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SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENTS AND THEIR IMPACT ON INTERNATIONAL SECURITY

Report of the Secretary-General

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I. INTRODUCTION

1. On 7 December 1988, the General Assembly adopted resolution 43/77 A, entitled "Scientific and technological developments and their impact on international security". Paragraph 1 of the resolution reads as follows:

> "The General Assembly,
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> "1. Requests the Secretary-General to follow future scientific and technological developments, especially those which have potential military applications, and to evaluate their impact on international security, with the assistance of qualified consultant experts, as appropriate, and to submit a report to the General Assembly at its forty-fifth session."

2. To assist the Secretary-General in the implementation of paragraph 1 of resolution 43/77 A, a consultative meeting was held at United Rations Headquarters on 31 May 1999. It was attended by some of the original co-sponsors of resolution 43/77 A and a small number of scientists and strategic analysts. The meeting discussed the wider context of the current debate on the interactions between the issues of technology, strategy and international security, It was felt important to build upon and broaden the political consensus for addressing the qualitative aspects of the arms race. The meeting also served to identify the broad fields in which scientific and technological developments are taking place,

3. In his report to the forty-fourth session (A/44/467 and Add.1 and 2), the Secretary-General informed the General Assembly of his intention to invite qualified consultants to prepare individual assessments in their specific areas of expertise in five major fields of technology.

4. On 15 December 1989, the General Assembly adopted resolution 44/118 A, which took note of the preliminary work undertaken by the Secretary-General and requested him to report to the Assembly at its forty-fifth session,

5. Individual assessments of scientific and technological developments were prepared by invited experts in the fields of nuclear technology, space technology, materials technology, information technology and biotechnology.

6. From 16 to 19 April 1990, a high-level conference on "New trends in science and technology: implications for international peace and security" was held at Sendai, Japan, The conference was attended by scientists, strategic analysts, arms limitation/disarmament experts, politicians and diplomats from over 20 countries,

7. The conference at Sendai addressed issues of technological change and global security, new technologies and the search for security in the post-cold war era, and national policy-making and international diplomacy in an era of rapid technological change. General approaches to technology assessment and technology trends in selected areas were discussed in separate working groups. The individual

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assessments prepared by experts in five specific fields wero discussed by the working group on "Technology Trends in Selected Areas" under the chairmanship Of Sir Ronald Mason, former Scientific Adviser to the Ministry of Defence, United Kingdom of Great Britain and Northern Ireland, The outcome of those diocusaions is included below.

8. The present report is submittod to the General Assembly in pursuance Of resolutions 43/77 A *and* 44/118 A. In fulfilling his mandate, the Secretary-General, in his note verbale dated 8 February 1989, drew the attention of the Member States to paragraphs 2 and 3 of resolution 43/77 A. The replies received were included in the Secretary-General's report to the forty-fourth session of the General Assembly (A/44/487 and Add.1 and 2). In another note verbale, dated 16 February 1990, the Secretary-General drew the attention of the Member States to paragraphs 3 and 4 of resolution 44/118 A. Replies were received from the Byelorussian Soviet Socialist Republic, Italy (on behalf of the European Community), Mexico, Togo, the Ukrainian Soviet Socialist Republia and the Union of Soviet Socialist Republics. All the roplies havo boen takon into account in the preparation of the present report.

II. NEW TECHNOLOGIES AND INTERNATIONAL SECURITY: AN OVERVIEW

9. In recent years, concern has been exproased by some commentators that modern technology has developed a momentum of its own and that technological change is outpacing the political process of seeking security at lower levels of armaments and armed forces. In the light of political events in the past two years, there is now a supplementary concern that modern technology may not be responding in directions that support the consolidation of political developments. Thus, in some respects modern technological advancos may be hindering rather than helping the pursuit of international security.

10. The dramatic improvement in *East-West* relations has brought about a major change in the international security environment, With the implementation of the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Rango Missilos (INF) 1/ in 1987-1988, an entire class of nuclear-weapon systems is being eliminated. New opportunities have opened up for the roduction, elimination and destruction of nuclear, chemical and convontional weapons. In the political arona, with some exceptions, there is a dominant trend towards tho replacement of confrontation by dialogue and rivalry by co-operation, In addition, the world as a whole is facing an unprecedented array of non-military threats to international security, such as ecological degradation, environmental pollution and political tensions arising from the persistent economic gap between industrialiaod and developing countries.

11. In this changed international security environment, the concorns over the nature and direction of technological change are essentially twofold. First, thoro is an overriding anxiety that modern technology should assist rather than hinder the positive trends in international relations. More specifically, there are concerns that the application of now technologies might result in continued

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qualitative development of nuclear weapons even as efforts are being made for their reduction and elimination. The use of new technologies for the qualitative moderairation of conventional weapon systems could bring dramatic increases in their range, accuracy and lethality. Technological advances could also lead to the development of weapons based upon the application of advanced physical principles such as beam weapons.

12. A second and more philosophical concern is that significant aspects of modern technology do not address many of the pressing problems facing the world. while it is generally recognized that a diffusion of technologies would be instrumental in closing the economic gap *between* the industrialized and developing countries, there are also doubts whether the international community is well-postured to deal with some o the harmful side-effects of technological proliferation. Particularly pronounced in this respect are misgiving8 over the likely development and acquisition of nuclear, chemical and biological weapons by countries at present outside the existing agreements for arms limitation. Apprehensions over the possible misuse of a combination of several available technologies by a national or sub-national group have been heightened by the persistence of tensions and unresolved conflicts in certain parts of the world.

13. Technology by itself does not threaten anyone. Efforts to steer the direction of technological changes can *only* make progress if the realities of contemporary life are taken into account. The current state of technological advancement represents decades of cumulative knowledge that cannot be erased. It is also unrealistic to believe that the process of technological innovation can be froxen to prevent its military application, However, the very technologies capable of improving existing weapon systems can also often be used in their limitation, destruction or conversion. A few of the many area8 in which militarily capable technologies could actually promote rather than threaten international security are the use of communication technologies for advance warning of impending conflicts, the employment of remote-sensing techniques for verification and the development of appropriate techniques for ecologically safe methods of weapons disposal.

14, A number of new technologies are now in public view, which, if fully developed and deplcyed, could have implication8 for existing military capabilities. The following review of the major fields of scientific and technological development8 in this regard is necessarily brief and more illustrative than exhaustive. It provides a basic description of the nature of technologies involved and a broad survey of mejor trends with some illustrations of their possible civilian and military applications.

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III. TECHNOLOQY TRENDS IN SELECTED AREAS

A. Nuclear technology*

15. The term nuclear technology is broadly interpreted as "the utilization of various properties of atomic nuclei". After three to four decades of rapid growth, nuclear technology has matured and is now at a point where no new major breakthroughs seem likely in the near future. Current trends are largely extrapolations of past developments.

16. The two important sub-fields of nuclear technology *are* nuclear explosive devices and nuclear power production. Methods for disposal and production of "special nuclear materials" are also relevant, as are potential new military applications such as X-ray lasers and particle beams. Although it is very important *from* a strategic viewpoint, the development of delivery vehicles and weapons platforms is not scientifically related to nuclear technology.

Nuclear explosive devices

17. A nuclear warhead contains an explosive device, which derives its energy either from fission or from a *combination* of fission *and* fusion. Major steps in the development of fission explosive devices were taken even before the mid-19508 and no *significant* improvements *are* foreseen. The possibility to use uranium-233 as a weapons material was recognised long ago but does not seem to offer *any* substantial benefits.

18. It is not quite clear whether there is a technical upper limit to the fission yield. What is *known* is that there is no lower limit to, the explosive yield of *a* fission device. In the 1960s and again in the late 1970s, there was a concern that "mini-nukes" with very low yields might tend to blur the borderline between conventional and nuclear weapons. *For a* time the United States deployed a short-range missile named "Davy Crockett'*, carrying a warhead with a reported yield of 0.25 kt or less. The weapon was removed from active service in 1971 without replacement. No similar weapons have since been deployed either by the United States or other countries since the 1960s.

19. *Since* it *was* first demonstrated in 1951, the technique to exploit fusion in a *nuclear* explosive has been perfected at a rapid pace to build warheads with virtually unlimited yield; to derive energy from the fission of uranium-2381 and to improve further the yield-to-weight ratio of warheads. Substantial *efforts* have been made over the last 25 or 30 years to design a fusion weapon without a fission trigger, in particular, by means of a laser-induced fusion. For all practical purposes the problem remains unsolved.

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* Contributions to the present section were made by Dr. Tor Larsson, Co-ordinator for Nuclear Weapons Related Research, National Defense Research Establishment, Stockholm and Dr. John Hopkins, Associate Director-at-Large, Los Alamos National Laboratory, New Mexico, United States of *America.*

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20. There is supposedly no upper limit to the explosive yield of a thermonuclear device. However . the quest is no longer for larger yields. The general trend now is towards smaller and lighter nuclear warheads, The most important possibilities seem to lie in the "tailoring" of nuclear warheads to enhance or suppress different explosion ef fects. Examples are enhanced radiation weapons (ERW), which give a pulse with an expanded frequency range or a shaped radiation field, and earth-penetrating warheads to maximise ground shock against underground installations. None of these warhead modifications have yet been achieved,

21, In general, advances in developments of warheads will depend upon continued testing. Testing is also deemed necessary for a new nuclear-weapon State wanting to develop thermonuclear warheads or advanced fission devices. It is debatable whether stockpile maintenance is possible without testing, but most affect studies could be done by means of simulation,

Nuclear power production

22. Nuclear power has several applications, of which energy production for civilian needs is obviously the most important. Concerns regarding the relationship between nuclear power and weapons proliferation have not been allayed, but the actual development has by no means followed earlier worst-case scenarios. Light-water reactors, fuelled with low-enriched uranium, are still prevalent and will probably remain so throughout the 1990s. Projectiona of nuclear energy demands have been revised downwards repeatedly. Thus, to date, there has been no severe shortage of nuclear fuel, no large proliferation of enrichment or reprocessing facilities and no establishment of a “plutonium economy*‘.

23. In the public eye, environmental concerns play an important role. Those concern8 have to do both with the possibility of severe accidents, as the one at Chernobyl, and with radioactive waste management. Current development ef forte in reactor technology are to a large extent related to safety. An interesting issue is the capacity to fabricate and burn mixed oxide fuels (MOX). MOX technology is essential for the destruction of fissile materials, should an agreement to that effect be negotiated. This capacity is increasing slowly.

Methods for the production of nuclear materials

24. Methods for uranium enrichment and for the production of other nuclear materials, mainly plutonium and tritium, have always been closely watched because of weapons proliferation concerns. The development of uranium enrichment techniques has not been dramatic, owing in part to the slower than expected growth of demand for nuclear power. Lasers could produce weapons-grade (highly enriched) uranium and it would also be technically possible to make reactor-grade plutonium more suitable for weapons purposes by removing some of the plutonium-240 by means of lasers. None the less, laser enrichment is still a maturing technology. The degree of advancement attained in the field of laser-isotope separation remains to be assessed. Estimates by the International Atomic Energy Agency (IAEA) suggest that lasers could provide about a quarter of the total separative work needed for reactor fuels in the early 2000s. The breeding of nuclear materials by means of accelerators has long been recognised as a theoretical possibility. This bears on proliferation problems, as accelerators are not internationally monitored like reactors.

Miscellaneous applications

25. A number of other applications of nuclear energy, nuclear particles or nuclear radiation are of interest in a disarmament and security context. One that does not seem particularly realistic is the use of radioactive substances au weapons. As ionizing radiation never kills instantly, even at very high intensities, radiological weapons (RWs) are not practical for battlefield use. The residual contamination in the area of their use would prohibit normal human activity there for many years.

26, As RWs are both militarily and ecologically quite unattractive, negotiations to prohibit them started about 20 years ago and were expected to lead to a rapid conclusion of an agreement. The proposal that such an agreement should also prohibit attacks on nuclear power plants, however, brought the negotiation8 to a standotill. This situation still prevails, although attacks on nuclear power plants are now banned in article 56 of the First Additional Protocol to the 1949 Geneva Conventions.

Lasers and particle beams

27. Lasers as such, or laser weapons, have a threefold relationship with nuclear-weapon technology. Lasers are regarded as possibly important components in a strategic missile defence as well as a threat to space-based assets ad regards command, control, connnunications and intelligence ("C^3I"). The X-ray laser has been discussed as a component of a ballistic missile defence and it has been suggested that the X-ray laser should utilise an exploding nuclear device as its source of energy. An this requires the laser and the nuclear device to be built together and to be annihilated simultaneously, such an X-ray laser might be viewed as an example of advanced tailoring of a nuclear weapon. Apparently the interest in X-ray lasers as weapons has begun to fade, probably not only because of the general decrease of emphasis on space defence programmes and the current cost-benefit assessment of the whole concept,

28. As compared to X-ray laser technology, particle beam technology is much older. Science-fiction writers talked about beam weapons long before lasers were invented, as particle acceleratcrs were being developed already in the 1930s. To be used as a weapon, a high-energy beam has to traverse large distances in the atmosphere or in apace and problems associated with this propagation generate additional, severe restrictions. On the one hand, only electrically charged particles can be accelerated by electromagnetic fields. On the other, when charged particles pass through matter they rapidly lose their kinetic energy by ionising the atoms that they hit or pass by.

29. The neutral particle beams that are the main object of current research and development use ionised hydrogen atoms. The technique as such is available in the laboratories, As far as can be understood, neutral particle beams would not be effective as weapons. It is estimated that a hundredfold increase in output over that presently available would be needed for a space weapon. This level of performance is unlikely to be attained in the next 20 to 25 years. In addition, such a powerful accelerator and its associated equipment, including the energy source, would be very large and heavy in comparison to the equipment now being tested.

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30. It might be more feasible to use a neutral particle beam to discriminate between real warheads and decoys en route in space, as this would require much less energy than is needed to destroy a warhead. Laboratory experiments over short distances have indicated that this technique works in principle, but enormous practical problems remain.

Nuclear technology and verification

31. Better understanding of nuclear weapons radiations and nuclear phenomenology could assist in the development of technology for verification of treaties restricting nuclear tests. Most verification methods and procedures available so far are of a non-nuclear nature, barring those which belong to the nuclear safeguards régime. However, there is a new class of verification problems where techniques for nuclear radiation measurement have been considered, for example, to determine the presence or absence of nuclear *weapons* at a given location, especially on ships.

32. In principle, there are no difficulties in determining whether an unknown object is a nuclear device or not. The methods of investigation could be passive or active. Passive methods can detect, record and analyse various forms of radiation emitted from the object under investigation, Active methods comprise irradiation from different outside sources and a subsequent analysis of the emanating signals. Active investigation could involve the recording of X-ray images using transmitted or scattered X-rays. For nuclear weapon diagnosis, other forms of irradiation employing ionizing particles, neutrons or gamma rays may be more useful. But to utilize such systems would require (a) more diversified and more unwieldy equipment than passive detectors1 (b) a high degree of intrusiveness in terms of time *and* proximity to relevant objects; and (c) a thorough knowledge of the possible consequences of an irradiation of the materials and components contained in the supposed nuclear weapon.

33. No fundamentally new principles for more sensitive detectors are within sight. Incremental improvements in existing systems are certain to continue and larger sensors might be manufactured in spite of the associated large expenditure. Background radiation, however, cannot be eliminated. For these reasons, there will always be a limit to the performance of detection systems. Also it is not possible to rule out categorically the problem of radiation shielding to impede verification,

B. Space technology*

34. Space technology is not a separate field by itself. Drawing upon a multitude of different scientific disciplines, space technology could be seen as a collection of new technologies directed towards the exploration and exploitation of the vast

* Contributions to the present section were made by Dr. Bhupendra Jasani, Fellow, Stockholm International Peace Research Institute, London, and Dr. George Lindsey, Former Chief, Research and Development of the Department of National Defence, Canada.

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region of the universe beyond the atmosphere. From the chemistry of a rocket propellant, through the mathematics of orbital calculations, to the psychology of virtual isolation in zero gravity conditions, practically every area of modern science has fed space technology.

35. Since the first satellite was placed in orbit in 1957, space capabilities have developed essentially in four areas: space transportation, sensors, spacecraft and ground segment, Many of these capabilities are unique and cannot be duplicated by airborne or ground-based systems. The data obtained from a space-based system, for example, could be 20 to 100 times more accurate, cover a much larger percentage of the Earth's surface area and be available on a 24-hour global basis under all. weather conditions. A satellite system is also a passive system in the sense that the user receives data without disclosing his own location.

36. Observation8 from space are used routinely to survey crop, forestry and urban areas for planning purposes, oil and gas exploration and ocean research, as well as ocean reconnaissance for organizing fishing activities. Sensors have been used to observe the Earth's surface from an altitude of between 800 and 900 km for more efficient exploitation and us8 of natural resources. Navigation by satellites is yielding position accuracies down to a few tens of metres. Greater use is being mad8 of the satellite-based communications and navigation systems for civilian, sea and land transport systems. The potential of increased accuracy in medium- to long-term weather forecasting through the use of orbiting spacecraft has long been recognised and it is now being put to extensive use. Ongoing improvements in remote sensing and satellites, could also yield promising returns for dealing with problems like ozone depletion, build-up of greenhouse gases, acidification of lakes and forests, large-scale deforestation and pollution of oceans.

37. Military activities in space have been devoted towards five traditional support missions: communications, reconnaissance and surveillance, navigation, meteorology and geodesy, The ease with which command and control can be exercised through satellite-based communications makes the military commanders ever more dependent on apace-based systems. Remote-sensing techniques are used for tracking fleet movements, locating rear area targets, sorting out enemy lines of supply and command, monitoring activities at airbases, intercepting field communications, warning of enemy advances and so on. Satellite navigation systems provide information for updating inertial navigation systems on strategic missiles and offer highly accurate world-wide three-dimensional position-fixing. Satellites for meteorology and geodetic survey can provide data for strategic operations or tactical weather information for the battlefield commander. The quantity of data that can be obtained, when coupled to increasingly powerful computers, offer8 more accurate, detailed and longer-term forecasting.

38. Broadly, the current trend in space and related technologies is towards the development of more effective satellite-based sensors, more survivable spacecraft and improved command and control systems. Both incremental advances and radical improvements in any one or more of these areas could contribute towards a more efficient performance of the traditional military support missions in space. Technological advances have also opened up the possibilities for a host of future military missions in space. Among those envisaged, the following have been frequently debated. 2/

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Elaboration of space-based nuclear weapons capabilities

39. These could be envisaged along four lines. First, space-based sensors might be used to seek out and directly attaok an adversary's relocatable or mobile targets, that is, air defence radars, mobile missiles, mobile (even airborne) command posts and so on. A second elaboration oould be a means by which to assess the damage to an opponent from an initial nualear strike and to re-strike whatever targets survived. This could reduce targeting requirements and the size of the stockpiles required to meet them. A third possibility would be to use satellite navigation to reduce missile guidance errors to tens rather than hundreds of feet, ushering in lower-yield strategic nualear weapons and even non-nualear strategic weapons. A fourth use of satellite navigation could be to reduce the cost of missiles like the Midgetman that must otherwise each carry an expensive guidance system in order to have silo-killing accuracy.

Support to conventional forces

40. This is a vast aategory that ranges from the monitoring of rear area8 to detailed participation in battlefield operations - locating targets, guiding "smart" weapon8 to them and relaying voice and data traffia.

Anti-satellite and satellite defense weapons

41. This aategory comprises all the features of a military competition in spacer (a) minor, directed-energy weapons, kinetic energy weapons, jammers and electronic countermeasure gods to destroy or fool enemy satellites; (b) defensive esaorts for friendly satellites, carrying jammers, decoys, shields or weapons to fight off anti-satellite weapons (ASATs); and (c) spacetracking and identification sensors for such missions and treaty monitoring.

Space-to-earth weapons

42. These types of hypothetical weapons would include beam weapons, orbiting nuclear and conventionally armed re-entry vehicles (RVs) and electromagnetic pulse (EMP) generators. Space-to-earth beam weapons have to contend with atmospheric attenuation with the abundant shielding available to terrestrial targets. Nuclear-armed RVs stored in space are not known to have competed in terms of cost, accuracy or command and aontrol with RVs stored in the noses of intercontinental ballistic missiles (ICBMs).

43. Some of the hypothetical future technological possibilities listed above are considered either technically fanciful or as addressing issues of peripheral military concern, not to mention the prohibitive costs. In order to be effective as space-based systems, the kinetic energy and directed energy weapons, for example, must have target surveillance and acquisition systems, discrimination against decoys, pointing and tracking systems, kill assessment capability, appropriate weapons and infallible command and control arrangements. All these require new developments in technology and may offer only a limited defence against nuclear weapons. In addition, the costs of hypothetical missions remain incalculable. In this respect, a major lesson learned from man's odyssey into space is that the cost of breaking free from the Earth's gravity remains very high.

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44. There are currently three major treaties in force that regulate various aspects of the use of space for military purposes:

(a) The 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water (the "Partial Test Ran Treaty") 3/ prohibits nuclear explosions such as auclear-weapons tests in space;

(b) The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the "Outer Space Treaty" (General Assembly resolution 2222 (XXI), annex) bans the statioaing of weapons of mass destruction in space;

(c) The 1972 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems (the "ABM Treaty") 4/ prohibits the testing, development, and deployment of space-based ARM systems or components.

4s. Although military support missions have been routinely carried out, space has not yet become a venue for weapons deployment. As of now, there are some 5,000 to *6,000 man-made* objects in space. Not all *of* them are equally capable of performing military support missions. There are also vast differences in the degree of their technological sophistication. Considerable amounts of human, technical and financial resources are known to have been allotted for safeguarding the existing spaae-based assets, protecting them from being dostroyed by the adversary and acquiring the technological means to destroy space-based systems. Herein lies a basio paradox of the technological dynamism of spaae-based military capabilities. To the extent that anti-satellite capability is suppressed, the temptation to deploy threatening spaceoraft will persist in a situation of military competition in space. And to the extent that such spacecraft are deployed, there will be pressures to deploy anti-satellite weapons. 5/

46. Removal of suspicion about each other's intentions is thus in the mutual interest of military Powers with known space-based military capabilities. Sever41 new technologies have already made it possible to use remote sensors for promoting confidence among space-based military Powers and for facilitating the conclusion of several types of arms control agreements. The central benefit of these types of systems is that, theoretically at least, they would permit the use of meaas of *verification* that can only operate effectively at close range, without compromising the integrity of weapon systems and jeopardising military security.

47. Remote sensors could also be used to monitor agreements to establish cease-fire lines, demilitarised zones and other arrangements to control military conflicts. The use of satellites to provide information in crisis situations, to facilitate communications, to verify measures of arms limitation and to warn of imminent danger *of* accidents has already been accepted as peaceful uses of space-based military capabilities,

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C. Materials technology*

48. Materials technology is a product and process enabling technology concerned with the intrinsic and fundamental nature of materials, their response to external stimuli and their properties and characteristics when exposed to a host of environmental conditions. In the past, man used the raw materials that nature gave to him. The new materials technology leads from the age of natural raw materials into the age of man-made raw materials.

49. Structural materials provide simply the mechanical strength or stiffness to support structures. Functional materials have special properties that take an active role in the device or applications such as electrical conduction, optical transmission or chemical separation. Conventional metals, alloys, polymers, glasses and ceramic materials do not seem to meet all the requirements of advanced industry, including its military sector, Advanced composites, that is, mixtures of two or more phases usually embedded in a matrix of a cementing material, have been developed over the last 20 years. Although it is developing at a tremendous rate, composite materials technology is a relatively immature technology, driven principally by the need to reduce weight and to increase the performance of space vehicles and civilian and military aircraft.

50. Many of the current advances in materials technology are bared largely on processes that affect and generate totally new properties and characteristics rather than discovery of new materials. Examples of such processes are rapid solidification, solid state amorphiaation and liquid state emulsification with amorphisation. A dissemination of the structures achieved through scientific advancer provides few clues to the processes involved and in this sense the new materials technology is fairly safe from reverse engineering. The stealth technology, for example, uses and relies heavily upon composite materials that are derived entirely from organic materials.

51. An area of particular interest to new materials technologies is the construction of materials for both high and low temperature use. The high-energy density of emerging magnetic materials is revolutionizing the way in which electromechanical and electromagnetic equipment is being designed. The particular benefit of high-energy systems is in the ability to miniaturise components and increase overall product efficiency. Magnetostriction in rare earth-iron compounds is also being experimented upon because of the potential benefits for underwater sonar and other advanced acoustic devices.

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* Contributions to the present section were made by Dr. Ian McGill, Research Manager, Johnson Matthey Technology Centre, Reading, United Kingdom of Great Britain and Northern Ireland, and Dr. Leslie Smith, Chief of Polymers Division, National Institute of Standards and Technology, Maryland, United States of America.

52, Data storage and retrieval systems based on thin multi-layer metallic systems are also being developed. The next generation of magnetic and optical storage and retrieval media will be based upon thermo-magneto-optic technology and will require the capability to store an increasingly higher amount of information per unit area of material. Advanced weaponry, space defence and satellite communications systems requiring rapid data storage and retrieval capability will depend upon new materials-enabling technologies.

53, Military and aerospace applications are also driving the new materials technology to acquire the means for providing high temperature oxidation resistance. Indications are that some carbon composites have exhibited only minor oxidation after hundreds of hours of thermal cycling at temperatures up to 1,400°C. For future applications such as thrust vectoring exhaust components for fighter aircraft, static and rotating turbine components and thermal shielding for hypersonic tactical missiles and various re-entry carriers, oxidation resistance up to 2,100°C needs to be achieved.

54. The use of oomposite materials as a fuel efficient and low-weight replacement for aluminium and other metals in jet aircraft has gained some acceptance both in the commercial and military segments of the aerospace industry. When properly treated, some high-strength, lightweight plastic materials can offer twice the strength and half the weight of aluminium. Some research programmes in the aerospace industry are currently aimed at replacing airplane weight by 40 to 50 per cent, lessening acquisition costs by 20 per cent and reducing the number of parts needed in the plane by 50 per cent. Widespread economic viability and immediate strategic value of a composite jet aircraft, however, still remain to be assessed. The composite material is expensive, time-consuming to manufacture and needs to be handled in a controlled environment and refrigerated when transported.

55. Commercial developments of advanced materials are also seen as relevant for improved tank armour and anti-tank weapons. Scientists concerned with the impact of projectile hit, for example, have been intrigued by the behaviour of hand-made ceramics when struck by high-speed metal projectiles. Experiments have shown that the brittle ceramic material is pulveriaed by the impact but, because of the chemical change it has undergone, the fragments expand and fill the hole as it is being drilled by the tip of the moving projectile. As the very hard ceramic particles expand, they grind up the body of the projectile and thus neutralise it.

56. The developments in new materials technology alone or in conjunction with other technologies could open up several possibilities in the field of military hardware and strategic planning. 6/ Super-hardening techniques based upon new methods of materials fabrication may enhance the survivability of ICBM silo basing against a full range of nuclear effects, whether blast, thermal or electrical. Knowledge of how to harden very small, sensitive electronic components, such as radios, is only just beginning. Given the progress so far, however, at least in theoretical understanding, such techniques could be applied in land-based, sea-based, air-breathing and space-based systems. Advances in propulsion design and materials fabrication could also open up possibilities for putting cruise missiles with multiple independently targetable re-entry vehicles (MIRVs), although such a development is already prohibited by the Treaty between the United States of

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America and the Union of Soviet Socialist Republic on the Limitation of Strategic Offensive Arms (SALT II) (General Assembly resolution 37/100 B). Construction of oonvertible warheads to deliver conventional warheads over strategic ranges aould be a fairly straightforward extension of the existing knowledge of insertable nuclear aomponents (INC). Aerodynamic systems aapahle of foiling prospeative detection and tracking capabilities are being developed, by reducing or suppressing observable features, such as the structural characteristics of the aircraft itself. Design modifications to surface angles and engine-inlet geometry can reduce substantially the likelihood of radar detection, particularly if coupled with radar-absorptive materials.

57. Materials technology is BOW in a state Of ferment. Many developments in new materials technology are also apparent offshoots of civilian research started, in some oases, several decades ago. Its military potentials oan best be understood by recognising that the modification of the molecular structure of materials has had an impact on military effectiveness since man discovered how to harden steel, However it is only in this century that the nature of matter has become understood in sufficient detail to tailor materials to requirements. Glass and ceramics, once synonymous with fragility, can today be stronger than steel. Strength, weight, electrical propertiee, melting points and all the other characteristics are BOW being designed, and this has enormous implications for future military equipment. Today, the nature of materials affeats the lethality of weapons, the survivability of troops, the performance of aircraft, the costs of production of new systems and every aspect of every component of defence equipment, Looking for greater effectiveness from weapons, efforts may be made to seek to provide new materials that offer benefits over the old either in capability, ease of manufacture or cost. Future development in materials may also offer designs not previously possible.

58. Looking into the military implications of new technologies, materials technology seems to be a crucial area. 7/ In the construction *of* weapon platforms, *new* materials will allow airaraft to fly faster, tanks to survive attacks better, ships to stay longer at sea and submarines to range further. Reduoed sloe for performance will reduce detectability and materials that absorb rather than reflect radars can be built into the design. Jet engines that can operate at higher temperatures produce greater efficiency and thrust. Communications will be more assured and information density greater. New computing power will become available *for* weapon guidance, control and information proces ìing. New sensors will make detection of the enemy much easier by day and by night. In space, the aew materials will assume yet greater importance. Indeed it has been the need to develop materials to cope with the heat of re-entry into the Earth's atmosphere that has prompted much of the research. The reduction of weight, increase in strength and increase in engine performance might eventually blur the distinction between air and space.

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D. Information technology*

59. "Information" spans a wide range, including raw data, the results of its analysis, the processing involved and the knowledge aaquired and used. Information teahnology provides fundamental tools for effectively managing and using information. The teahnology includes proaessing, storage and telecommunications capabilities aonfigured into systems.

60. Based upon a cluster of interrelated innovations in microelectronics, aomputers and telecommunications, information technology is an extraordinarily pervasive technology. It underpins advances in materials, space, nuclear and bioteahnologies, yet is itself dependent only on materials. All major technologies are heavily dependent on information in their research, management and control systems, to euah an extent that information is sometimes singled out as being at the centre of the present wave of teahnologiaal change.

61. For a technology to have pervasive effects it should: (a) generate a wide range of new products and/or services; (b) have applications in many sectors of the economy; (a) reduce the oosts and improve the performance of existing processes, produots and systems; (d) gain widespread soaial acceptance with minimal opposition; and (e) generate strong industrial interest based on perceived profitability and competitive advantage. 8/

62. On all these counts, information technology comes at the top, as is illustrated by the following table aompiled for the Organisation for Economic Co-operation and Development (OECD):

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* Contributions to the present section were made by Dr. Steven Squires, Information Science and Technology Office, Defense Advanced Research Projects Agency, Virginia, United States of America, and Dr. Janet Aisbett, Principal Research Scientist, Information Technology Division, Electronics Research Laboratory, Australia.

Ranking of economic significance of several generic technologies a/

Characteristics favouring or retarding diffusion	Bio-technology	Materials	Space	Nuclear	Information
Range of new products and services	4	4	2	2	9
Improvements in costs or technical attributes of existing processes, services and products	3	4	2	1	9
Social acceptance	5	9	6	3	9
Strength of private industrial interest	3	6	3	2	10
Sectors of application	4	4	2	2	10
Probable employment impact in 1990s	2	2	1	1	10

Source: High-Level Experts Group on the Social Aspects of New Technologies, Paris, 1988.

a/ A value of 10 represents the highest ranking and a value of 1 the lowest.

63. With lead times down to two to three years, information technology is moving very fast. Physical limits were earlier foreseen to bring an end to the exponential growth of computer capability, including miniaturization and power consumption. New materials, however, have opened up new possibilities for high-temperature superconductivity and optical processing that will maintain growth rates of computing capability well into the next century. The theme right across this technology area is one of cheaper, faster, physically smaller devices handling vastly more information in many different formats and from many different sources. Software is still a weak link in the chain, so more and more of the hardware capability is being diverted to making the user's job easier, application development time faster and maintenance costs lower, with 80 per cent of software resources currently being- employed in maintaining systems.

64. Described sometimes as an effective force multiplier, information technology could bring about further dramatic developments in the military sector, which has been a leading user of advanced technologies at any point in time. The military application conditions are generally more stressful because of the physical environments, the need for reliability in life-critical situations and the need for swift response in time-critical situations. As a consumer of advanced technology, the need to acquire a competitive edge over potential adversaries is stressed even more by the military than the civilian sector of industry.

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65. The use of advances in information technology by the military sector could bring about significant increases in the efficiency of reconnaissance and communications, and confer greater accuracy on the performance of existing weapon systemu. Technologies for military applications could include (a) greatly improved sensors of several types, capable of discriminating faint signals against cluttered backgrounder (b) vastly improved command, control, communications and intelligence systems that could enable more flexible and tactically effective use of military forces, and (c) extremely accurate weapons, particularly anti-tank systems, capable of locating and tracking their targets autonomously, Eventually, the use of advanced computers and software systems could also permit the application of artificial intelligence to military systems. Combined with robotics, these technological developments could reduce manpower requirements per unit of combat effectiveness for et least that portion of military manpower which must be placed "in harm's way".

66. A sizeable part of the spiralling costs of weaponry and countermeasures is known to be due to information systems. Complex navigation, communication, sensor, decoy and weapon systems become increasingly integrated with more selective presentation of information, using advanced processing and graphics. System design and operator training both take advantage of more sophisticated simulators. Missile guidance systems become better equipped at identifying targets, making it possible to have increasingly "brilliant" weapons. Information technology continues to play a vital role in the modelling of new generations of weaponry, for example, modelling of detonics using supercomputers.

67. The importance of C^3I in strategic planning is well understood. What needs to be pointed out is the rapidity with which changes are occurring in the criteria for command and control as well as the standards of measurement. The new information systems are not only composed of hundreds of important components but their operational potential can be varied fundamentally by exchanging small components. As more diverse and up-to-date information becomes available, decision-making will be aided by automatic systems capable of limited reasoning about the information and its display in a digestible form.

66. At the simplest, the dependence of nations on information makes them vulnerable, either to disinformation or to direct action against communication links. Insurgents can be prepared for small-scale conflicts with cheap, hard to counter equipment by information technology, for example, reprogrammable hoppers, jammers and frequency-agile laser weaponry. Readily obtainable heat-seeking missiles can be equipped with countermeasures. Moving up the scale, crudely targeted cruise missiles could be easily constructed using GPS guidance systems from airliners, lightweight economic engines and lightweight materials for bodies. Meteorological, positional and target information is likely to become readily available from opon sources.

69. The role of information technology in contributing to confidence-building and verification issues is widely recognised. Cheaper communication and cheaper, faster computation capacity are not essential for the monitoring of underground explosions, but together with more automated preliminary analysis decrease the cost of comprehensive monitoring. In so far as chemical and biological weapons

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verification is assisted by analysing movements of materials and equipment, for example, for containment in electronic data bases, information teahnology has a role to play.

70. Given its extraordinarily pervasive and its increasingly dual nature, one aannot put too strongly how developments in all teahnologies and developments in industrial processing rely on information teahnology, If a nation falls behind in computing and communication teahnology, it falls behind everywhere. It aannot produae sophistfooted materials, it struggles in biotechnology, it does not even consider space or nuclear power except in the role of paying customer for expensive services it aannot do without. There is a trend in all areas of endeavour to value intellectual property more highly, demonstrated by both the need to encrypt and efforts to decrypt data outside the military arena. For the developing countries without the means to acquire information, the inoreasing real aost of information makes it more difficult to catch up. Some of them are deeply concerned that the information teahnology revolution should not bypass them as the industrial revolution had done. Security lies in access to information.

E. Biotechnology*

71. Biotechnology is the utilisation of living organisms and/or their aonetituents and produatr for medical, agricultural, industrial and research purposes, It encompasses a number of more or less independent though interrelated complexes of methods such as genetia engineering, protein engineering, aell teahnology and immune trohnology. Bioteohnological methods provide the capability to study and to manipulate genes and other parts of genetia material, proteins, including antibodies, viruses, bacteria, cells, including germ cells and neurons, as well as multiaellular organisms.

72. Currently advances in protein engineering represent the second wave of the revolution in biotechnology. The first phase was the advent of genetia engineering in the 1970s, when scientists developed methods to extract individual genes from mammalian cells and insert them into miaro-organisms such as bacteria. The new technology takes genetic engineering one step further, by making changes in the amino-acid struoture of the proteins themselves. Because biologists cracked the genetic code many years ago, they can write out a DNA sequence for the change they want and the cell obligingly produces the altered protein.

73. At present one of the major effects of biotechnology is in basic and applied biological research. The fundamental structures and functions of living organisms, including viruses, can be studied on the molecular level to gain knowledge about pathological processes. A majority of these insights contribute to practical consequences in health care, agriculture and environmental protection.

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* Contributions to the present section were made by Prof. Erhard Geissler, Central Institute for Molecular Biology, Academy of Sciences of the German Democratic Republic, Berlin-Buch, and Dr. Raymond Zilinskas, Associate Director, Center for Public Issues on Biotechnology of the Maryland Biotechnology Institute, University of Maryland, United States of America.

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74. As in the past, current advances in biotechnology are also accompanied by some concern about possible risks and deliberate misuse. Ecological hazards caused by the release of genetically engineered organisms into the environment, genetic manipulation and human cloning, and development of biological and toxin warfare agents are among some of the persistent concerns associated with biotechnology.

75. There is, however, scant scientific evidence of the actual release of harmful organisms. In more than 15 years of research and development using genetic engineering techniques in virtually tens of thousands of laboratories, no known harm resulting from any accidental release of genetically engineered organisms has been reported. This does not entirely mitigate concerns over the deliberate misuse of biotechnology and its military potential for developing biological warfare (BW) agents.

76, The essential requirements of BW agents are believed to be consistency in effect; ease of production; stability in store; ease of dissemination; and stability after dissemination. Depending on its particular role, a BW agent will need a number of other qualities: short incubation period; appropriate persistence) difficulty of detection; and resistance to countermeasures with easy self-protection, The question of the period from delivery to the onset of incapacity is crucial. It is possible to imagine a BW agent that is slow to act but is also rapidly spread by cross-infection being used in an undeclared war. The problem would be that the forces delivering the weapon would in due course be at risk from it. 9/

77. Although biological warfare has been waged with limited and inglorious success on a few isolated occasions prior to the Second World War, there is no proven recent interest in the military utility of BW agents. These agents differ from all other combat methods by being entirely anti-personnel, that is, they can be used only for their crippling effect rather than any striking ability. Military authorities generally like to know the exact effects of the weapons they employ. The results of use of infective agents as a biological warfare weapon in human populations cannot be predicted with any degree of certainty. Morbidity and mortality from communicable disease agents cannot be accurately forecast because of differences in population groups with respect to physiological, genetic and socio-cultural variables, nutritional status, previous exposures to infective agents, immunization histories and various other factors. 10/

78. The development, stockpiling and acquisition of harmful biological agents for hostile purposes or in armed conflict are prohibited under the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction (the "Biological Weapons Convention") of 1972 (General Assembly resolution 2826 (XXVI), annex). Well over a hundred nations of the world, including the United States and the Soviet Union, are parties to the Convention. Under article I, signatory nations pledge never to produce "microbial or other biological agents, or toxins whatever their origin or method of production, of types or in quantities that have no justification for prophylactic, protective or other peaceful purposes",

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79. The use of accumulated knowledge of biotechnology for deadly purposes affecting humans, animals and craps would be an ultimate perversion. It would take many years - some 10 to 15 years is the usual period - of secret research and development to obtain a new biological weapon by recombinant DNA *technology*, if it were successful. Effective testing in human populations would be virtually impossible. The risk of discovery of such research pertaining to man, lower animals or plants is great and, if uncovered, would undermine the credibility of *a* nation with respect to its signature on any treaty.

80. Bioteahnalogy is a relatively young science with a vast potential. The developments in biotechnology, for the most part, are likely to be driven by the needs of the civilian sector. *In* the medical sphere this will be in the prevention and cure of disease. *In* the industrial field, the early work *on* production of fuel from sugar by fermentation points to the prospect of new fuel sources. Microbes are already being used in industrial processes to concentrate minerals, clean up pollutants and synthesise plastics, Biotechnology is also moving towards electronics and photonias in the realm of computing, Photonics offer6 one method of increasing chip density and computing speeds and power.

81. Beyond the obvious application of harnessing biotechnology for economic development, biotechnologies may be applied directly in arms cc trol activities. The most promising application at this time relates to *sensors.* Thus, conventional, proven sensor techniques (chromatography, mass spectra, optical beams, radio-immuno assay, *etc.)* could be used to verify compliance with the chemical weapons convention, while biosensors and monaalonal antibodies are being developed to be the heart of ultra-sensitive and highly specific detectors useful to verify compliance to the Biological Weapons Convention and *to* detect *and* quantify pollutants in the air and *water.*

82. As more and more countries participate in the endeavours to revolutionise biotechnology, *openness* of research may provide an effective deterrent against its misuse. Steps in this direction could include publiaation of research findings; laboratories and research teams to *enter* into co-operative projects with foreign partners; continuous exchange visits between laboratory personnel; and the publication of institute and laboratory work programmes, including budgets,

IV. CONCLUDING REMARKS

83. Compared with the spectacular results of preceding decades, the current wave of technological change is mostly evolutionary and largely incremental, Fur thermore, it is even more evident that much technology with military application has a dual nature. Military applications independent *of* civilian research are less common now than earlier when civilian spin-offs from military research were better known. In the modern weapon systems, more improvements are taking place in the field *of* supporting technologies than in the weapons themselves. Some of these supporting technologies are also helpful in verifying agreements on arms limitation or in other similar functions that promote peace and security.

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84. The traditional mechanisms for controlling the military applications of technology are international agreements to ban, inter alia, the development, production, acquisition, deployment or use of separate categories of weapon systems. There could also be other effective means such as unilateral measures of restraint, preclusive arrangements for banning qualitative innovations clearly intended for destructive purposes and regional and subregional dialogues on military restraint and the removal of uncertainties over the intended use of technological advances.

85. Greater predictability and the removal of speculative uncertainty about technological advances can be achieved by encouraging the present trend towards more openness and greater transparency in military-related matters. Co-operative research and development practices through data exchanges and scientific visits can serve to promote technology diffusion and to reduce uncertainties about the intended use of a specific programme. There are some areas in which efforts to prevent dangerous technological advances must be employed at the research and development stage, as in the case of biological weapons. In other cases, it is only at the production stage of the process that it can be determined whether technology is being used for military or civilian purposes, as in the case of chemical weapons. Within the limits set by proprietary claims on patents, inter-co-operative research and development endeavours also provide a framework for promoting ethical responsibility among scientists.

86. In order to develop a realistic set of criteria for technology assessment, the international community needs to be better equipped to follow the nature and direction of technological change. Recognising that there are already a number of institutions involved in devising and implementing adequate mechanisms for technology assessment, the United Nations can serve as a catalyst and a clearing-house of ideas. Among suggestions already made are several that aim at examining whether new technologies call into question the existing international agreements on arms limitation or the tacit understandings crucial for their adherence. An illustrative framework for assessment of "new technologies" could include such criteria as:

(a) Will they offer new military options either by significantly improving known weapons or by creating new weapons systems?

(b) What will be their impact on crisis management in peace and during conflict?

(c) Will they promote better means of verification or weapons disposal?

(d) Will they create a new set of issues for ongoing negotiations?

87. These and similar questions represent the dimensions of new challenges that must be addressed if the international community is to find ways of allowing technology the freedom to develop and yet, at the same time, ensure that technological advances promote rather than place at risk international peace and security in the years ahead.

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Notes

1/ The United Nations Disarmament Yearbook, vol. 12: 1987 (United Nations publication, Sales No. E.88.IX.2), appendix VII.

2/ Joseph S. Nye, Jr. and James A. Schears, eds., Seeking Stability in Space: Anti-Satellite Weapons and the Evolving Régime, Aspen Strategy Group and University Press of America, Boston Way, Maryland, 1987, chap. II.

3/ United Nations, Treaty Series, vol. 460, No. 6964.

4/ Ibid., vol. 944, No. 13446.

5/ Nye and Schears, op. cit., p. 97.

6/ "Deterrence, Technology and Strategic Arms Control", in Adelphi Papers No. 215, The International Institute for Strategic Studies, London, winter 1966-1987, pp. Q-13.

7/ Timothy Garden, The Technology Trap: Science and the Military Brassey's Defence Publishers, London, 1989, pp. 83-88.

8/ New Technologies in the 1990s: A Socio-economic Strategy, OECD, Paris, 1988, pp. 35-37.

9/ Garden, op. cit., pp. 89-93.

10/ Susan Wright and Robert L. Sinsheimer, "Recombinant DNA and biological warfare", in Bulletin of the Atomic Scientists, vol. 39, No. 9, November 1983; and Martin M. Kaplan, "Another view", in Bulletin of Atomic -, vol. 39, No. 9, November 1983.