concerns related to synthetic biology', Apr. 2010, <http://oba.od.nih.gov/biosecurity/pdf/NSABB%20SynBio%20DRAFT%20Report-FINAL%20(2)_6-7-10.pdf>, pp. 2–3.

[32] Ilchmann, K. et al., 'Synthetic biology & the BWC', *S&T Reviews,* Apr. 2011, Harvard Sussex Program on Chemical and Biological Weapons, 'Results & publications, briefing note', <http://hsp.sussex.ac.uk/sandtreviews/results>; Schmidt, M. and Pei, L., 'Synthetic toxicology: where engineering meets biology and toxicology', *Toxicological Sciences,* vol. 120, no. 1 (2011), pp. 204–24; Organisation for Economic Co-operation and Development (OECD), *The Bioeconomy to 2030: Designing a Policy Agenda* (OECD: Paris 2009); and British Royal Society (note 24), pp. 14–22.

[33] Synthetic Biology Project, 'Trends in synthetic biology research funding in the United States and Europe', Research brief 1, June 2010, <http://www.synbioproject.org/process/assets/files/6420/_draft/final_synbio_funding_web.pdf>.

[34] US National Science Advisory Board for Biosecurity (note 31), p. 3.

[35] See e.g. Evans, W. and Relling, M., 'Moving towards individualized medicine with pharmacogenomics', *Nature*, 27 May 2004, pp. 464–68; and Abrahams, E., Ginsburg, G. and Silver, M., 'The personalized medicine coalition: goals and strategies', *American Journal of Pharmacogenomics*, vol. 5, no. 6 (2005), pp. 345–55.

> Systems biology depends on high-powered computation to construct predictive models. Typically these draw upon the large amounts of quantitative data generated by high-throughput techniques such as genomics (DNA content of cells), transcriptomics (the messenger RNA produced from active genes) proteomics (the proteins produced from the messenger RNA) and metabolomics (small compounds in cells). The models relate these data to research on metabolic and other functions in cells and tissues, and to the physiology and behaviour of whole organisms.[36]

As indicated above, systems biology integrates concepts and tools from scientific disciplines such as computing, engineering and mathematics. In particular, the field has been assisted by technological advances in large-scale data collection strategies, increased computation power for managing the large amounts of data, and advances in mathematical and statistical modelling theories. Systems biology, and in a more general sense the life sciences as a whole, is also taking advantage of refinements of Internet applications. James Meadway notes that moving from the static content that characterized Web 1.0 to the more interactive, collaborative and user-generated content of what is termed Web 2.0 is changing the manner in which scientific knowledge is produced and shared.[37] For example, advances in cloud computing are facilitating open source publication of research data whereby research data such as laboratory notebooks and raw experimental data are placed into accessible digital databases that can be updated or mined by fellow scientists. Creating such virtual research environments is easing real time international scientific collaboration. The Internet is also changing the process of purchasing. Internet-based purchasing systems have emerged for the purchasing of whole genes, custom oligonucleotides (essentially short DNA sequences) and, more recently, whole genomes. [38]

[36] Biotechnology and Biological Sciences Research Council (BBSRC), 'Systems biology', Oct. 2007, <http://www.bbsrc.ac.uk/publications/corporate/systems-biology.aspx>.

[37] Meadway, J., 'How the Internet has changed scientific interchanges', eds K, Bowman et al., *Trends in Science and Technology Relevant to the Biological and Toxins Weapons Convention*, Summary of an international workshop, Beijing, 31 Oct. to 3 Nov. 2010 (National Academies Press: Washington, DC, 2011), pp. 30–31.

[38] For more on this see Smithson, A., 'Pathogens and arms control: can bioscience police itself?', *Survival*, vol. 52, no. 5 (2010), pp. 117–34.

V. GLOBAL DIFFUSION OF SCIENCE AND TECHNOLOGY

The exploitation of advances in computing and the Internet by systems biology and the characterization of synthetic biology as 'making biology easier to engineer' (including by lowering skill levels required) are two illustrations of the general trend towards greater 'democratization of science'.[39] The Royal Society, for example, noted that science is being conducted in more places than ever before, which is leading to significant changes in the global scientific landscape.[40]

Several indicators can be used to illustrate changes to the global scientific landscape. One is the level of investment into research and development (R&D), usually measured as a percentage of gross domestic product (GDP). According to the UN Educational, Scientific and Cultural Organization (UNESCO) the world devoted 1.7 per cent of GDP to R&D in 2007, a percentage share that has remained stable since 2002. In monetary terms, however, this translates into $1146 billion, which is a 45 per cent increase since 2002.[41] Regions traditionally regarded as scientific leaders (North America, Japan, Europe and Australasia) increased their investment in scientific R&D between 2002 and 2007 by around one-third, but during the same time period new scientific countries were emerging that more than doubled their expenditure on R&D. Prominent among the emerging

[39] With respect to the lowering of barriers to entry the iGEM competition is interesting. Here undergraduate student teams from around the world are given a kit of biological parts from the Registry of Standard Biological Parts at the beginning of the summer and, working at their own schools over the summer, they use these parts and new parts of their own design to build biological systems and operate them in living cells. Participation in the annual competition has grown from 5 teams in 2004 to 167 teams in 2011—64 from the Americas, 46 from Asia, 50 from Europe and 7 high school teams. High school students have been involved in iGEM for the past 3 years, although it has only been recently that the competition has evolved to permit the direct participation of high school teams. International Genetically Engineered Machine (iGEM), 'Synthetic biology bases on standard parts', <http://2011.igem.org>.

[40] British Royal Society, 'Knowledge, networks and nations: global scientific collaboration in the 21st century', RS Policy Document 03/11, Mar. 2011, <http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2011/4294976134.pdf>, p. 14.

[41] Hollanders, H. and Soete, L., 'The growing role of knowledge in the global economy', UN Educational, Scientific and Cultural Organization (UNESCO), *UNESCO Science Report 2010: The Current Status of Science Around the World* (UNESCO: Paris, 2010), p. 5.

Table 1. Scientific publications according to discipline

	Biology		Biomedical		Chemistry		Engineering		Mathematics		Physics	
Region	2002	2008	2002	2008	2002	2008	2002	2008	2002	2008	2002	2008
North America	20 234	24 976	44 700	49 590	19 378	21 690	27 183	33 763	7 573	10 765	25 307	28 685
Latin America and the Caribbean	4 321	10 232	3 426	6 216	3 181	4 401	2 646	4 535	925	1 570	4 278	4 579
Europe	24 133	33 809	43 037	50 464	40 404	44 644	39 625	53 069	11 834	18 064	49 022	53 599
Africa	2 255	3 366	1 122	2 397	1 535	2 012	1 306	2 358	494	893	1 071	1 498
Asia	10 796	20 062	19 022	31 895	30 017	50 501	32 946	58 754	5 544	11 614	31 405	49 363
Oceania	4 014	5 034	3 120	4 353	1 552	2 038	2 497	3 403	716	985	1 693	2 326
World	**58 478**	**84 102**	**99 805**	**123 316**	**88 310**	**114 206**	**96 194**	**139 257**	**23 142**	**37 397**	**96 593**	**119 799**

Source: UN Educational, Scientific and Cultural Organization (UNESCO), *UNESCO Science Report 2010: The Current Status of Science Around the World* (UNESCO: Paris, 2010).

scientific states are Brazil, China, India and South Korea.[42]

A particularly relevant set of indicators for the biosciences that are traditionally used to capture the scientific capacity of a country are publication counts, which indicate a country's capacity to produce new scientific knowledge.[43] In 2008 the total number of new scientific publications was 986 099, an increase of 252 794 from the total number of science publications in 2002 and an increase of 387 622 from the 2001 total.[44] The USA was found to have a 27.7 per cent share of the total number of scientific publications produced in 2008, but this represented a decrease of 3.2 per cent from its share of the total in 2002, the highest rate of decrease experienced by any country. The European Union (EU) remained the leading region for this indicator in 2008 with 36.5 percent, but it too suffered a total decrease from the 39.6 per cent share of the total it had enjoyed in 2002. In contrast, Asia's percentage share rose from 24.2 per cent to 30.7 per cent thanks largely to China's share more than doubling (from 5.2 to 10.6 per cent) and India's share rising from 2.6 per cent to 3.7 per cent. Latin America and the Caribbean also saw an increase in the total share of publications from 3.8 per cent in 2002 to 4.9 per cent in 2008. Table 1 extracts data from the *UNESCO Science Report 2010* for the levels of publication according to the disciplinary boundary of journals for certain regions. It shows a rise of total scientific publications in all regions of the world over the period 2002–2008. Just as the Royal Society noted in relation to GPD investment in R&D, states that are traditionally considered as scientific leaders in terms of publications are being caught up by emerging scientific nations, predominately in Asia.

The data provided by the authorship line of scientific publications also indicates changes in the processes underpinning the authorship of papers. Aided by advances in information technology, such as database design, access to the Internet and the speed by which data can be transferred over the Internet, instances of transnational co-authorship are increasing. According to the Royal Society 'today over 35% of articles published in international journals are internationally collaborative, up from 25% 15 years ago'.[45]

Recent investigations performed by the Harvard Sussex Program into five technological areas that have previously been included in national contributions to the review conference consideration of science and technology developments found evidence of increasing levels of transnational co-authorship.[46] However the results showed that the instances of transnational co-authorship differed according to the maturity of the technology and the relevance of the scientific area to the country concerned.

[42] British Royal Society (note 24), p. 16.

[43] Publication data is from table 3 in Hollanders and Soete (note 41), pp. 10–11, unless otherwise stated.

[44] The data for 2001 is taken from Tindemans, P., 'Producing knowledge and benefiting from it: the new rules of the game', UN Educational, Scientific and Cultural Organization (UNESCO),*UNESCO Science Report 2005* (UNESCO: Paris, 2005), p. 9.

[45] British Royal Society (note 24), p. 6.

[46] The 5 areas were vaccines and vaccine development, disease reporting and surveillances, synthetic biology, nanotechnology, microencapsulation and toxin production. On details of the project see Harvard Sussex Program on Chemical and Biological Weapons (note 10).

Three maps illustrate this point: figure 1 shows the global distribution and patterns of collaboration of publications on synthetic biology, a new technological area that has received significant attention from states parties since the most recent review conference in 2006; figure 2 illustrates the global distribution and patterns of transnational co-authorship relating to vaccines and vaccine production, a much more mature field of scientific investigation; and figure 3 relates to disease reporting and surveillance. In each map the countries in which papers have been authored over the past decade are shaded brown, instances of authorship that have occurred between 2006 and 2010 are represented by the blue nodes—the size of which is proportional to the number of instances—and the levels of international co-authorship are shown by the thickness of the connecting lines.

Evident in figure 1 is that publications on synthetic biology between 2006 and 2010, as represented by the blue nodes, tend to originate from research institutes in the triad of geographical areas that dominate publication output overall: Asia, Europe and the USA. While involvement by some countries in the Global South is evident and some transnational co-authorship is occurring, it is much less than is evident in figures 2 and 3, which illustrate global distribution and patterns of transnational co-authorship of publications relating to vaccines and to disease surveillance and reporting.

In figure 2, on vaccines, the dominance of Asia, Europe and the USA is again evident, but, when comparing this map to figure 1, on synthetic biology, what is immediately obvious is the greater number and density of the interconnecting lines. Representing instances of transnational co-authorship, the eye is drawn to the density of lines to and from the USA and the number of interconnections in and between countries in the southern hemisphere, particularly Australia. Another feature of this map, compared to the synthetic biology map, is the increased instances of authorship, particularly in sub-Saharan Africa and Latin America. Five significant hubs of publication activity during 2006–10 are evident: Argentina, Brazil, Colombia, Mexico and South Africa. This increased level of engagement and interconnectedness is also evident in the map below showing publications as they relate to disease surveillance and reporting.

Again figure 3 shows the dominance of Asia, Europe and the USA in disease surveillance and reporting. However, when comparing this map to figure 1, on synthetic biology, two things are particularly striking.

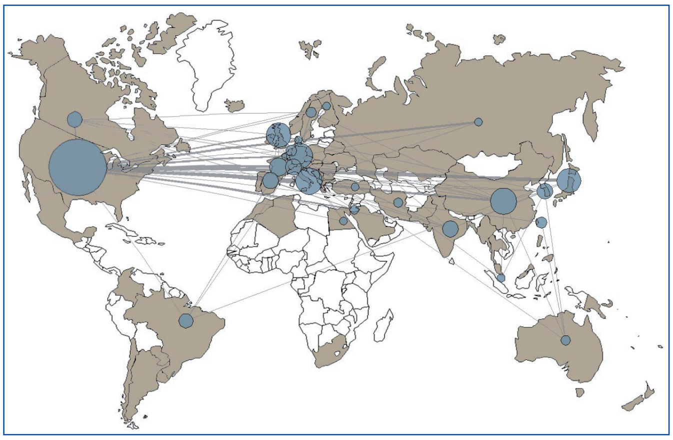

Figure 1. Global distribution and patterns of collaboration in publications on synthetic biology, 2000–10

Source: Data extracted from Institute for Scientific Information (ISI), Web of Science.

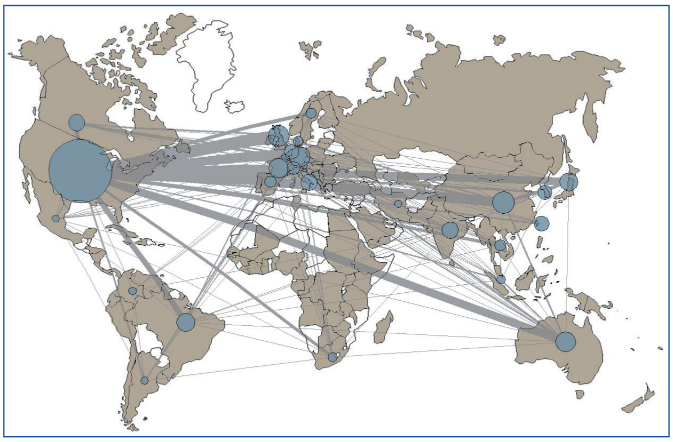

Figure 2. Global distribution and patterns of collaboration in publications on vaccines, 2000–10

Source: Data extracted from Institute for Scientific Information (ISI), Web of Science.

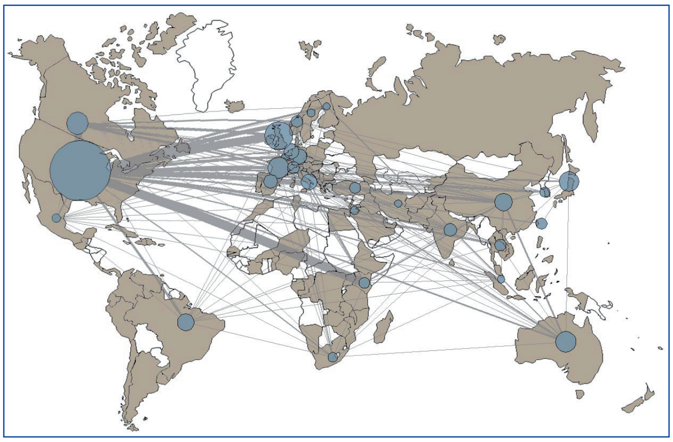

Figure 3. Global distribution and patterns of collaboration in publications on disease surveillance and reporting, 2000–10

Source: Data extracted from Institute for Scientific Information (ISI), Web of Science.

The first is that, as with publications relating to vaccines, compared to synthetic biology there is a greater number of shaded countries showing instances of authorship over the period 2000–10; a greater number of nodes representing instances of authorship between 2006 and 2010; and a much greater number of connecting lines showing instances of transnational co-authorship over the period 2006–10. Indeed, the number and thickness of the connecting lines indicate that many more papers are transnationally authored in this domain than for publication on synthetic biology and vaccines.

The second striking difference in both figure 2 and figure 3 is the instances of authorship in sub-Saharan Africa during the period 2000–10. Authors whose address lines indicate that they are located in African research institutes are more numerous in research into disease reporting and surveillance than synthetic biology. In both of these technology domains at least one hub is noted: for vaccine research, South Africa; and for disease reporting and surveillance, Kenya and South Africa. Together with table 1, this data suggests that countries choose areas for scientific knowledge creation not only based on their own needs (clinical medicine) and geographical opportunities (biology), but also based on cultural affinities (mathematics, physics) and expertise born of industrial growth (chemistry).[47]

Consequences for the reviewing of science and technology under the BTWC?

This brief discussion on scientific and technological indicators has shown clearly that levels of scientific activity around the world are increasing: in monetary terms, new investment in R&D at the global level has increased by nearly 50 per cent over the period 2002–2008. Looking deeper at statistics indicates that while science is being done in more places around the world it remains concentrated—publication indicators, for example, show a total rise in terms of overall numbers of publications but output remains dominated by the triad of Asia, the EU and the USA. However, particularly for some science and technology areas, such as disease reporting and surveillance, there is an increasing number of countries acting as hubs of activity, as well as increasing levels of international collaboration. Comparing publication data for journals of different scientific disciplines is also a reminder that the capacity to produce new knowledge is not ubiquitous but is dependent on a number of factors, including the level of maturity of an area or a country's own particular needs, cultural affinities and industrial emphasis.

The areas of science and technology studied by the Harvard Sussex Program's project are dynamic fields but, especially where the science and technology field is emerging, such as synthetic biology, high levels of uncertainty and unpredictability are present. If viewed through the lens of potential misuse for biological weapon purposes, these levels of uncertainty and unpredictability increase perceptions of vulnerability. Consequently, while the benefits of areas such as synthetic biology for the BTWC promise to be plentiful and include identification of drug candidates, improvement in drug production and delivery, and determination of the sources of engineered pathogen strains in support of investigations into suspected biological weapon incidents, they are often less emphasized.

Instead, scientific advances are most often portrayed as increasing the risks that the life sciences will be put to hostile purposes. Advances in knowledge, for example, are portrayed as providing a base for novel forms of attack or more subtle ways of causing harm; associated technological developments are depicted as making the development of biological weapons easier, quickening the progression from R&D to manufacture, and enabling better delivery to selected targets.[48] Increased global engagement in particular areas of science and developments such as open source publication of research data has been portrayed as increasing 'the risk it could be used in contravention to the aims of the Convention'[49] and 'spreading expertise and capabilities and increasing the accessibility of biological pathogens suitable for disruptive attacks'.[50] Additionally, the increased automation of certain areas of life science research have been portrayed by some commentators as pushing down economic and intellectual barriers and deskilling once complex and labour intensive processes, such that 'automation and miniaturisation have allowed postdoctoral researchers

[47] Hollanders and Soete (note 41), p. 12.

[48] See also McLeish and Trapp (note 14).

[49] UN Office at Geneva, 'Disarmament', <http://www.unog.ch/bwc/science>.

[50] US National Intelligence Council, 'Global trends 2025: a transformed world', Nov. 2008, <http://www.dni.gov/nic/PDF_2025/2025_Global_Trends_Final_Report.pdf>, p. 70.

to be replaced by master's students; master's students to be replaced by undergraduates; and technicians, with only minimal higher learning, to replace the undergraduates'.[51]

In part, this framing through which advances in science and technology are viewed has been developed through the past practice of assessing developments in terms of whether the scope of the BTWC is sufficiently broad to encompass the new science and technology developments. Thus, for example, in relation to the top-down method of synthetic biology (i.e. the redesign of existing, natural biological systems for specific purposes) what tends to be noted is that there is potential to deliberately create novel pathogens, enhance the pathogenicity of naturally occurring pathogens and redesign a non-pathogen into a pathogen using synthetic biology technologies.[52]

Also contributing to the framing of science and technology advances is the way in which the wording of Article XII has been understood. Examination of previous science and technology papers authored by states parties suggests that taking into account *any new scientific and technological developments* has tended to be understood as meaning new advances. Consequently, papers have emphasized the cutting edge of science and technology, such as synthetic biology. Emphasizing the cutting edge, however, means that some types of new developments, such as new uses of older sciences and technologies, have not been reviewed. To give an example of new uses of older technologies: examining global distribution of science and technology indicates the importance of the Internet and large databases. Neither is a new technology; what is new though is the manner in which these old technologies are being used by life scientists in the social process of producing knowledge. The importance of taking into account new uses of older technologies, or older technologies which have been vastly increased by capacity, was highlighted by several of the participants in the study as essential for future reviews with one remarking, '[After all] it took a long time until gunpowder use was effective'.[53]

The need for the BTWC's states parties to consider some sort of inter-review-conference process is to a large extent the result of the pace of scientific change and the increased complexity of science. The current tie to the approximately five-year review conference cycle reflects understandings of science and technology prevalent at the time of the convention's entry into force: a pre-molecular-biology pace of change in science, a pre-biotechnology level of diffusion of technology in industry and a linear understanding of the relationship between science and technical change.[54] The increasing convergence of life sciences with other disciplines, such as chemistry, computing and engineering, means that the difficulties of performing a science and technology review have also increased. More areas of science have to be reviewed for relevance to the BTWC and with convergence leading to increasing specialization, 'it would be dangerous to expect a single person to do all the collecting of the information'.[55] Empirical data is suggesting the need for a more inclusive reviewing system where those who perform science and technology, such as industry and the academic scientific community, are somehow included.

At the upcoming review conference in December 2011 the opportunity arises for states parties to consider the future of the process in which science and technology advances might be accommodated. Momentum has been growing on 'doing something' about how to review science and technology and there appears to be consensus growing among states parties around considering some sort of science and technology component during a third intersessional process.[56]

[51] Implementation Support Unit, 'Background information document on new scientific and technological developments relevant to the convention submitted to the Sixth BWC Review Conference', BWC/CONF.VI/INF.4, 28 Sep. 2006.

[52] See e.g. USA, 'Synthetic biology: a transforming technology', BWC/MSP/2008/MX/WP/4, 30 July 2008; and the 'Scientific and technological developments relevant to the Biological Weapons Convention' documents submitted to the Sixth Review Conference by the UK and the USA.

[53] Participants 1 and 2, 1 Mar. 2011.

[54] See McLeish, C. and Nightingale, P., 'Biosecurity, bioterrorism and the governance of science: the increasing convergence of science and security policy', *Research Policy*, vol. 36, no. 10 (Dec. 2007), pp. 1635–54.

[55] Participant 60, 17 Aug. 2011.

[56] See McLeish, C. and Revill, J., 'Reviewing science and technology in the context of the Biological Weapons Convention', Discussion paper presented at the 31st Workshop of the Pugwash Study Group on Implementation of the CBW Conventions *Getting Ready for the Seventh BWC Review Conference in 2011* Geneva, 4–5 Dec. 2010.

VI. OVERVIEW OF RESULTS FROM A PROJECT ON THE FUTURE OF SCIENCE AND TECHNOLOGY REVIEWS

In the Harvard Sussex Program's project on the future of reviewing science and technology in the BTWC context there was unanimous agreement among the 84 participants from 16 countries that the current process of collecting and sharing information on science and technology developments could be improved.[57] One of the working assumptions for the project was that the obligation to review new developments in science and technology as they relate to the operation of the convention as part of the review conference process would continue to exist in the future. This assumption was shared by the participants.

On how science and technology might be reviewed at future review conferences there was unanimous agreement that developments should be considered not only in terms of their relevance to Article 1 but also in terms of other articles of the BTWC. This included science and technology as they relate to the implementation of: Article 3 (not to transfer, or in any way assist, encourage or induce anyone else to acquire or retain biological weapons), Article 4 (national implementation), Article 6 (investigations of alleged breaches), Article 7 (assistance to states which have been exposed to a danger as a result of a violation of the BTWC) and Article 10 (implementation of the convention in a way that encourages peaceful use). Some of the participants did caution against a review of advances in science and technology which took the focus too much away from Article 1.[58] If this sentiment was found to be unanimous among all states parties, one way in which it could be realized is by modest adaptation to the format of papers on science and technology. Rather than being organized under technology headings, the paper could be organized, for example, to include a section, either at the beginning or the end, detailing how the particular advances relate to the operation of relevant articles of the treaty. Another method proposed was for there to be, following a dedicated discussion period at a review conference, a written summary of the outcome. Participants also agreed that it would be valuable for this document to contain two sections: the first containing a technical description of the chosen topics, followed by the second proposing the impact of these topics Article by Article.

Near unanimous agreement also extended to the idea of increasing the frequency of science and technology reviews: 90 per cent of those participants with a previous connection to the BTWC thought that science and technology should be reviewed during the inter-review conference period. However, when asked about the details of how more frequent consideration of science and technology might be operationalized, participants expressed divergent views. For example, opinions were split over whether these more frequent reviews should be organized around a discrete and different topic each year, organized around a theme or topic(s) linked to an intersessional topic (e.g. national implementation), or organized as a comprehensive review. For some there was a need to first stocktake to establish a baseline of information before addressing specific topics or themes.[59]

Divergence also occurred around whether the reviewing of science and technology developments should be conducted by states parties using governmental scientific experts who take advice from other experts (academics, industry etc.) as required, or by forming some sort of expert advisory body or working group. Some thought that an expert body or working group should involve outside experts so as to continue and deepen the engagement with members of the scientific community that has been occurring during the intersessional process. For those who did feel that non-governmental scientific experts should be included in future reviews, there was not agreement as to whether their involvement in the process should be direct or indirect. This is reflected in the quote: 'I think some means of forming groups of technically trained folks would be good, and I'm in favour of recruiting outside of government to do this.'[60] As well as in the quote: 'Maybe we should think in terms of gathering together handpicked scientists on the basis of their expertise and have a meeting which is somehow fed into the organisation.'[61] For those who did see

[57] This was the situation as of 1 Sep. 2011. Participants included members of past and present national delegations to BTWC review conferences and scientists in public and private laboratories that work in 5 areas of science and technology that have been previously highlighted by states parties or the Secretariat as being of relevance to the operation of the convention. These 5 areas were nanotechnology, synthetic biology, vaccines and vaccine development, disease reporting and surveillance, toxin production and microencapsulation.

[58] E.g. participant 8, 30 Apr. 2011 and participant 22, 9 July 2011.

[59] Participant 29, 6 July 2011.

[60] Participant 37, 11 July 2011.

[61] Participant 62, 1 Sep. 2011.

the benefit of using future discussions of science and technology as a method of deepening the dialogue between the BTWC's states parties and the science community, views converged around the idea that outside experts should track developments in science and technology rather than be asked to review the implications of those developments for the convention: 'We can bring in well respected scientists together with experts and have an exchange of information. This would then go to the states parties. Scientist are neither able nor interested in doing implications so leave this for [state party] scientists . . . In terms of political feasibility though, the objective would be to keep the science away from politics.[62]

One way in which it was thought to keep 'science away from politics' was to have future science and technology review as primarily a technical discussion. To do this scientists, whether government technical experts or experts from the wider scientific community, would be the primary participants in this discussion, and it was considered important that that their report should not be a consensus report. As one participant noted: 'You should not expect consensus among scientists. Disagreement is part of our culture and healthy so it would be odd to expect us to agree.'[63] Others commented: 'Non-consensus or disagreement is important and should be brought to the attention of the diplomats to form a more sound and reliable basis for decision making.'[64] 'At the technical level [consensus] could be difficult. You could ask groups to come to majority decision and if needed allow dissenters to write a paper explaining why they disagree.'[65]

VII. CONCLUSIONS

The divergent views expressed by the project participants on the operational details of future science and technology reviews suggests that there is much work to be done if something is to be agreed at the Seventh Review Conference in 2011. While the minutiae of how a science and technology review might operate in the future does not have to be decided in December, states parties do need to be cognizant that their political decision making at the review conference will affect what is achievable in future. To assist in their deliberations three of our findings should be kept in mind: first, empirical data on the nature and distribution of science and technology relevant to the BTWC suggests that not only are more frequent reviews of science and technology needed, but also that some form of systematic engagement with the users and producers of science is required. Second, that future reviewing of science and technology in a BTWC context should be holistic in terms of examining both the potential positive and negative implications for the operation of the BTWC. This will mean that discussions on science and technology should extend beyond a narrow focus on Article 1. Finally, that in whatever structure might be agreed to conduct these reviews, consensus is not a normal state for science. Reporting of technical discussions should, if necessary, record divergent views which, in addition to allowing states parties to make better decisions, will acknowledge the limitations of scientific advice.

[62] Participant 23, 9 July 2011.
[63] Participants 14, 15, 16, 17, 8 June 2011.
[64] Participant 9, 31 May 2011.
[65] Participant 37, 11 July 2011.

ABBREVIATIONS

BTWC	Biological and Toxin Weapons Convention
GDP	Gross domestic product
ICT	Information and communication technology
NSABB	National Science Advisory Board for Biosecurity
OECD	Organisation for Economic Co-operation and Development
PrepCom	Preparatory Committee
R&D	Research and development
UNESCO	United Nations Educational, Scientific and Cultural Organization

EU Non-Proliferation Consortium

The European network of independent non-proliferation think tanks

A EUROPEAN NETWORK

In July 2010 the Council of the European Union decided to create a network bringing together foreign policy institutions and research centres from across the EU to encourage political and security-related dialogue and the long-term discussion of measures to combat the proliferation of weapons of mass destruction (WMD) and their delivery systems.

STRUCTURE

The EU Non-Proliferation Consortium is managed jointly by four institutes entrusted with the project, in close cooperation with the representative of the High Representative of the Union for Foreign Affairs and Security Policy. The four institutes are the Fondation pour la recherche stratégique (FRS) in Paris, the Peace Research Institute in Frankfurt (PRIF), the International Institute for Strategic Studies (IISS) in London, and Stockholm International Peace Research Institute (SIPRI). The Consortium began its work in January 2011 and forms the core of a wider network of European non-proliferation think tanks and research centres which will be closely associated with the activities of the Consortium.

MISSION

The main aim of the network of independent non-proliferation think tanks is to encourage discussion of measures to combat the proliferation of weapons of mass destruction and their delivery systems within civil society, particularly among experts, researchers and academics. The scope of activities shall also cover issues related to conventional weapons. The fruits of the network discussions can be submitted in the form of reports and recommendations to the responsible officials within the European Union.

It is expected that this network will support EU action to counter proliferation. To that end, the network can also establish cooperation with specialized institutions and research centres in third countries, in particular in those with which the EU is conducting specific non-proliferation dialogues.

http://www.nonproliferation.eu

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