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Role of science and technology in the context of international security and disarmament

Report of the Secretary-General

Contents

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Introduction

1. The present report is submitted pursuant to General Assembly resolutions 51/39 of 10 December 1996 and 52/33 of 9 December 1997. In resolution 51/39 the Assembly requested the Secretary-General to update and further develop an earlier report dated 17 October 1990 entitled "Scientific and technological developments and their impact on international security" (A/45/568) in order to evaluate the impact of recent scientific and technological developments, especially those which have potential military applications. In resolution 52/33, the Assembly recalled resolution 51/39 as well as its request to the Secretary-General to submit an updated report no later than at its fifty-third session.

2. The 1990 report contained assessments of trends and developments in five major fields: nuclear technology, space technology, materials technology, information technology and biotechnology. The assessments were prepared by scientists who presented their papers for discussion at a high-level conference on "New trends in science and technology: implications for international peace and security" held at Sendai, Japan, in April 1990. The conference was hosted by the Government of Japan. The papers presented were elaborated in the light of the discussions held there.

3. In pursuance of the request contained in resolutions 51/39 and 52/33, the experts who had prepared the original contributions for the 1990 report were requested to update their earlier assessments by providing a brief overview of broad new trends since the earlier report; specifying any new trends with illustrations where possible; and making observations on peaceful and other applications of latest developments. The updated assessments reproduced below represent the views of their authors.

Technology trends in selected areas

A. Nuclear technology*

4. In the 1990 report, it was noted that, after some decades of rapid growth, nuclear technology seemed to have matured to a level where no significant improvements were likely to take place in the next few years. The term "improvements" did not refer to normal progress in scientific research but rather to developments which could be expected to have an impact – positive or negative – on international security policy and efforts towards disarmament. This prediction has been borne out, as will be further shown below.

5. In the 1970s and 1980s, it was sometimes said that technology had taken the lead over politics. The thoroughgoing changes in international relations during the 1990s have to some extent restored the primacy of politics. This is perhaps more evident in the nuclear area than in many other fields, as much of the nuclear research and development now underway is aimed at the implementation of political decisions made in the wake of these changes.

6. Since the writing of the previous report, the world has witnessed, among other events, the dissolution of the Soviet Union and the transfer of all Soviet nuclear weapons to the territory of the Russian Federation, the withdrawal of almost all substrategic nuclear weapons from Europe and probably the scrapping of many of them, the continued work of implementation of the Strategic Arms Reduction Treaty (START), the signing (although not yet the ratification) of START II and the preliminary discussions with regard to a future START III. On the multilateral level, there has been the indefinite extension of the Treaty on the Non-Proliferation of Nuclear Weapons, the conclusion of the Comprehensive Nuclear-Test-Ban Treaty – albeit with provisions which may prevent it from entering into force in its current form – and renewed efforts to achieve a treaty banning the production of nuclear weapons materials. The Gulf war and its aftermath has provided important lessons. Most recently, both India and Pakistan have demonstrated their capability to produce nuclear weapons by each openly testing several explosive devices.

7. Ideally all of the new developments mentioned above should be considered in revising the 1990 report, which covered the trends with regard to:

- The development of nuclear weapons;
- The development of civilian nuclear power production;
- Methods for the production of nuclear materials;
- So-called radiological weapons;
- Laser or particle beams as options for active missile defences or otherwise applied in a nuclear weapons context;
- Nuclear technologies for detection and for treaty verification.

8. In reality, the changed circumstances mentioned above make it necessary to shift the emphases in comparison to 1990. There is also a need to introduce topics which were treated only briefly or not at all in the previous report, in order to reflect the directions of further development which have

* This section was authored by Dr. Tor Larsson, Coordinator for Nuclear Weapons Related Research, National Defence Research Establishment, Stockholm.

assumed importance in the light of recent events. As in the earlier report, the developments in the field of delivery vehicles (missiles, etc.) and weapons platforms are excluded, as they were considered scientifically unrelated to nuclear technology.

Nuclear weapons

9. The 1990 report paid particular attention to the extremes with regard to both weapon yields and to the possible manipulation, i.e., “tailoring” of weapons effects. These themes seem to be of less concern today. One reason is simply that further development of new nuclear weapons systems seems to have ceased. Another is that the possibility of a nuclear war, where such particular weapon features might be considered useful, now appears to be very remote.

10. An important factor in slowing down or stopping the development of new types of nuclear explosives – if indeed such were sought for earlier – has been the long suspension of nuclear testing observed by the United States of America, the Russian Federation and the United Kingdom of Great Britain and Northern Ireland. These three States made their latest and possibly last test explosions in 1992, 1990 and 1991, respectively, while China and France tested as late as 1996. However, later in 1996 all of the five traditionally acknowledged nuclear weapon Powers pledged to cease testing altogether by signing the Comprehensive Nuclear-Test-Ban Treaty. While the political impact of the Indian and Pakistani tests in May 1998 is very substantial, there is no reason to believe that these tests signify technological advances beyond what has long been available to the original five nuclear-weapon States.

11. On the other hand, some nuclear-weapon States have been concerned with the problem of maintaining the technical quality of their nuclear stockpiles (or the stockpiles left when arms reductions were implemented), if full-scale testing is no longer available. For this reason, the United States Government has allocated substantial funds to what is commonly called a “stewardship program” and a similar but much smaller programme is also under way in France. There is, however, considerable uncertainty with regard to the future content of these programs and hence also to the possibilities they may offer for technical modifications and improvements of the nuclear warheads which they are intended to “steward”.

12. As described by its proponents, the “stewardship program” should ensure that: (a) all knowledge acquired from earlier testing is preserved and understood; (b) weapon effects could be simulated to the greatest possible extent; and (c) computational methods are adequate for the replacement, renovation or modernization of weapon components which reach the end of their service life. The second of these points relates primarily to the radiation effects on modern microelectronics, which is critical to both offensive and defensive systems. The emphasis on this aspect could be an indication that the requirements posed by a nuclear strategic duel are still considered relevant. The third point brings into focus an aspect which was well known but largely left out of the discussion at the time the previous report was written, i.e., the ageing of various parts in a nuclear warhead.

13. It is common knowledge that if the function of the warhead is dependent upon the presence of tritium, that substance has to be replaced at regular intervals as it decays with a half-life of about 12 years. However, many other, non-nuclear parts may also age. For instance, there may be radiation-induced decomposition in the high-explosive, heat-induced degradation of some components or corrosion at interfaces between different materials. Generally speaking, it is believed that nuclear warheads need to be overhauled within a period of 5 to 10 years. Because of the strained economic situation in the Russian Federation, which has made it difficult to uphold earlier maintenance practices, some Russian commentators indeed argue that the Russian nuclear inventory is now to a large extent technically unreliable. Many observers, however, doubt that such large, ambitious and expensive research programmes are really necessary to provide the ability to deal with these problems. Hence they believe that there also might be ambitions to circumvent the test ban and develop new weapon designs.

Nuclear power production

14. While the development of civilian nuclear power undeniably holds some potential for weapons proliferation, the previous report noted that actual events had not shown this relationship to be particularly significant. There is no reason to change this assessment today, as the proliferation which has indeed occurred has been driven by political considerations and probably would have taken place even if the States in question were less dependent upon nuclear energy. Nonetheless, nuclear power may influence international security indirectly in other ways, notably through its role in the global energy supply but also because of environmental and safety concerns among the general public. These concerns have in all likelihood slowed down the development of nuclear power in many countries.

15. One consequence of this slow evolution of nuclear power production is that there is no shortage at all of nuclear fuel or of uranium ore as the raw material for such fuel. With currently available techniques and at the present growth rate, the known uranium reserves are expected to fill global needs for many years to come, although the International Atomic

Energy Agency (IAEA) estimates that more efficient use of uranium resources probably will have to be considered before the year 2050. Regarding reactor fuel, the supply exceeds the demand, if plutonium is taken into account.

16. The 1990 report observed that there was an increasing interest in the mixed oxide fuel (MOX) technology, related to the need to do something about the growing stockpiles of plutonium. Some of this plutonium comes from scrapped nuclear weapons, but the bulk stems from irradiated power reactor fuel. This trend has continued, and there are today several research programmes oriented to addressing the plutonium problem, with or without simultaneously supporting power production. One of the ideas brought forward here is that of a sub-critical reactor which is driven by an accelerator. This would be an arrangement that is virtually immune to reactor accidents, as it can be turned off simply by turning the accelerator off. The problem of plutonium disposal is discussed further below.

17. The quest for methods to generate nuclear power using processes other than fission is proceeding in incremental steps. In spite of large international research programmes such as Joint European Torus (JET) and the International Thermonuclear Experimental Reactor (ITER), the future practical utilization of fusion energy remains uncertain. This seems to be true also for other, scientifically interesting approaches which are being pursued, notably “inertial confinement fusion”.

18. Other, rather exotic ideas, such as the use of nuclear spin isomerism and electrostatic acceleration of deuterium ions to produce a high flux of neutrons, remain even more speculative. These are mentioned only for the sake of completeness, and they have not been described as potential energy sources as neither will produce more energy than it consumes.

Production and disposal of nuclear materials

19. Around 1990, there was substantial interest in new methods for producing fissile material, particularly those utilizing laser radiation. To a large extent this was related to proliferation concerns but there was also the prospect of producing low-enriched uranium for reactor fuel in a cheaper way. The first of these aspects seems to have lost much of its salience. Proliferation has taken place and the materials involved have been produced by traditional methods. Indeed, the aborted proliferation effort in Iraq was undertaken partly by use of electromagnetic isotope separation, a method abandoned long ago by the five recognized nuclear-weapon States because of its low efficiency and high cost.

20. As for the reactor fuel aspect, as stated above, the main problem today is the abundance of fissile material rather than the lack of it. Furthermore, only about 80 per cent of the total enrichment capacity in the world is currently being used. Nevertheless, there is still a commercial interest in developing more economical methods to produce enriched uranium. For this reason, research continues into the techniques known as atomic vapour laser isotope separation (AVLIS) and molecular laser isotope separation (MLIS), both in the United States and elsewhere. In addition a new method called separation of isotopes by laser excitation (SILEX) is being developed. All of these are believed to be able to become, in due time, potentially superior to centrifuge separation. The once dominant enrichment technique, that of gaseous diffusion, is regarded as obsolescent and economically not viable for the future. These considerations have no immediate bearing on the disarmament efforts but will have to be borne in mind when verification means for a possible future cut-off treaty are considered.

21. Transmutation technology was not discussed in the previous report, as it was then seen as a rather speculative and superfluous method of producing fissile materials. During the 1990s, however, transmutation research has assumed importance as it could offer possibilities to dispose of both nuclear waste from power reactors and surplus weapon material. Today there are ongoing research programmes in several countries, including the United States, the Russian Federation, France and Japan. The basic idea is to use a particle accelerator to produce a very large flux of fast (high-energy) neutrons through a process called spallation. When these neutrons interact with the material to be disposed of, they will transform that material into other nuclides which are less proliferation-prone and reduce (although not entirely remove) the need for final disposal in geological repositories. Some proposed solutions are specifically thought of as waste disposal methods, while others might add to the energy supply if this proves economically attractive. In spite of the many technical problems which are still unsolved, transmutation might be seen as the currently most promising and important sub-field of nuclear technology.

22. One factor that complicates the plutonium problem is the lack of an agreed policy with regard to it. Basically there are two different schools of thought: one, to which many Russian scientists belong, claims that the plutonium now on hand represents a very high economic value and should be put to the best possible use for power production. The other school, with many American supporters, maintains that the surplus plutonium has a negative value because it is not needed for power production and because there will be large costs associated with its utilization in MOX fuel or otherwise.

Radiological weapons

23. This topic was included in the previous report mainly for the sake of completeness, but was not elaborated upon, as such weapons are quite unattractive for a number of reasons, including military ones. Nothing has happened that would alter that assessment, and no development of such weapons is known to have taken place anywhere. There is still no international agreement to ban them, however.

Ballistic missile defence technologies

24. The decision by the United States Government, in 1983, to proceed with the "Strategic Defence Initiative" prompted a discussion on various technical alternatives for disabling ballistic missiles in flight, including both laser beams and particle beams of different types. As ballistic missile defences obviously were relevant to nuclear strategy considerations, the 1990 report offered some comments on beam weapons, in spite of the fact that interest was already waning and the technologies discussed do not belong to the nuclear field as such.

25. The Gulf war demonstrated both the usefulness of so-called theatre defence systems and, paradoxically, the shortcomings of the system then available. As a result, the years after that war have seen a burgeoning research and development effort in this field, and about 10 different programmes are now under way in the United States. While lasers are not completely out of the picture, the majority of the systems envisioned are "kinetic-energy-weapons" i.e., they destroy an incoming missile by colliding with it. Even though this technology is not by far mature, it is seen by many supporters as an important future cornerstone of national security. The continued relevance of this development for the nuclear weapons area is primarily that it causes anxiety on the part of some Russian observers, who believe that one or more of these systems may in the future be upgraded to serve in a strategic role. This creates a further obstacle to the progress of bilateral nuclear disarmament.

Detection and verification technologies

26. In the 1990 report, some attention was given to the instrumentation necessary to ascertain whether a particular object was a nuclear device or not, and it was noted that this instrumentation was available in principle, although the practical application might prove difficult in many situations. In later years this problem has taken on a new dimension owing to the concern now held in many States that nuclear materials may be stolen and smuggled across national borders, with implications both for proliferation and for nuclear terrorism. For this reason, customs and police authorities in many countries have felt the need to enhance their capabilities to detect radioactive objects, and consequently instruments more adapted to these requirements have been designed and marketed. While these instruments do not represent any new technology, they signal a new aspect of the nuclear era.

27. The previous report also mentioned treaty verification. Having noted that better understanding of nuclear weapons radiation and nuclear phenomenology could be helpful in the development of verification methods, the report also stated that most verification methods were of a non-nuclear nature. This observation is certainly still true. However, in the political climate prevailing throughout the 1990s, and particularly after the conclusion of the Comprehensive Nuclear-Test-Ban Treaty, verification has also entered a new phase. Again, no basically new nuclear technologies are involved, but the new emphasis on worldwide, cooperative monitoring by different technical means is an important development. Among these means are a network of automated stations for measuring airborne radioactivity, which now also may have the ability to detect radioactive isotopes of noble gases. The so-called "93+2 programme" initiated by IAEA is another form of cooperative monitoring. It aims at reducing proliferation risks and fears through increased transparency of national nuclear technology efforts, and is also significant by virtue of its developing new methods, if not new technical instruments.

28. Finally, a topic that was not at all treated in the 1990 Report should be mentioned: the environmental radioactive contamination resulting from earlier nuclear weapons production and testing, and from lack of maintenance of nuclear systems components such as submarine reactors. In the pre-1990 world, these problems were largely disregarded as minor to national security concerns or, in some cases, not known at all. After the ease of political tensions between the major Powers, however, environmental issues have come to the forefront and are now subject to international research efforts. At the same time, methods for radio-ecological measurement and analysis have evolved in the wake of the Chernobyl accident. While the hazards to human beings from these contaminations are sometimes exaggerated in the public debate, the attention given to them is most appropriate in a world that continues to strive for the improvement of the international climate, both metaphorically and literally.

B. Space technology*

29. From the point of view of security, the following major areas of activities in outer space can be identified:

- The use of space-based assets to enhance not only the capabilities of terrestrial nuclear weapons but also conventional weapons;
- A perceived need to develop and to some extent deploy anti-satellite weapons;
- The use of space capabilities to defend a nation against an adversary's short- and long-range missiles;
- The increased capability of the civil remote sensing satellites and marketing the images thus generated.

The following sections briefly review trends in these areas along with some new developments.

Satellites for military support missions

30. The period since 1990 has seen some changes in the way outer space was used and the space capabilities have been enhanced. In the United States, the military use of outer space continues to expand because space systems are seen to "play a unique role".[1] In the Russian Federation, military space activities continue in traditional areas, such as meteorology, navigation, communications and reconnaissance.

31. ***Meteorological satellites***. In the United States, separate military and civil low-altitude meteorological satellites have been orbited and both are being used by the armed forces and are manufactured by the same company. The military spacecraft are launched under the Defense Meteorological Satellite Program. The current trend is to integrate military satellites in the armed forces for their use in combat situations. Weather satellites are no exceptions. They are planned for use during, for example, Army landings or supply drops.[2] In the Russian Federation, a single network of meteorological satellites is deployed. There is no reason to believe that it is using their space assets any differently from the way the United States does.

32. The focus now is also on the forecast of "space weather", which mainly means solar activities such as flares and the ejection of various kinds of materials from the Sun's surface. These result in electromagnetic radiation ranging from radio waves to X-rays, high-energy protons and changes in the interplanetary solar winds. Interactions of these with earth-orbiting satellites affect the sensors and electronic systems of the latter.

33. ***Navigation satellites***. The Russian Federation operates discrete military and civil low-altitude navigation satellites using the same kind of platform. In contrast, both the military and the civil users use the United States Transit and the Global Positioning System (GPS) satellites. Spacecraft in the GPS consisting of a set of 24 satellites transmit two separate signals. One for the military generates an accuracy of some 10 m. For civil uses this is degraded to give an accuracy of about 100 m. This is known as "Selective Availability" (S/A) which may be discontinued by the year 2006.[3] This will mean that an accuracy of position determination will be improved for others from 100 m to 10 m. If differential correction is used, then this can be improved to about 5 metres or less.[4] United States plans to add navigation signals for civil use on a second GPS frequency were also recently announced. It is proposed that differential-correction signals will be transmitted under this new frequency for civil use.[5]

34. ***Communications satellites***. Both the United States and the Russian Federation are launching separate communications satellites for military and civil uses. The United States communications satellite system consists of the Air Force Satellite Communication (AFSATCOM), the Defense Satellite Communications System (DSCS), the Fleet Satellite Communication (FLTSATCOM) and the Military Strategic and Tactical Relay (MILSTAR) satellites. All the military services as well as a number of governmental agencies use the DSCS. The strategic communications and intelligence data are relayed via the Satellite Data System (SDS) but the MILSTAR satellites will replace them. The latter were designed to withstand attacks from nuclear or even from anti-satellite weapons. Three satellites in the MILSTAR 1 series were built and modified with much larger capacity to become MILSTAR 2 series.[6]

35. ***Reconnaissance satellites***. There are essentially four types of reconnaissance satellites, namely photographic, electronic, ocean surveillance and early-warning satellites. Both the United States and the Russian Federation continue to orbit such spacecraft. The only difference is the total numbers have gone down. For example, in 1990 some 132 defence-related satellites were launched by China, France, Israel, the United Kingdom, the United States and the former USSR; the figure for 1992 was reduced to about 74 in 1992 and was even lower in 1998, mainly because the Russian Federation is not launching as many satellites as it did in the past. China, France and Israel have launched optical observation satellites. The United States, for several years now, has not launched a large number of satellites,

* This section was authored by Dr. Bhupendra Jasani, Professor, Department of War Studies, King's College London, University of London.

presumably because it has developed more sophisticated, capable and long-lasting satellites.

36. In the past, it was a matter of routine to conduct photographic reconnaissance. Recently, the United States Administration has authorized a declassification of intelligence imagery acquired between 1960 and 1972 by some of the early generations of United States photoreconnaissance satellites. Images acquired by these satellites are now commercially available. The best images, with a resolution of about 15 cm, are from the more advanced version of the KH satellites, KH-11 and KH-11/Improved versions or KH-12, which deploy sensors sensitive to visible and near infrared light as well as thermal infrared radiation to detect heat emitted from industrial facilities. With the infrared sensors, camouflage can be detected. It is possible to detect buried structures by observing differential thermal signatures. The first of these new satellites was launched on 28 November 1992.

37. To overcome the inability of the above satellites to see through clouds, radar sensors were developed and deployed. Information derived from imaging radar, such as synthetic aperture radar (SAR), is very different from that obtained from optical sensors, since an SAR is particularly sensitive to the geometrical characteristics of the surface and the object being monitored as well as to their dielectric properties. Microwave radiation can penetrate significant distances into an object, the depth of which could be comparable to the wavelengths of the radiation. Generally the longer the wavelength the greater the penetration. For example, radiation with C-band wavelength can penetrate very small distances while an L-band, SIR-C radar beam is known to have penetrated several metres of dry sand.[7]

38. So far only the United States and the Russian Federation maintain military radar satellites in orbit. The latest United States spacecraft in orbit is the Lacrosse SAR satellite, which orbits the Earth at an altitude of just under 700 km and has an SAR resolution of about 1 m. Three such satellites were launched: the first in December 1988, which is no longer in orbit, the second in March 1991 and the third in 1997. A new improved Lacrosse was launched on 23 October 1997 at an orbital inclination of 68º and at an altitude of about 680 km.[8] The Russian Federation continues to launch its radar satellites in the Almaz and the Cosmos series of spacecraft.

39. The other very important category of satellites is the electronic reconnaissance spacecraft, but even now very little is known about their capabilities as they still remain highly classified. In the United States, four groups of such satellites are deployed, namely, communications intelligence (COMINT) in the geostationary orbit (GSO) and signals or electronic intelligence (ELINT) satellites in the GSO and in high elliptical Earth (HEO) and low Earth (LEO) orbits. The ELINT satellites are designed to detect transmissions of such communications signals as the broadcast over radios and telephones as well as radar and telemetry of missiles emitted during their tests.

40. Most of the United States SIGINT/ELINT satellites are placed in the GSO and do not get a good coverage of the northern and the southernmost parts of the Earth. This is overcome by the satellites in the Trumpet series that are placed in highly elliptical orbits with the apogee (the longest distance from the Earth’s surface) about 37,000 km above the northern hemisphere and an orbital inclination of 63º. Two satellites were launched in 1994 and 1995 and a third upgraded satellite was poised for launch at the end of 1997 carrying a complex phased-array broadband electronic listening antenna measuring some 90m across.[9] The satellite can monitor all types of military electronic signal traffic originating in China and the Russian Federation. The same antenna technology will be applied to advanced commercial communications satellites.

41. The early-warning satellites have been deployed by both the United States and the Russian Federation. The United States deploys them in the GSO. The satellites use infrared sensors to detect heat from missile plumes as soon as they are launched or heat is generated from an atmospheric or space-based nuclear explosion. They also track the missile and determine its trajectory. The effectiveness of these spacecraft was demonstrated during the 1991 Gulf war. The United States early-warning satellites detected the launch of the Iraqi scud missiles, providing timely warning to the coalition forces. The vulnerability of such satellites to attacks on their ground stations will be minimized by deploying a laser communications system on board.[10] New generation Follow-on Early Warning System (FEWS) are expected to deploy such systems as the Brilliant Pebbles and Brilliant Eyes developed under the Strategic Defense Initiative. The latter will have an on-board data processing capability so that it can send early-warning messages directly to the battlefield for tactical use.

Some new developments

42. Apart from technical developments such as those mentioned above, considerable effort is being made in the United States to develop several new intelligence-gathering systems. The early developmental satellites such as the Lacrosse radar and the advanced KH-11 optical intelligence satellites are now coming into operational phase. Moreover, a new missile launch detection satellite is also under development, which may use the sensor technology developed

under the Strategic Defense Initiative Booster Surveillance and Tracking System programme.

43. Among the other new developments are the small, lightweight, so-called Cheapsat satellites and signal intelligence satellites in the GSO and a new Space-Based wide Area Surveillance System for global, aerial and maritime surveillance. For example, a satellite system consisting of 24 spacecraft with SAR (STARLITES) onboard is under consideration for tactical use by commanders in the field, with a rapid revisit time of some 15 minutes. It can be expected that the development of such small, more affordable satellites is likely to continue.

44. Considerable improvement has been achieved in the quality of civil remote sensing satellites. Over the past two and half decades, the capabilities of the civil remote sensing satellites have increased some 180 times, with resolutions ranging between 2m and 30m. It is now possible to purchase images acquired by various countries. These commercial satellites are summarized in table 1.

Table 1
Current and future commercial remote sensing satellites belonging to various countries

		Resolution in pixel size (m)		
Country Satellite	*Date of launch of first satellite*	*Panchromatic*	*Multi-spectral*	*Thermal*
China/Brazil				
CBERS	1998	20	20	160
France				
SPOT-1,-2,-3,-4	1986	10	20	
SPOT-5A,-5B	2002-3	2.5,5	10	
India				
IRS-1C,-2D	1995, 1997	5.8	23	
IRS-P6	1998?	2.5		
Israel				
Eros-1,-2	1998	1.5	5(3-4 bands)	
David	1998	5		
Japan				
ALOS	2002	2.5	10	
Russia				
Kosmos	1991	2	20	
USA				
Landsat-4,-5	1982		30	120
Landsat-7	1998?			60
IKONOS-1,-2	1998	0.8–1	4	
Quickbird-1,-2	1999	1	3.3	
Orbview-3,-4	1999	1	4	
Earlybird-1	2000	3	15	

45. Several countries are operating satellites with SAR sensors on board. These are listed in table 2. Interaction of microwave energy with materials depends not only on its frequency but also on the polarization of the radar beam. Thus, using differently polarized beams of various frequencies and assigning different colours to them it is possible to generate a multi-spectral image. The United States SIR-C/X-SAR experiments in April and October 1994 generated such multi-parameter SAR data from space. Combining this with optical data, the technique could become a very useful tool for monitoring the surface of the Earth. Civil remote sensing satellites can now be used for acquiring

information on an adversary's military targets. They can also be used for monitoring arms control agreements as well as for confidence-building measures. These factors have now made them potential targets for Air-launched anti-satellite (ASAT) weapons.

Table 2
Characteristics of some past, current and future commercial radar (SAR) satellites

Country Satellite	*Date of launch*	*Resolution (m)*	*Band/Frequency (GHz)*	*Polarisation*
Canada				
Radarsat-1	1995	8-100	C/5.3	HH
Radarsat-2	2001	3	C/5.3	QUAD
Europe (ESA)				
ERS-1,-2	1991,1995	26-28	C/5.3	VV
ENVISAT	1999	30	C/5.3	HH, VV
Japan				
JERS-1	1992	18	L/1.3	HH
ALOS	2002	10	L/1.3	HH, VV
Russia				
ALMAZ-1	1991	15	S/3.125	HH
ALMAZ-2	1998	5	S/3.125	HH
USA				
SEASAT	1978	25	L/1.3	HH
SIR-C	1981	8-30	L/1.28, C/5.3	HH, VV, VH, HV

Anti-satellite weapons and related satellite and defence

46. The importance of satellites was widely seen during the 1991 Gulf war. At the beginning of the conflict, the United States had in orbit one Lacrosse SAR satellite, three older KH-11 and three advanced KH-11 optical reconnaissance satellites. With these satellites it was possible to conduct 12 passes per day over the region of conflict.[11] In addition there were some 15-20 signals intelligence satellites intercepting low- and high-power[12] transmissions. During the conflict there were three Defense Meteorological Satellite program (DMSP) satellites,[13] some 15 GPS satellites,[14] as well as two FLTSATCOM[15] and at least two DSCS-III satellites[16] in orbit. The United States also used images acquired from the United States civil Landsat and the French SPOT remote sensing satellites for updating the maps of the conflict region.[17]

47. The above was the first active use of almost all types of satellites in a conflict. In a recently published plan for United States military space programmes through the year 2020, several recommendations have been made. One of these is for the development and deployment of a weapon based in space to destroy targets on the Earth. The other deals with methods of dealing with attacks against space systems (i.e. ASAT weapons) and also how to deter such attacks.[18] For the former, a long-term project, the United States Air Force has launched a design competition for a space-based laser weapon.[19] While this would demonstrate just the feasibility of the laser to destroy ballistic missiles in their boost phase, the ASAT weapons may, in the short term, become a reality.

48. ***Anti-satellite weapons***. Two types of ASAT weapons are currently being developed and tested. These are the Kinetic Energy ASAT (KEASAT), which would destroy a target by collision, and the Mid-Infrared Advanced Chemical Laser (MIRACL), which could either damage the sensors or destroy the satellite altogether. A number of types of KEASAT are being investigated. These include an electromagnetic rail gun, a Kill Vehicle and a miniature-homing vehicle. The latter two can either be a space-, air- or ground-launched weapon.

49. Many of the United States space weapon systems had counterparts in the former USSR and to some extent in the Russian Federation at present. The major difference has been that the latter has placed considerable emphasis on the role of these weapons as anti-satellite weapons. In the early 1970s, space-weapons development was carried out in two phases. Phase one was code-named Fon-1, under which advanced concepts and technologies were to be developed; the aim of Fon-2 was to translate these into realities.[20] The Fon-1 programme began formally in about 1976, with much of the effort spent on ASAT weapons rather than on ballistic missile defence (BMD). Research has focused on strategic as well as tactical laser weapons mounted on aircraft, armoured vehicles and ships. Apart from the conventional kinetic energy ASAT weapons using land-based direct ascent interceptor missiles, a prototype free-electron laser at Storozhevaya, a 1MW gas laser at Troisk near Moscow and a major laser complex at Sary Shagan were constructed. The Russian Federation has acknowledged the possession of ASAT systems.[21]

50. ***Ballistic missile defence***. BMD, although mainly ground-based, is considered here because some of the space-based assets such as the reconnaissance, communications and the navigation satellites form an important part of the system. For example, an observation satellite would locate the deployment of missiles; an early-warning satellite can warn of a launch of a missile; much of this information and subsequent communications would be conducted via military communications satellites; and finally any anti-missile launched would be guided by the navigation spacecraft.

Moreover, some of the missiles to be countered travel through outer space.

51. The current United States ballistic missile defence programme consists of theater missile defence (TMD), national missile defence (NMD) and advanced ballistic missile defence technologies. Some of the missiles are capable of reaching outer space, so that they may be regarded as potential ASAT weapons as well. A more significant United States TMD programme is called Theatre High Altitude Area Defense (THAAD). This is intended as defence against missiles at ranges of up to several hundred kilometres. The THAAD missiles are intended to collide with ballistic missiles rather than destroy them by exploding in the vicinity of the target. Thus, the THAAD deploys a hit-to-kill interceptor. An infrared seeker on the hit-to-kill vehicle provides final guidance to the target. The interception occurs either high in the Earth's atmosphere or well above it in outer space. The range of the THAAD system is expected to be 200 km horizontally and 150 km vertically. This would make the system a potential ASAT weapon.

52. Finally, under the advanced ballistic missile defence technologies, research will be carried out on advanced hit-to-kill interceptors with improved sensors, projectile structures, guidance and control systems. Directed energy weapons, particularly chemical lasers, will be investigated in order to provide an option for space-based global boost-phase interception capabilities. These systems would require such advanced sensor technologies as focal plane arrays and laser radar. It will be important to study and catalogue missile plume signatures and other characteristics in order to identify and track the missiles. The directed energy weapon is mainly an airborne laser (ABL). The aircraft, YAL-1A, will be flying at an altitude of just over 12 km. It is envisaged that without adaptive optics, the kill range of the laser could be about 240 km and with adaptive optics this could be extended to about 400 km. In the first test, the ABL may shoot down its first theatre ballistic missile in the year 2002.[22]

53. Not much information is publicly available on the Russian TMD systems. However, the Russian Federation has decided not to deploy nuclear warheads on the SH-11 Galosh and SH-08 Gazelle missiles in the one anti-ballistic missile defence system placed around Moscow.[23] In the early 1970s, under the Terra-3 programme, the former USSR had constructed an experimental laser at the Sary Shagan air defence proving ground. While much was learnt by the USSR on the interaction between the laser and the missile re-entry vehicles, the Terra-3 did not show promise as a workable weapon.

Some conclusions

54. In the past eight years, significant advances have been made in military space capabilities and their applications. One of the most significant applications was the actual use of space assets in the conduct of a conventional war – during the 1991 Gulf crisis – when at least 40 United States satellites were used to enhance the ability of the ground forces in intelligence-gathering. The acquisition of such a capability may become more attractive to other countries since the intelligence gathered by the reconnaissance satellites is shared very sparingly. This may well trigger the desire for wider acquisition of such capabilities for those who do not already have them. Thus, it will not be surprising if more and more States strive for the acquisition of military satellites.

55. The proliferation of such spacecraft will further increase if it is shown that small, easily affordable satellites can be built and orbited without much loss in their performance. Such satellites increase transparency, which may play a very important role in the verification of bilateral and multilateral arms control treaties. In this context, the increased capabilities of civil observation satellites becomes very important. Data from such satellites can be purchased by anyone who can afford to purchase the images. However, the spread of such capabilities has caused some concern, causing some States to embark upon anti-satellite weapons capabilities, which may in turn lead to a further arms race in outer space. One way of avoiding such a situation might be to encourage the establishment of regional arms control verification agencies. For example, in Europe, the Western European Union (WEU) has established a WEU Satellite Centre near Madrid for treaty verification, crisis monitoring and environment monitoring.[24] If the verification and confidence-building measures are performed by a multinational or an international agency, the satellite data may be less prone to misuse.

56. Another area in which some progress is being made is in strategic defence capabilities. In spite of the 1972 Treaty on the Limitation of Anti-Ballistic Missile Systems between the United States and the former USSR, research, development and to some extent testing is continuing on certain types of weapons. An example of this is ground- and space-based kinetic energy and laser weapons. This is progressing because some of these weapon systems are thought to be anti-tactical ballistic missile defence systems and not anti-strategic ballistic missile defence systems. In any case, the former are now allowed as the United States and the Russian Federation have agreed that the ABM Treaty does not prohibit such systems. However, there is considerable overlap in the technologies required by the anti-tactical and anti-ballistic missile defence and anti-satellite systems, and many

of such weapons have been defined as space weapons.[25] Thus, even though the cold war has ended, there is real possibility that an arms race in outer space will gain momentum.

C. Materials technology*

57. Materials science is the study of the principles that govern the useful properties of substances. Materials technology is a product or process enabling technology that exploits materials for commercial objectives. This emphasis on utility means that materials technology is inherently driven by applications. During the past decade new applications have been discovered primarily in the civilian commercial markets, where cost and adaptability to high-volume production are paramount considerations. Requirements for ultimate performance in a small number of expensive products, typical of defence needs, have become relatively less important as stimuli for materials development.

58. The performance and reliability of advanced materials depend upon their composition and microstructures, which impart unique functionality to products and devices. The following are three major technical trends in advanced materials technology, all driven by the need to precisely engineer microstructures to contain the desired physical and chemical compositions:

(a) The drive towards structures of diminishing size. As the physical size of a material or its component microstructure becomes smaller, its properties are generally changed. Enhanced mechanical, electrical, thermal and chemical properties have been measured in nanostructured materials, compared to similar materials whose compositions contain crystals or particles of larger dimensions. Researchers are now working to develop cost-effective methods to achieve these desired nanoscale structures;

(b) The production and characterization of novel materials that are needed for highly specialized applications. Industry roadmaps and other indicators have identified future needs in many high-growth areas such as biomedical devices, computer components and communications. New materials, or materials with improved performance and reliability, are being systematically developed to meet those requirements. In addition, novel molecules which have been serendipitously discovered are being intensely investigated to discover how their unusual properties can be exploited;

(c) The inspiration of biology that uses the molecular composition of a material to spontaneously build a desired microstructure. Processing materials into precisely controlled and often very small structures presents formidable obstacles to the high-volume, low-cost production of high-technology devices. Biological structures are built up by the assembly of molecules that contain the information that directs their assembly coded into the molecular structure. The concept of the spontaneous formation of microstructures that possess useful functionality is driving materials research, particularly in those areas that see applications in medicine and electronics.

59. These trends are evident in the following sections, which briefly describe several specific types of materials in terms of their current status and the research issues that affect them.

Nanostructured materials

60. These materials contain structures that generally range in size from 1 to 100 nanometres, and it is in this size regime in which some novel and useful properties have been observed. The physical, chemical and mechanical properties of nanostructured materials can be substantially different from those of bulk materials of similar composition. The key factors responsible for these variations from bulk behaviour are the size and size distribution of phases and structures, chemical composition of phases and the interactions between phases at the interfaces.

61. Nanocomposites, with nanometer-scale reinforcing elements within a continuous phase of metal, polymer or ceramic, are an important class of nanostructured materials. Ceramic-based nanocomposites are commercially available for specialty applications. Some polymers reinforced with clays that have been exfoliated to produce sheets with nanometer spacing have shown greatly increased mechanical properties and higher service temperatures with only a few per cent of the clay additive. If this behaviour can be understood and extended to common commodity polymers, such nanocomposites could compete effectively with higher-priced engineering plastics and find widespread application. The future of all nanostructured materials is ultimately linked to the development of commercially viable production methods for them.

Thin films and surfaces

62. The surface of a material has different properties from those of the bulk and as the size of the material decreases the importance of surface properties increases. Microstructures of surfaces and interfaces control the performance and

* This section was authored by Dr. Leslie E. Smith, Director, Materials Science and Engineering Laboratory, National Institute of Standards and Technology, Maryland, United States of America.

reliability of many advanced materials. The needs of advanced electronics and communications have created enormous interest in the production and modification of film surfaces with precisely controlled structures and compositions.

63. To prepare these materials, several process technologies have been extensively developed. Chemical vapour deposition (CVD), physical vapour deposition (PVD) and methods employing lasers, electron beams and ion beams have evolved into reliable techniques to form thin films. CVD is a high-temperature, thin-film deposition technique that is primarily used on silicon, ceramic or carbon substrates. PVD requires a lower operating temperature (<500°C) and therefore may be used to make coatings on ferrous materials.

64. High-pressure synthetic routes to the production of diamonds have been known for about 50 years. However, efficient and (in some cases) relatively low-energy processes for synthesizing diamond and diamond-like carbon (DLC) films have only recently been developed. The potential use of diamond and DLC films in electronic circuits, where their high thermal conductivity and electrical insulation make them unique, as well as in cutting and grinding tool surfaces has led to increased commercial interest and activity.

Amorphous carbon structures

65. Carbon has long been considered to exist in only two fundamental forms exemplified by diamond and graphite. The diamond structure is a three-dimensional crystal while the graphite form consists of stacks of two-dimensional sheets. In 1985, the startling discovery of a new class of all-carbon molecules formed in high temperature arcs stimulated an intense effort to exploit their unique properties. These compounds were called fullerenes because their curved shapes are similar to those forms used by the noted architect, Buckminster Fuller. The most symmetric form is C_{60}, which has the form of hollow spheres containing 60 carbon atoms. They have some rather unusual properties, including high solubility in solvents and unconventionally high vapour pressure for carbon-only compounds. New synthetic routes to these compounds have been discovered that make them available in quantities large enough for extensive investigation. Their unique cage structures have prompted scientists to use the hollow interior to contain a variety of atoms that can then be protected or delivered to other sites. These materials may find future use as catalysts, superconductors, hydrogen storage materials or photovoltaics. For example, C_{60} can be intercalated with three alkali metal atoms and the resulting superconductors possess superconducting transition temperatures second only to ceramic superconductor materials.

66. Nanotubes are giant fullerenes with tubular structures that consist of many concentric tubes. Unusual electrical, thermal and mechanical properties arise from their geometric form and high aspect ratios. Fullerenes and their derivatives have not been commercially exploited as yet, but exciting research results reported over the last four years suggest that important applications for these materials in products and devices will occur within the next decade.

Structural ceramics

67. Advanced structural ceramics (ASCs) are used in applications where high mechanical strength at high temperature, wear resistance, low density, corrosion resistance, hardness, stiffness and light weight are critical performance parameters. These properties make ACSs materials of choice for many energy, aerospace and defence-related applications. ASCs are currently used for wear-resistant parts (seals and valves), cutting tools, bearings and thermal barrier coatings. The largest market for advanced structural materials is in wear-resistant parts.

68. Over the next decade, ASCs will find increased use in such products as heat exchangers, heat engines and bioceramics. In the United States, demand for these and other applications is projected to reach $2 billion to $3 billion by the year 2000. This growth, however, depends upon the industry's ability to overcome major technical and economic barriers towards more widespread use of these components. They include improving performance and reliability of ASCs through better processing technology and reducing costs of ASC components so that they are more competitive with conventional materials.

Composite materials

69. During the 1980s, interest in composite materials escalated owing in large measure to the realization that drastic changes in the mechanical, electrical, optical and chemical properties of these materials could be achieved if they were nanocrystalline. Composite materials are produced from the integration of a structurally reinforcing material into a second substance or matrix. The behaviour and properties of composites are determined by the form and structural arrangement of the components, their composition and any interactions between the components.

70. Research on ceramic matrix composites (CMCs), metal/intermetallic matrix composites (MMCs) and polymer matrix composites (PMCs) is being actively pursued. Ceramic matrix composites are classified either as discontinuously reinforced or continuously reinforced. Continuously reinforced CMCs, or those consisting of an array of ceramic

fibres embedded in a ceramic matrix, are currently in the pre-commercialization stage for applications where high temperatures and high stresses (e.g., high- pressure heat exchangers, gas turbine combustors and gas turbine nozzles and seals) occur. Discontinuously reinforced CMCs, which consist of a matrix phase to which a reinforcing phase is added, are in the early stages of commercialization. Current applications include cutting tools, wear parts, canning dies, extrusion dies, armour and radomes. The current United States market for CMCs is estimated to be more than $200 million, with most of the market falling in the discontinuous category.

71. Polymer matrix composite technology is currently more mature than CMC technology. These materials have been commercially exploited by many industries, including medical devices, offshore oil, transportation, construction and marine activities. More widespread use of PMCs will require better capability to predict long-term performance and more cost-effective fabrication methods.

72. Metal matrix composites are engineered materials that contain one or more internally reinforcing phases which have been introduced into the metal or intermetallic matrix during processing. MMCs have been shown to possess the following advantages over unreinforced metal alloys: lighter weight, greater resistance to wear and impact, lower coefficient of thermal expansion and greater strength and stiffness. These materials are very expensive to produce and, as such, are used in niche markets (e.g., missiles, spacecraft components and select aircraft). Future applications of composite and intermetallic MMCs will be in airframe and skin parts, and advanced turbine engines for future generations of military aircraft as well as in national space planes. Reduced volume costs may lead to a great demand for these materials, especially for automobiles in the next two or three years.

Magnetic thin films

73. Over the last decade, magnetic thin films have replaced metal oxide particles as the source of magnetic flux in rigid-disk magnetic storage media. These precisely structured multilayer films exhibit giant and colossal magnetoresistance (GMR, CMR), a large change in the electrical conductivity when the direction of magnetism is reversed. The general phenomenon is understood, but the many factors that govern the response of practical systems are still under intense investigation. Current technology for controlling the microstructures of these materials has led to film disks capable of 500 Mb/in.^{2} and are expected to grow to 10 Gb/in.^{2} within the next decade.

Smart materials

74. Smart materials are those materials that are capable of "sensing" external stimuli (e.g., heat, pressure, electrical potential, light, etc.) and responding in highly specific and desirable ways. Smart material types include piezoelectric polymers, conductive polymers, piezoelectric and electrostrictive ceramics, electrorheological fluids, magnetorheological fluids, electrochromic coatings, magnetostrictive materials, micromachined integrated devices, and biomimetic polymers and gels, shape memory alloys and polymers. These materials are in various stages of research and development or commercialization.

75. Piezoelectrics, electromechanical materials that respond to the applied electric current by changing dimensions, occupy the largest share of the smart material market. Applications primarily in consumer products such as timing devices, video camera autofocus units and computer hard disk head positioners have helped piezoelectrics grow to almost a $1 billion industry.

76. Chromogenic materials change colour in response to external stimuli. Most of the current research effort involves electrochromic (electrical potential), thermochromic (heat) and photochromic (light) materials. Chromogenic coatings for automotive and architectural glass may offer the largest potential for economic growth of smart materials. However, the largest near-term market growth will involve micromachined integrated silicon sensor devices. Smart security systems, smart noise and vibrational control and smart structures using fibre-optic sensors are other markets where smart materials will find significant future growth. Military and defence markets for smart materials are diminishing, and dual-use applications will become increasingly important in the future.

77. Biomimetic materials react to chemical and electric stimuli by changing size or chemical diffusivity. They act as excellent imitators of biological systems. Although biomimetic polymers and gels are currently at the research and development stage, future use as biosensors and neural prostheses is possible.

78. Shape memory alloys and polymers can return to their original shape upon being heated to a higher temperature after being shaped under thermomechanical conditions. Shape memory alloys are commercially used in orthodontic arch wires, eyeglass frames and coil spring thermal actuators. Shape memory polymers are commercially available in a number of convenient physical states, including pellets, solutions and liquids. Their properties are used in medical, industrial and consumer applications that include catheters and custom moulded protective gear.

79. Conductive polymers can change colour and conductivity in response to chemical and electronic stimuli. They are commercially used in secondary batteries and coatings for shielding against radio-frequency and electromagnetic interference.

Electronic materials

80. Active electronic devices based upon polymeric materials now appear to have some, and perhaps considerable, commercial potential. Polymeric light emitting diodes (LEDs) have already achieved performance figures comparable to inorganic LEDs. The polymeric materials can be deposited on lightweight flexible substrates, giving designers considerable freedom with new devices. The particular colour emitted by the material is determined by a dopant molecule so that different colours can come from the same base polymer. Polymeric transistors have been developed that can be used in rather simple integrated circuits. While such devices will not soon, if ever, rival silicon-based devices in speed or density they do have the advantage of being somewhat flexible if fabricated on a flexible substrate. A variety of other electro-optic components such as waveguides, switches and modulators have been demonstrated and some may well find their way into small, inexpensive components of fibre-optic communication and computing systems.

81. The technical challenges remaining for these materials lie in extending their service lifetimes and in developing the processing methods needed to produce large numbers of devices at low cost. Useful lifetimes have already shown considerable improvement as the manufacturing technologies have been improved.

Supramolecular assemblies

82. Both natural and synthetic polymers can be designed to form large assemblies of molecules with useful properties. The most widely studied of such assemblies are self-assembled monolayers where molecules with the right structure spontaneously line up to form uniform, closely-packed layers on an appropriate substrate. Because these layers form spontaneously, devices containing these materials could be manufactured inexpensively and in large quantities. They may also be able to self-heal damaged layers by assembling additional molecules in the right locations to repair defects. These layers can carry a wide variety of functional groups on their surfaces in order to carry out specific tasks. For example, they can carry a specific binding site for a target chemical and serve as a sensor. They can carry a site that mimics a physiological factor in order to produce a desired response in the body. Such surfaces may find use as scaffold materials for the development of replacement tissue. Self-assembled monolayers have been proposed as micro patterns for electronic circuits by using their wetting characteristics to protect the silicon surface as an alternative to conventional photolithography. More intricate three-dimensional assemblies have been produced through complex synthetic routes. As the principles that govern the assembly of such molecules become better understood, they will be capable of correspondingly more complex functions.

Implications of technology trends

83. The social, economic and political implications of these materials technology trends are determined by the applications that they enable. The applications that are easiest to forecast are in electronics and communications where device development and market trends are well established and show no signs of abating. Computing power for a given price continues to grow at the same rapid pace as in the past decade. Wireless communication is widespread and very rapidly growing, with portable computers and telephones becoming ever smaller and lighter weight. This puts information in the hands of many more people worldwide than ever before and certainly changes the ways individuals view themselves and the ways Governments control and lead their citizens. Advances in smart materials and sensors based on them will lead to highly specific detection systems that can protect against chemical or biological threats, whether natural or man-made. The potential advances in medicine based on advanced materials are expected to be truly revolutionary. The growth of living cells on an artificial scaffold to produce new cells, tissues or even whole organs seems not only possible but perhaps close to realization.

84. The greatest impetus in materials technology continues to be the need to develop and process materials with predictable performance and reliability characteristics. The size and composition of materials microstructures are critical to their performance in end products and devices and materials are now being assembled at atomic and molecular levels by controlled processing technologies. Advanced materials continue to penetrate the marketplace, usually beginning in niche markets where performance is more important than cost. More widespread commercialization of advanced or molecularly tailored materials will depend upon our ability to develop reliable processing technologies that can compete in cost with conventional materials.

D. Information technology*

85. The speed, size and price of processors and data switches has continued to reduce exponentially or at the least. Revolutionary developments have occurred in the distribution of information in digital form, brought about by improvements in communications infrastructure, the development of exchange protocols and machine-independent software. The storage, processing and application of non-alphanumeric digital information has significantly advanced, and our ability to sense the environment, through smaller and more integrated devices, has been matched by developments in robot effectors. However, the complexity of developing large systems remains a hurdle in the move to global information networks.

86. In addressing the changes since the 1990 report, the present section begins with the earlier assessment that since information technology provides the tools and techniques for managing and applying information, it is potentially concerned with all societal and military activities, from the feedback of low-level control information in machinery operation to the support of high-level strategic or philosophic argument.

87. Like all technologies, the impact of information technology can only be described in terms of its application. The impact of application is in turn dependent on the combination of information technology with other technologies into devices or systems, on the procedures invoked in developing and using these devices or systems and on the human and organizational reaction to the resulting applications. The pervasiveness of information technology continues to increase in each of the major indicators: spread of application; range of goods and products to which it contributes; speed of adoption; and support by investors.[26] The huge expansion of the global digital information resource base in the last decade, reflected in the currency of the term "information age", has generated an economic and military dependence on information systems.[27] The duality between information technology competitive advantage and strategic vulnerability thus raises new security issues for the coming century.

Advances in processing and communication technologies

88. At the heart of information technology expansion is the electronic processor unit. Its exponential rate of miniaturization has been maintained, bringing commensurate rates of reduction in processing times, costs, sizes and weights.[28] The performance improvement is expected to continue, with increased integration of functionality on the same chip.

89. However, the key developments in information technology in the last eight years have been the networking of computer systems and the technologies associated with the Internet. Innovation in the computing, electronics and media industries coupled with agreement on standards to support interoperability have contributed to the revolutionary adoption of the Internet. Many statistics on the spread of the Internet have been published. According to some estimates,[29] 122 million users were expected by mid-1998, of which almost 60 per cent are in North America. Currently, only 0.75 per cent are in Africa.

90. The penetration of the Internet will continue to depend upon the extension of the underlying communication infrastructure. In the developed nations, high-bandwidth optical fibre is replacing existing copper networks, with integrated optics technology promising to overcome communication switching problems. Capacities of megabits per second are becoming available for home services.

91. The spread of the Internet in nations with poorer land line infrastructure will rely on decreasing costs and greater capacity of satellite-based communication. This will be achieved through the introduction of more powerful transmitters, improved digital compression, decreased launch costs and cheaper ground stations. Another potential development is wireless communication services based on high-altitude aeronautical platforms, which would allow rapid deployment of high-bandwidth communication services.

92. The particular success of the World Wide Web as an Internet technology is attributable to the fact it has harnessed innovation in interactive digital multimedia. The Web has radically improved the flexibility with which information can be exchanged compared with previous distance modes of communication, information-sharing and entertainment – e.g. the telephone, books and television. The potential to share scarce educational and skill resources, through the supervised conduct of specialist tasks such as surgery, through distance education and the like, is only starting to be exploited. Given wide access to the Web, there is real potential to redress the imbalance between the information "haves" and "have-nots", both intranationally and internationally.

93. This will be assisted by compression technologies, which allow more efficient use of existing communication

* This section was authored by Professor Janet Aisbett, Head of the School of Management and the School of Information Technology, The University of Newcastle, Newcastle, Australia.

bandwidth and digital storage capacity. These will be propelled by forward-looking standards bodies such as the Moving Pictures Expert Group.[30] Efficient compression is achieved through so-called "intelligent" methods which partially interpret the raw data, and so transform not only communications and storage infrastructure requirements, but also the ability to automatically interpret compressed information for improved retrieval and filtering.

Multimedia technology

94. There will continue to be an increase in the proportion of information technology research efforts directed at information-related issues as opposed to technology-related issues (processors, compilers, etc.), although this is difficult to measure accurately owing to the range of research activities involved. Interactive digital multimedia technology draws together information processing and presentation mechanisms that were previously developed separately, e.g., those concerned with image, audio, text or spatial data. Thus, training for dangerous or expensive civilian and military tasks has been assisted by information technologies such as electronic classrooms, virtual reality and simulators. The educational potential of related technologies is only starting to be exploited.

95. The way that humans use such information is becoming better understood through research in the cognitive sciences. Improvements will be achieved in the ability to automatically retrieve information relative to a person's task, regardless of whether the information is contained in an image, a text file, etc. Filtering of information to prevent "information overload" will also steadily become more effective as a result of intense research efforts. An improved ability to locate and filter information has security implications both for its application to authorized monitoring and to espionage.

Trends in sensing and robotics

96. Advances in information technology have enabled an escalation in both commercial and military intelligence and surveillance information-gathering. Already, there is a 24-hour collection of intelligence from across the planet, assisted by Internet connectivity and improvements in positioning, sensing and monitoring devices. These devices have benefited from a combination of innovations in active and passive sensor technologies, in the processing infrastructure and in sophisticated processing algorithms that rely on complex models of the environment and the sensor.

97. Miniaturization, coupled with developments in sensor technologies, will continue to reduce the cost and size of sensors, just as it has with processors. Coordinated networks of small smart sensors offer enhanced low-cost capabilities for intelligence gathering, surveillance and reconnaissance. As well, improved computing resources and better sensor and environmental modelling will continue to increase the usefulness of fused data – for example, electro-optic, infrared, acoustic and seismic data collected by unattended ground sensors, or infra-red and radar data in aerial surveillance systems. Such data can be processed on-site, compressed, transmitted, analysed and eventually stored in data warehouses to enable low-cost monitoring and tracking for civilian, military and peacekeeping purposes including weapons tracking and disposal monitoring.

98. Evolutionary enhancements in transport technologies occurring alongside the miniaturization of sensors has fostered the development of smaller, more autonomous, more mobile monitoring units. The trend will lead to cheap sub-centimetre "micro robots" which can team to perform complex tasks. With intelligent control and communications, smarter sensing devices allow the development of more capable unmanned autonomous vehicles, which are only starting to play the significant military and commercial roles that have been forecast for several decades. The potential exists for relatively cheap drones or autonomous vehicles, marketed for tasks such as monitoring traffic accidents, to be redeployed for military or terrorist use. Generally, the increased capability of autonomous vehicles opens up the potential for acts of warfare to be conducted by nations without the constraint of their people's response to loss of human life. A related concern is the accessibility to such technology as costs decline.

99. Increase in the effectiveness of human performance in a range of areas is being achieved through the development of personal digital assistants. So-called "information apparel", that is, the wearing of information sensing, processing and distribution devices within clothing, or as clothing, will soon move out of niche areas such as medical or military monitoring. More generally, information appliances, dedicated to performing specific tasks such as monitoring vehicle engines or traffic flows, will become more widespread as a result of increased affordability and robustness with new-generation "systems-on-a-chip" and supporting sensors such as the differential GPS.[31] The convergence of sensing, processing and actuation technologies is being applied to the development of autonomous weapons and weapons systems.

Information warfare and illicit use of information

100. The difficulty and relatively poor pay-off for being at the leading edge of weapons development will continue to cause poorer nations rely on relatively cheap and crude weapons, as will terrorists (who will also possibly rely on the hire of high-technology mercenary forces). For similar reasons of cost, the political advantages of destabilizing, as opposed to controlling and employing sophisticated weapons, may prove an attractive option to poorer nations and terrorist groups.

101. Destabilization in an information age is arguably made easy because the possible impact of information warfare is underestimated in the civilian sector, despite the prominence given information attack in the media, and through the Internet, for example.[32] The protection that will be afforded from new-generation encryption devices and protocols will not stop either the very sophisticated aggressor or the very crude physical aggressor. There is real potential for low-budget terrorist groups and smaller States to shut down vital services. Yet on the other hand, improved cryptographic methods that have resulted from commercial exigencies will make it easier to monitor weapons dealers, criminals and terrorists.

102. In the military sector, the benefits of system connectivity and interoperability have led to the recognition that security risk management strategies must be adopted in preference to risk avoidance strategies. This is particularly true of C3I systems. While the countries of the North Atlantic Treaty Organization (NATO) or similar countries such systems are generally still very secure, information warfare has attracted substantial funding in these nations and has given rise to a burgeoning vocabulary of cyber-terms: cyber operations, cyber attacks, cybermunitions, etc. Information warfare is like terrorism, in that it is hard to identify attackers against which to counterstrike. Low-level attacks from small players are regularly experienced in military as well as civilian systems.

103. In line with its impact on legal communication trends, information technology has strengthened international criminal networks, allowing minority groups, including pornographers, to exchange information for training and other illegal purposes. The means to commit offences has changed, with electronic fund counterfeits, industrial espionage and other telecommunications fraud operating on a global scale.[33]

Development trends in information technology

104. In the context of information technology development, the trend from reliance on military to civilian research and development will continue, with close working relationships among industry, university and government partners. This is being matched by integrated production of military equipment at commercial facilities and the use of commercial components in military systems. Off-the-shelf solutions will always cost less than custom-built software systems, and with miniaturization, off the shelf equipment is becoming more rugged.

105. There has been a widespread increase in the number of small, specialist, information technology developers and producers. This is partly as a result of the reduced cost of entry into high-technology industries, made possible by the general declines in prices of components and of development tools such as Computer-Aided Software Engineering (CASE). This trend may lead to difficulty in monitoring the production of medium-technology devices that have significant military capability.

106. There has also been a strong move by information technology vendors and developers to open systems architectures in both the civilian and military sectors.[34] This has resulted in radically changed architectures for weapons and sensor systems which offer the potential for modular enhancement over time. Nevertheless, the continuing difficulty of containing cost and time blowouts in the implementation and maintenance of major software systems, such as those involved in C3I, will continue to contrast starkly with the decreasing cost and increasing sophistication of the components used in information devices. This is a consequence of the ever increasing complexity of requirements, of demands for integration or seamless connectivity and of the failure of the information systems research community to be proactive.[35]

107. Large system development has been a major problem for both military and civilian sectors, in response to which there has been a recent trend towards centralized systems development and operation. Vendors of integrated solutions have gained tremendous power in the civilian market on a global basis, notably with Microsoft and SAP AG taking hold of different market segments and also forming alliances. The power of these corporations is challenging traditional State powers. The current trend towards huge companies dominating production of software in some sectors is being mirrored in the rise of the large multinational information system support houses. This rise can again be attributed to the failure of conventional (in-house) providers of through-life support for information systems. However, the trend to centralization is likely to reverse within the next decade as smarter ways to cross information system and subsystem boundaries, through mediation and translation, are developed.

The future

108. We are in an era of global interconnectivity, in which national boundaries cannot realistically be defended against the passage of information. The borderless dissemination of information on the Internet will have both a stabilizing and a destabilizing influence, with complex cultural, political, legal and commercial implications. Counterbalancing adverse propaganda or information applications of the Web are a range of stabilizing applications, from crisis management to awareness-raising of such issues as biological weaponry. The barriers of language and time, as well as distance, are significantly reduced in the world of the Web. The global academic community was one of the first beneficiaries of the Internet; now at least some of the schoolchildren in almost every part of the world can communicate directly with their peers.

109. The commercial application of information technology has shifted the balance between corporate and State power. A growing number of firms have annual production exceeding gross national products. Developed nations court such companies. Information technology companies in particular can move freely between suitors offering inducements to attract information technology fabrication factories and software houses.

110. Developments in information technology have changed the nature of financial services and stock markets, providing the means to electronically amass global information, monitor prices and execute in many financial instruments. The nature of global retail markets is being transformed through consumer-level electronic funds transfers and on-line delivery of some services. There is more competition for Government-backed money.

111. In the face of such changes, traditional nationally focused legislation for trade practices, and consumer protection and the like must continually be revised.[36] Nations will be forced to adjust and agree upon the basis on which they raise taxes on transnational products, services and transactions, and enforcement of national regulation in many spheres will become more difficult, or impossible.

112. However, the commercial rationale of cultural or national specificity in information may prove a more compelling argument than regulation. Cultural, religious and racial diversity has proved resistant to technology in the past. With the potential to nurture such differences while eliminating misunderstandings caused by them, the information age offers the greatest hope we have yet had for generating a common vision for peace.

E. Biotechnology[*]

113. Since 1990, when the report of the Secretary-General on “Scientific and technological developments and their impact on international security” was published, the level of public concern worldwide about the proliferation of biological weapons and their possible use by aggressive national leaders and terrorists has risen substantially. This development has occurred for three main reasons: (a) the actions of the Aum Shinrikyo terrorist group in Japan; (b) revelations about the former Soviet Union’s large and sophisticated biological warfare (BW) programme; and (c) the discoveries of the United Nations Special Commission (UNSCOM) concerning Iraq’s BW capabilities. Understandably, many farfetched stories also have appeared in magazines and newspapers about the threat of biological weapons, as well as about biotechnological techniques being applied by unscrupulous scientists for the purpose of creating ever more menacing bacterial and viral pathogens to arm these weapons. In fact, the threat of molecular biology procedures being applied for military or nefarious purposes remains, for now, largely theoretical.

114. What is not theoretical is that molecular biology research has led to the development of many sophisticated techniques that are being used in basic and applied research, development of new products and processes, the industrial production of pharmaceuticals and specialty chemicals, and many other applications. Of relevance to the present report, molecular biology has provided public health officials with powerful methods for detecting pathogens and toxins in the environment and in manmade structures; diagnosing and treating infected persons, animals and plants; and monitoring the movement of pathogens during epidemics and pandemics. As discussed below, these techniques, which have largely been developed in the course of peacefully directed pursuits, are also available to those involved in biodefence and international arms control.[37]

115. Trends in biotechnology were described and discussed in the 1990 report. During the intervening eight years, however, substantial new developments have been achieved in that field, necessitating an updating of the original report; this is provided below. Accordingly, the present section consists of four parts. The first offers a brief background on pertinent arms control activities. The second reviews the more important of the new biotechniques. The third discusses the

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[*] This section was authored by Raymond A. Zilinskas, Associate Professor, Center for Public Issues in Biotechnology, University of Maryland Biotechnology Institute, Maryland, United States of America.

applicability of new biotechniques to biodefence and arms control issues. The fourth considers likely future developments.

Background of pertinent international arms control activities

116. UNSCOM inspectors working in Iraq have employed a wide variety of biological, chemical and physical techniques in their work to uncover details about Iraq's weapons of mass destruction.[38] One example is particularly pertinent in the context of the present report. Before Iraq's main BW production plants at Al Hakam and Al Manal were destroyed,[39] UNSCOM teams collected 350 samples from equipment, floors, sewage systems and the environment surrounding the facilities. These samples were analysed at reference laboratories in three nations, including the United States Naval Medical Research Institute (NMRI) in Bethesda, Maryland. NMRI scientists used an array of advanced methods (described in more detail below), including immunoassay and polymerase chain reaction (PCR), to detect two BW agents, botulinum toxin and the pathogen *Bacillus anthracis*, in 15 samples. One positive test result proved important because it revealed that the Iraqis had been producing a particular BW agent in a facility where they claimed no such production had ever taken place.

117. UNSCOM is the first international arms control agency that has worked in the field to detect biological and chemical agents of compliance concern. It is not unreasonable to assume that its experience will prove valuable to those charged in the future with enforcing compliance regimes established by international arms control agreements. In the first instance, this experience will benefit the Organization for the Prohibition of Chemical Warfare, which oversees the 1997 Chemical Weapons Convention.[40] The UNSCOM experience will also benefit the inspectors who will staff the compliance regime now being negotiated for the 1972 Biological and Toxin Weapons Convention.[41]

Survey of advanced biotechnology techniques

118. A score of innovative techniques were developed during 1980s and 1990s for use in research, development, testing and production. However, consideration here is limited to those techniques not previously described in the 1990 Secretary-General's report that appear to hold particular promise for biodefence and arms control. There are three sets of such techniques: biosensors, nucleic acid analysis and mass spectrometry analysis.

Biosensors

119. In general, measurements are performed through the use of sensors. In classical bioprocessing, sensors typically are analytical instruments ranging in complexity from temperature gauges and pH metres to radio-immunoassay and gas chromatography. However, here the focus is on one special type of sensor, the biosensor.

120. All biosensors have two components: an immobilized biological material, such as an enzyme, an antibody, or a whole cell, which is joined to a transducer or signal-generating element. When the immobilized biological material attaches to, or reacts with, an analyte, the fact of that event is transmitted to the transducer. The function of this device is to convert the information received from the biological material into a signal (e.g., electric current, heat or light). Data-processing equipment gauges the reaction by quantifying the signal and providing results to the operator within seconds or minutes, depending on the nature of the data received.

121. Two specific types of biosensors are worthy of description. The first is the electrochemical biosensor. In this configuration the sensing molecules, most often enzymes, are immobilized on the tip of the probe or held in place by a membrane. The sensing molecules react with the substances whose presence is being tested, generating an electric signal proportional to the concentrations detected. Depending on the sensing molecules, the sensor can be designed to react to a range of reactants, from a specific chemical to entire classes of compounds.

122. The second is the immunological sensor. It consists of two elements: an antibody and the molecular recognition element. The antibody has the ability to bind selectively to antigens, which can theoretically be any one of a great variety of substances, including biomolecules, drugs, bacteria, viruses and cellular material. The observed signal reflects the antibody-antigen interaction in a quantitative way.

123. For completeness, three additional types of biosensors may be described briefly. Although these do not appear to have immediate application to biosecurity and arms control, this could change in the future. The first is the optical sensor, which reacts to the behaviour of light passing through the test solution, recording such phenomena as the absorption or fluorescence of light, light scattering or spectrophotometry. By using different wavelengths, multiple analytes may be detected. Optical biosensors are particularly useful in the clinical laboratory. The second type is the piezoelectric biosensor. In this device, sensing molecules respond to the analyte by mechanical vibrations that, in turn, can be translated into electric signals proportional to the amount of analyte. The third type is the chemoreceptor. This biosensor

actually is a biomolecular assembly involved in physiological functions, such as smell and taste, and in metabolic and neural biochemical pathways. Biosensors using intact chemoreceptor structures from natural sources, such as crustaceans and fish, have demonstrated quantitative responses to amino acids, hormones, nucleotides, drugs and toxins.

124. The major advantage of biosensors over conventional sensors is that they yield results more quickly, can be more sensitive and are more selective. For example, in industrial bioprocess control, biosensors allow technicians and engineers to monitor complex reactions in real time and, when needed, to adjust reaction rates to achieve maximum production. In the environment, biosensors may be deployed to detect the presence of pollutants in air, soil and water and to track their spread from source points, including factories, agricultural combines, waste disposal plants, etc. As the technology advances, inexpensive biosensors will be developed, possibly to the point where they will be disposable after a single use.

125. There are also disadvantages and costs in the use of biosensors. At this stage of their development, it is necessary for highly trained technicians to employ biosensors, especially in the field. Biosensors may easily be "poisoned"; i.e., some chemicals encountered in the environment may damage or destroy the sensing element. Some types of biosensors, which can be expensive, cannot be used repeatedly; i.e., once the sensing element detects a target substance, a one-way chemical reaction takes place, and the spent sensing element must be replaced.

Nucleic acid analysis

126. Every life form possesses sequences in its genetic makeup that are specific to that organism; in theory, therefore, the origin of any genetic sequence can be determined. For example, if UNSCOM inspectors collect samples from fermenters and dryers that contain genetic material, properly performed analysis could in principle identify the source organism.

127. In practice, however, difficulties often arise. Two problems in particular are commonly encountered. First, the amount of genetic material found in a sample might be minute. Since standard methods employed by reference laboratories usually require quantities of the analyte in excess of milligrams or, in some cases, grams, smaller amounts cannot be analysed conclusively. Secondly, the great majority of micro-organisms occurring in nature have not been identified and classified. Even the smallest soil sample contains billions of micro-organisms, of which microbiologists will have characterized less than 5 per cent. Consequently, most genetic material found in environmental and other samples will be unknown, and analysts will have difficulty determining its origin.

128. Three advanced biotechnology techniques may be used to overcome difficulties associated with sample analysis, especially of environmental samples: polymerase chain reaction (PCR) amplification, restriction fragment length polymorphism (RFLP) analysis, and ribotyping analysis.

129. In brief, PCR is a method for amplifying genetic material found in a sample; i.e., a single copy of a DNA sequence can be copied millions of times. A variety of PCR techniques have been developed,[42] but they all work according to the same principle. The analyst begins the PCR reaction by adding to the sample a pair of short synthetic DNA sequences, called primers, that bind to known sequences on either side of the DNA that is to be amplified. During the reaction that follows, a copy of the sequence of interest forms. The reaction is repeated until the number of DNA copies is sufficient for analysis by standard techniques. Typically, the amplified products are separated by electrophoresis, the separated products are sequenced and the resultant sequences are compared to known sequences stored in a data bank.

130. While only DNA can be subjected to PCR analysis, RNA in RNA virus genomes can also be amplified if a modification to the technique is made. If an analyst believes that RNA might be present in a sample, the first step is to treat it with the enzyme reverse transcriptase, which produces a DNA copy of the RNA. This DNA copy can now be amplified using PCR.

131. In RFLP analysis, certain enzymes that cleave DNA sequences are added to the sample, and the resulting reaction mixture undergoes electrophoresis in order to separate fragments of different sizes. The pattern of fragments, which is unique for each type of organism, commonly is termed as the analyte's "fingerprint" or, more accurately, genetic fingerprint or profile. The pattern produced by the analyte is then compared with known patterns stored in a database. RFLP is useful for quick analysis when the analyst has a fairly good idea of what agents might be in a sample.

132. A variation of RFLP analysis is ribotyping. Ribotyping begins when the analyst lyses (dissolves) cells in the sample, then cuts the DNA released by dissolved cells into fragments with a restriction enzyme. The analyst then uses gel electrophoresis to separate the fragments by molecular weight. Next, the fragments are hybridized with a DNA probe and a chemiluminescent agent is added. A digital camera photographs luminous images of the fragments, and images

are then processed through a series of algorithms adjusted against markers of known molecular weights.

133. A prototype instrument that employs ribotyping is already on the market. The so-called RiboPrinter, developed by Quaicon in Wilmington, Delaware, United States, is used in agriculture to detect and identify bacterial pathogens that attack animals. The system's computer has software that enables it to rapidly compare the patterns of unknown organisms with patterns of known organisms stored in the database. If a complementary pattern is found, identification is accomplished. The results are automatically printed out and stored in the database for future reference. For most types of bacteria, the analysis can be completed in eight hours.[43]

134. Nucleic acid analysis techniques are sensitive and specific; i.e., very small quantities of DNA in environmental or clinical specimens can be identified with a high degree of precision. However, these methods are difficult to perform and tests must be conducted carefully. Therefore, they require the services of highly trained technicians or scientists. In addition, pure, expensive biochemical reagents must be used for the reactions to take place and sophisticated equipment is needed for analysis. For these reasons, these techniques can presently be applied in the laboratory context only. Only several years from now will nucleic acid analysis be able to be performed routinely in the field using portable equipment. Further, although the number of DNA sequences recorded in databases is rapidly rising, many more still need to be characterized before extensive detection and identification of micro-organisms can be carried out in the environment.

Mass spectrometry

135. Mass spectrometry (MS) is a well-established, classical technique employed by chemists and physicists to characterize small molecules. MS analysis begins with the operator physically fragmenting the analyte into electrically charged ions, each of which has a characteristic mass. Ions in a gas phase are injected into the instrument and the distance they move in an electric field is measured (alternatively, the time it takes for an ion to move a specific distance is measured). The distance over which an ion moves, or the amount of time it takes to move a distance, is proportional to its mass. The MS signature of the specimen consists of the pattern of distribution of its constituent ions, which can be compared to known signatures of substances determined experimentally. Computers may be used to facilitate comparison between the signature of the unknown substance with signatures stored in databases.[44]

136. Traditionally, MS equipment is large, bulky and energy inefficient. However, the technology is evolving rapidly. Three improvements to MS are pertinent to the present report. First, methods have been developed in the last few years that enable MS analysis of large molecules, including proteins and DNA. Secondly, much work has been done to miniaturize MS equipment; portable devices have already been installed in Jeeps and taken into the field for on-the-spot analysis of samples. Third, computer programmes are being developed that greatly increase the ability of analysts to interpret data generated by MS analysis.

137. An example of a recently developed technique that makes it possible to subject large molecules to MS analysis is matrix-assisted laser desorption ionization (MALDI). Briefly, to perform MALDI the sample is deposited on a suitable organic material. Then energy in the form of a laser is directed at the deposited material, which causes it to separate into ions liberated (desorbed) from the matrix. These ions now can be injected into the instrument as described above.[45]

138. As with other substances, the proper identification of signatures produced by MS is vital. Since samples containing biological and/or toxin agents usually contain much extraneous organic material, there is a need to filter out whatever signatures they produce. Further, since the chemical composition of biological and toxin agents tends to be complex, their signatures also are complex. For these reasons there needs to be further research and development to generate computer programmes that filter out background noise and produce recognizable patterns from protein-containing samples undergoing MS analysis. This will also require a large database of signatures of known bacteria, viruses and toxins.

Conclusion

139. Those involved in biosecurity and arms control need to be prepared to adopt advanced biotechniques, even if these methods cannot be applied with ease today. Modern biotechnology is advancing rapidly; today's laboratory-based research techniques will become available for fieldwork in the not-too-distant future. These detection methods will enhance the ability of Governments to protect their populations from biological threats and improve the credibility and effectiveness of international BW arms control efforts.

140. In working to safeguard general populations against a BW threat, a high level of protection could be achieved if civil defence authorities were able to deploy sensors capable of detecting pathogens and toxins in real time. This capability should be coupled with public health preparedness, including, for example, the development of a communications network

and the stockpiling of therapeutic drugs and decontamination equipment. For military purposes, troops deployed in both front-line positions and rearguard staging areas would be better prepared to defend themselves against biological weapons if they were personally equipped with biosensors that would immediately sound an alarm if aerosolized pathogens or toxins were detected in the bearer's vicinity.

141. Unfortunately, existing biosensors are capable of detecting only a very small number of pathogens or toxins, and they do not work in real time. More generally, contingency plans for dealing with biological events are woefully lacking at all levels of government in most countries. It is not an exaggeration to state that most nations of the world are underprepared to meet biological threats, whether emanating from nature or from the laboratory.

142. Since prior detection cannot presently be achieved, the first indication that a biological event has occurred will be when a large number of ill persons suddenly present themselves at emergency hospitals or military aid posts. Civilian and/or military health providers would then face an immediate crisis for which they are largely unprepared, and casualties would be high. For example, if the agent used were *Bacillus anthracis*, the causative agent of anthrax, proper antibiotic treatment would have to be administered to exposed persons within a few hours of the first appearance of symptoms, otherwise the mortality rate would be over 60 per cent.[46] To properly treat those affected, health providers would need both a means for rapid identification of the disease agent and an adequate supply of relevant antibiotics.

143. Methods presently employed in clinical microbiology laboratories do not produce results quickly. The culturing and identification of bacteria takes at least 24 hours; more than three weeks might be needed to identify a virus, and six weeks, or more, for a toxin. Clearly there is a need in public health for technologies that can rapidly detect and identify pathogens and toxins.

144. New detection and identification technologies have been under development in the last few years and are close to realization. Two are particularly promising: enhanced MS analysis and array-based applications.

145. Although traditional MS methodology has several important drawbacks that restrict its usefulness as a field technique, the advances mentioned above may soon overcome these liabilities. Techniques have been developed that allow bacteria and toxins to be analysed by mass spectrometry; MS instrumentation and equipment are being miniaturized and made sufficiently rugged to withstand field conditions; and work is being done to subject known pathogens and toxins to MS analysis, record the signatures of those agents in databases and develop software for identifying signatures against a "noisy" background. These advancements are converging. Within five years mobile MS apparatus will be available that is specially equipped to analyse BW material and remotely connected to databases to enable instant comparison of signatures from agents collected in the field with known, stored signatures. Analysts will be able to prepare and analyse environmental or clinical samples in less than 30 minutes and make a definitive identification of the causative pathogen or toxin in less than one hour.

146. At present, public health officials and health care providers responding to a biological event will not know what agent or agents are causing the outbreak. As a result, the ability to identify a large number of pathogens and toxins at once in a single, rapid assay would be immensely helpful. One promising technique is to use an array of biosensors, such as antibodies, in micro formats such as microchips.[47] Scores of antibodies can be immobilized on the surface of microchips that can be immersed in the solution containing the analyte. The event of an antibody binding to an antigen generates a signal, which is visually conveyed to the operator. Since antibody-antigen reactions are highly specific, the event of binding will precisely identify the antigen. Although kits containing arrays already exist, problems pertaining to sample preparation still have to be overcome before they can be reliably used in the field. But this problem is likely to be overcome within five years.

147. Unlike acute situations such as a biological attack, where immediate detection and identification of the causative agent is of the highest priority, in an arms control situation the security of collected samples and the accuracy of their analysis are the most important considerations. The security of samples in transport and storage must be guaranteed, otherwise their value as evidence diminishes or disappears. Such is also the case with the accuracy of the analysis; if those who will adjudicate compliance cases cannot be assured that the analysis carried out on the samples was accurate and specific, the results from analysis will not be admitted as evidence.

148. One of the ways of addressing problems pertaining to samples is to test the samples where they are collected. This would help mitigate another concern: how to secure whatever proprietary information may be contained in collected samples as facilities are inspected. If inspectors for the Chemical Weapons Convention compliance regime, and in the future those working for the Biological Weapons Convention compliance regime as well, were to analyse samples *in situ*, this problem would be reduced. To conduct on-site testing, however, inspectors would have to provide all necessary equipment, reagents and supplies. What

materials and equipment will they need to perform appropriate tests on-site?

149. If we consider the UNSCOM experience, which includes the collection and analysis of many hundreds of specimens from facilities, we know that if there is suspicious material in a sample it is likely to be found in exceedingly small quantities. For this reason, it would be important for inspectors to be able to perform PCR to amplify minute DNA segments. Once amplification has been accomplished, the product could be analysed by standard immunoassay procedures. However, as discussed above, in a few years the arsenal of analytic techniques available to inspectors will be significantly enhanced as portable MS instruments prove their effectiveness. It is not farfetched to believe that by the time that the Biological Weapons Convention compliance regime is established, its inspectors will be able to use many of these techniques in the field.

150. To conclude, during the last decade, significant advances have been made by the international community in controlling the proliferation of nuclear weapons, including the continuation of the Nuclear Non-Proliferation Treaty and the development of the Comprehensive Nuclear-Test-Ban Treaty (which is not yet in force). If it is unable to acquire nuclear weapons, a nation or a terrorist group may have recourse to alternative weapons of mass destruction, especially chemical or biological weapons. However, the acquisition of chemical weapons also involves expensive and technically advanced processes (although less so than nuclear weapons) and entails the construction of specialized facilities that are relatively easily detected by national technical means. In addition, most of the precursors for production of chemical weapon agents are sufficiently uncommon so their import/export, especially in large quantities, can be detected and monitored by national intelligence services and the Technical Secretariat of the Organization to Prohibit Chemical Warfare, which operates under the Chemical Weapons Convention. Since aggressive leaders of nations and subnational groups are likely to find it difficult to acquire either nuclear or chemical weapons, some may seek to acquire biological weapons. As has been discussed and analysed in this section, the techniques of molecular biology can be useful tools in monitoring compliance with international regimes, detecting illicit BW development and in attempts to quickly determine the aetiology of disease outbreaks. With the rapid growth and development of biotechnology generally, molecular biology techniques are certain to gain an ever increasing role in attempts by Governments and international agencies to protect the world’s populations against disease and to deter the proliferation of biological weapons.

151. Of course, sophisticated molecular biology techniques have applications that extend far beyond arms control. Molecular biology research has generated findings that are being applied in both developed and developing nations for purposes related to improving production in agriculture and animal husbandry, enhancing industrial production with essentially pollution-free techniques, remediating polluted marine and terrestrial environments, developing new pharmaceuticals that would never have seen the light of day if only conventional chemical techniques were available, and for many other purposes. Thus, it is most important to keep in mind that techniques such as molecular cloning of genes, gene transfer, genetic manipulation of animal embryos and plant seed, embryo transfer, genetic manipulation of rumen micro-organisms, the construction of genetically engineered cells, such as monoclonal antibodies, for immunodiagnostics and immunoprophylactics, and the development of genetic probes are being used, and will be used at an ever increasing rate, in peacefully directed research, development and production to benefit all peoples of the world. With this observation in mind, it is most important for States parties to the Biological Weapons Convention to work towards activating article X, thereof, which enjoins those nations that have chosen to belong to the treaty to cooperate internationally in applied microbiology for peaceful purposes. Unfortunately, States parties have so far neglected to implement article X, probably because they are unwilling to provide the necessary funding. Perhaps this obstacle could be overcome if it was made clear that supporting article X collaborations in peacefully directed research would help prevent researchers who otherwise might be tempted to perform lucrative illegal weapons-directed research from doing so.

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