

15

Preventive Arms Control as a Prerequisite for Conversion of Military-Related R&D

*Jurgen Altmann, Wolfgang Liebert, Gotz Neuneck, and
Jurgen Scheffran*

INTRODUCTION

Throughout history, military innovation has provided decisive advantages in battle.' Particularly in the nuclear age the major powers have pursued superiority by very large efforts devoted to research and development (R&D) for new weapons. In many cases, however, the net outcome was a situation less stable and less safe than before. Even when the opponents began to limit numbers of weapons and carriers, qualitative 'improvement' continued at an undiminished pace.² Researchers have pointed out the essential role of military R&D in permanently undermining equilibrium and stability.³ A comprehensive process of disarmament and confidence-building has thus to include military R&D. Both conversion of R&D facilities to civilian purposes and limits on certain military-related R&D activities seem necessary in such a process.

The process of converting military R&D to civilian purposes can only work well if the whole security environment provides sufficient incentives to disarm and convert. Especially after the Cold War, economic reasons and criteria should be more easily applicable, since the strongest security motives no longer stand against them. Given such an environment, one aim of converting military R&D must be to block future qualitative arms races that would not only divert funds, but could also create new threatening and instable situations.

In order to work towards comprehensive security the existing arms control and arms export control processes need to be examined and extended by preventive measures, supported by technology assessment tools. Disarmament, preventive arms control - especially restrictions on militarily related R&D - and non-proliferation are necessary conditions for an irreversible conversion of military R&D. Conversion and R&D restrictions are complementary paths for preventing dangerous military-technological innovations and proliferation. In this chapter we shall present some ideas along these lines.

THE NECESSITY OF QUALITATIVE AND PREVENTIVE ARMS CONTROL

Traditional arms control has not paid sufficient attention to the issue of qualitative improvements in the arms build-up. In the past the guiding principles were parity and the establishment of upper quantitative limits rather than the aim of (complete) disarmament. Qualitative arms control, on the other hand, would focus on characteristics of types of armaments and would ban complete classes of weapons and carriers.⁴

Preventive arms control can be seen as qualitative arms control applied to the (near or far) future. It would ban qualitative 'improvements' of existing weapons systems or armaments of new kinds that have already been tested, but not introduced, or that may come into being in the future. The concept of preventive arms control aims at cutting off the military-technological innovation process as early as possible. Furthermore, preventive goes beyond qualitative arms control in that it addresses also the danger of the world-wide spread of most destabilizing military technology before the scientific-technological prerequisites for proliferation have been established in more states.

Despite the preponderance of quantitative aspects, some existing bi- and multilateral arms control treaties contain a few commitments that one could call first steps toward qualitative or even preventive arms control through restrictions on the testing, use, manufacturing, production and acquisition of mainly weapons of mass destruction. Some agreements contain explicit restrictions on the development and testing of specific weapon systems and components, others influence R&D and testing indirectly, e.g., a ban on the deployment of certain systems reduces military incentives for R&D in that field (Table 15.1). It should be mentioned that the recent European agreements - the Conventional Armed Forces in Europe (CFE) Treaty of 1990 and the Vienna Document of the Conference on Security and Co-operation in Europe of

Table 15.1
Arms Control Treaties that Include Qualitative Aspects or Have a Direct or Indirect Impact on Research, Development or Testing^a

Treaty	Year	Obligation Concerning RD&T	Verification Method
Antarctic Treaty	1959	no weapons tests in Antarctica	open access
Limited Test Ban Treaty	1963	no nuclear tests above ground	(NTM)
Outer Space Treaty	1967	no nuclear weapons in orbit no weapons tests on moon and celestial bodies	(NTM), open access on moon and celestial bodies
Latin-American Nuclear Free Zone	1967	no testing and manufacture of nuclear weapons	IAEA safeguards, inspections
Non-Proliferation Treaty	1968	non-nuclear weapons states: no manufacture of nuclear weapons	IAEA safeguards
Biological Weapons Convention	1972	no development of biological weapons	(NTM) (discussions on augmentation underway)
Anti-Ballistic Missile Systems Treaty	1972	limits on land-based ABM systems, no development and testing of sea-, air-, space- or mobile land-based ABM systems	NTM
Threshold Test Ban	1974/90 ^{bn}	no underground nuclear test above 150 kt TNT	NTM, inspection
Peaceful Nuclear Explosions Treaty	1976/90 ^b	limits and procedures for 'peaceful nuclear explosions'	NTM, inspection
Strategic Arms Limitation Talks (SALT 2)	1979	restraint in development of some new types of strategic offensive arms	NTM
Intermediate-range Nuclear Forces Treaty	1987	complete ban on ground-based missiles between 500 and 5,500 km range	NTM, inspection
Strategic Arms Reductions - Treaty (START 1)	1991	restrictions on production and testing of new types of strategic offensive arms	NTM, inspection, exchange telemetry data
Chemical Weapons Convention	1993	no development and production of chemical weapons	inspection, continuous monitoring instruments

^a The year given refers to signature; some of the most recent treaties are not yet formally in force. Some agreements are bilateral, others are multilateral. If a treaty does not mention verification methods explicitly, this is indicated by parentheses.

^b Verification Protocols were concluded in 1990.

Abbreviations: ABM: anti-ballistic missile system. IAEA: International Atomic Energy Agency, NTM: national technical means of verification.

1992 - do not contain qualitative, let alone preventive, limits and do not affect R&D. The obligations of the Vienna Document to submit annual deployment plans and to demonstrate new types of major weapon and equipment systems work only after R&D and testing have been completed.

In the present situation after the Cold War, there are specific reasons for introducing or strengthening preventive arms control. One lies in the increased efforts of the highly industrialized nations, above all the United States, to use high technologies for war-fighting purposes.⁵ Some developing countries follow dual-use concepts for their own arms development and production, similar to northern countries. With currently more than 50 military conflicts, a third reason stems from the demand of developing countries to procure high-technology weapons.

CONCEPTUAL ISSUES

When thinking about preventive arms control, one has to deal with several conceptual issues. These have to do with the relation between conversion and preventive arms control, with those parts of R&D which - though not declared military - are militarily relevant, and with the role of the military in general, and of weapons innovation in particular, in the future.

Conversion and preventive arms control are complementary. Irreversible conversion of R&D is unthinkable without R&D restrictions, which have to be introduced simultaneously. Preventive arms control would include the whole process of weapon creation, from certain types of research via development to testing and deployment.⁶ It would cut new military-technological options at their sources and would thus open the way for conversion of related and obsolete R&D. This would also contribute to creating an international climate of increased security and would reduce mistrust and thus provide incentives for conversion. A debate on adequate preventive arms control would sharpen the view of scientists about which technologies are stabilizing and which are not. The result of such a process - the prohibition of specified weapons - should simultaneously exclude undesirable paths of conversion (e.g., restrictions on space nuclear power should also exclude related R&D for potential civilian applications). The development of new verification methods for old and new arms control regimes provides new tasks for scientists and engineers from the Cold War military establishments, being a form of conversion in itself.

Conversion and preventive arms control meet different difficulties at the various stages of R&D. Conversion seems to be easier at an early (research) stage in the creation process of new weapons, when the path to military or civilian applications is less clearly predetermined. It is just that indeterminate quality, however, that makes preventive arms control more difficult there. The opposite situation pertains at the later stages of development and testing, when the military application dominates: here conversion is more complicated, whereas limits are more easily applied. In certain cases, however, even at the research stage one may be able to find specific criteria for preventing or limiting unwanted military-related work. Likewise a need for conversion exists for the institutions active in the development and testing stages.

Restricting only declared military R&D is not sufficient, since part of the civilian R&D base is militarily relevant and contributes to the military technological innovation process.⁷ This holds all the more if dual-use concepts are pursued that organize the support of civilian-labeled R&D projects for simultaneous military development. In addition, including civilian R&D in the limits prevents continuation of banned military projects under a civilian guise. Thus the relevant concept for preventive arms control is 'military-related R&D.' When civilian R&D is included under limits motivated by preventive arms control, however, it should be done with the goal of minimizing impediments to non-military-related work, and legitimate private information should be protected.⁸

As long as intentions, plans or options for new military technology exist, military-related R&D will be pursued and will impede efforts to convert R&D in relevant areas. This could result in diversification instead of conversion, with military R&D programs re-labeled to include 'promising' civilian applications in order to improve the economic competitiveness of such R&D. But behind that is the concept of maintaining the military R&D, base with the possibility of returning to an emphasis on military projects at any time.⁹

More generally, as long as states will find armed forces necessary for the eventuality of war there will be a motive to enable them to fight as effectively as possible and thus to provide them with the most modern equipment. This provides a strong resistance from states and their militaries against comprehensive limits on military-related R&D.¹⁰ Since much of the effectiveness of armed forces in war depends on secrecy about weapons, deployment and strategy, there will be opposition to too far-reaching transparency in military matters in general, and in military-related R&D in particular, which will impede agreement to intrusive confidence-building measures or verification regimes.

Thus, conversion of and limits on military-related R&D can work successfully only within a comprehensive process of disarmament in which the role of the armed forces is continuously being reduced while political and juridical ways of solving conflicts take over. The challenge for arms control and verification research in the field of military-related R&D lies in creatively looking for ways to expand limits, to increase openness and to build confidence, while at the same time conciliating the desire of the militaries and governments to preserve what they feel to be essential capabilities and important secrets. International seminars on military doctrines and adherence to the principle of defense sufficiency may contribute to softening these positions over time.

Finally, there are the questions - at the moment, somewhat hypothetical - of whether in a world gradually renouncing national military force a supranational (UN) force for peace-keeping or peace-enforcing is required, and if so, whether it would need modernization, thus legitimizing a certain amount of military R&D. We feel that this question needs more time and much more study, but it seems that if such R&D were done in an international, agreed setting, it could be done in a limited, circumscribed way and destabilizing consequences could probably be prevented.

STRENGTHENING AND EXTENDING QUALITATIVE AND PREVENTIVE ARMS CONTROL

Including qualitative aspects into existing arms control regimes is necessary on a regional as well as a global level. One approach could be to integrate future arms control issues into regional security systems. Bilateral treaties should be clarified and strengthened where they concern qualitative aspects, the most important example being the ABM Treaty of 1972. In order to avoid a situation where states not formally bound by such treaties transgress their limits and thus undermine compliance by the United States and Russia/CIS, the traditional concept of arms control, created within the framework of the Cold War, should be extended to multilateral approaches.

The end of the Cold War gives unprecedented opportunities to scale back the oversized arsenals of the nuclear superpowers and dampen the proliferation of weapons of mass destruction. Concerning nuclear disarmament, the Nuclear Non-Proliferation Treaty (NPT) should not only be interpreted as stemming horizontal proliferation, but also as clearly aiming at nuclear disarmament and at stopping the dynamics of qualitative improvement of nuclear arsenals, according to its article VI

and the preamble." Additional agreements should be envisioned which, if well drawn-up, would directly or indirectly lead to reductions of the relevant R&D:

- a comprehensive nuclear test ban;
- an agreement subjecting all nuclear facilities that are unsafeguarded or unreported so far, in particular those of declared and de-facto nuclear weapon states, to international inspections;
- the halt of the production (and of civilian use) of nuclear-weapon-grade materials, except for insignificant amounts; and
- international storage of all existing weapon-grade material with the goal of finding long-term disposal options making the materials irretrievable for weapon use.

Should in the long run a Nuclear Weapon Convention replace the NPT, the realization of a nuclear-weapon-free world would lead to a marked re-orientation of R&D for nuclear weapons.

Concerning delivery systems, the following steps would have a dampening impact on military-related R&D:

- strengthening of the ABM Treaty and international restrictions on ballistic missile defense systems;
- a treaty banning space weapons (including anti-satellite weapons);
- the inclusion of aircraft in regional arms control regimes;
- global restrictions on the production of ballistic missiles and stringent constraints on missile flight tests;
- expansion of the INF Treaty leading to a world-wide ban of ground-based missiles above 500 km range (with obligations for the existing nuclear-weapons states to reduce their ballistic missile arsenals drastically); and
- a worldwide agreement that includes the potential recipient countries to stop the proliferation of missile technologies and to introduce international verification.

In the chemical weapons field, the Chemical Weapons Convention of 1993 flatly bans development and provides an effective verification regime. The Biological Weapons Convention also bans development, but verification mechanisms still have to be added.¹² Research is not covered in either convention because of difficulties of definition and verification, but creative approaches could lead to effective limits at that stage (for examples in other fields see the following section).

As mentioned, in the area of conventional weapons there are practically no qualitative, let alone preventive, limits in existence. With the Cold War over and with many restrictions on weapons of mass destruction in place, the main thrust of military-technological development will be in the conventional field, and new qualitative agreements and limits will be needed for existing weapons, as well as for R&D for new ones. The following section will give some possible approaches for the latter.

LIMITS ON R&D OF SPECIFIED WEAPON SYSTEMS

Preventive arms control tries to stop new weapons at an early stage. In order to implement such a concept, a few proposals have been brought forward to put limits on militarily relevant R&D.¹³ This is a very complex issue and raises difficult conceptual and practical problems. Whereas in most cases it is possible to decide on the military relevance of R&D activities, the difficulty lies in finding separation lines between civilian and military paths of development. Only careful analysis can disclose such distinctions.¹⁴ It may, however, often be impossible, particularly in basic research. This is obvious in many fields, e.g., in materials science, artificial intelligence or optical computing.

There are, however, examples where a distinction between future civilian or military applications can be made at an early stage. This is the case where new weapons principles raise scientific questions. Research work on propagation of high-energy laser or particle beams over long ranges through the atmosphere, for example, is nearly completely motivated by the military goal of creating beam weapons. R&D projects on electromagnetic acceleration of projectiles nearly exclusively have military goals, namely to create electromagnetic guns that would allow higher muzzle velocities. In most areas of explosion, shock wave, and penetration research military considerations dominate.

Another distinction concerns specific large activities that, if banned, would prevent continuation of research in several areas. Underground nuclear explosions are the most prominent example; with a comprehensive test ban, experimental analyses of the ultra-high-temperature and -pressure plasmas produced as well as of the effects of strong radiation are no longer possible.¹⁵ But one has to note that even with a comprehensive nuclear test ban, some work could continue in the context of inertial-confinement fusion (ICF), which can be looked at as very small hydrogen bombs. Thus, in order to stop such research completely, limits would have to be applied here, too.¹⁶ Also

the so-called Above-Ground Experiments (AGEX) - laboratory-scale experiments including contained explosions - are intended to serve to maintain R&D capabilities for nuclear weapon improvements.¹⁷

It would be a useful task for the United Nations to establish scientific study groups to analyze these matters in much more detail. In parallel, national expertise in assessing the military relevance of R&D programs should be established. Proposals have been made to introduce the requirement for a Defence Technology Assessment (DTA) or technology control statements (TCS) systematically into the decision process on military R&D, with international co-operation.¹⁸ Considering that technology today is intimately connected to basic science, it is also necessary to establish a kind of science assessment with the aim to detect, describe and reduce the use of science for militarily relevant purposes.¹⁹ Depending on the results of the assessments, limits on R&D could be applied in certain circumscribed areas, e.g., nuclear tests, high-energy beams in the atmosphere and in space, inertial-confinement fusion research, laser isotope separation, electromagnetic acceleration of projectiles.

To prohibit special new weapon technologies there is a need for well-defined quantitative and qualitative thresholds with procedures in every area of application for separating legal from banned R&D activities. These will have to hold for military and civilian R&D, possibly with different threshold values and different degree of verification.

In working out the thresholds and verification schemes, the following guidelines could be used: the rules and their verification should be simple; ambiguity should be avoided; a safety margin should exist between the limits and the parameters required for weapons; civilian uses should be restricted as little as possible, but continuation of military R&D under civilian guise should be prevented reliably; possible civilian prospects should be weighed against the risks of military diversion of results. Efficiency, cost and intrusiveness of verification methods have to be considered, and suitable compromises between different goals - e.g., concerning protection of sensitive information versus transparency - have to be found.

Applying these guidelines is not easy and requires a thorough analysis for each area of R&D. For the areas mentioned before, we can give a few examples of how it could be done. One could introduce limits on the following: the yield of conventional underground explosions, with rules for notification and provision for observers above some threshold yield; the power-aperture product for laser beams, and on the average power for particle beams radiating in the open; a ban of laser-driven

Inertial Confinement Fusion (ICF) (allowing only experiments using heavy-ion impact); wavelengths, average powers, etc., for lasers used to separate isotopes; the kinetic energy, mass and velocity of projectiles accelerated electromagnetically.²⁰

CONFIDENCE-BUILDING MEASURES FOR MILITARY-RELATED R&D

Besides limits and bans on military-related R&D activities there are several options for confidence-building measures. These may be applied either voluntarily or in a legally or politically binding way. In the following, they are listed according to an increasing degree of intrusion or obligation:

- publish military and military-relevant R&D budgets;
- publish military and military-relevant R&D plans, projects and possible deployment schedules;
- publish military R&D institutions, such as laboratories and test ranges (location, size, general task, special projects, personnel);
- conferences on special issues (e.g., weapon programs);
- publish the results of military R&D;
- inspect laboratories and test ranges;
- monitor the careers of scientists and engineers in military R&D;
- mutual visits in specific regions of high mistrust or tension (e.g., to dispel suspicions about secret nuclear programs);
- planning and restraining of military R&D in international coordination among potential opponents; and
- exchange of scientists, safety personnel, planning staff members.

As mentioned above, the more intrusive measures of this list will only become acceptable at later stages of a confidence-building and disarmament process.

VERIFICATION METHODS

In the conversion of military R&D unilateral and multilateral voluntary initiatives play a prominent role. In order to dispel mistrust, these initiatives should, however, be augmented by binding confidence-building measures as well as preventive arms control limiting military-related R&D, both of which would include effective verification. Verification of

confidence-building measures would, as in the Vienna Document 1992, consist mainly of visits and on-site inspections. Some of the methods to be discussed below can also be applied. Verification of limits on R&D activities require various specific methods, most of which will be new. The traditional ones, namely national technical means of verification (NTM) and on-site inspection (OSI), will still have important uses.

NTM can be utilized where R&D activities are large, produce strong signals and/or take place in the open. Examples are nuclear explosions (including their preparations), anti-satellite (ASAT) tests, and beam weapon tests in the atmosphere and in space. NTM can be used to trigger challenge inspections. Capable NTM, however, are only available to a very few countries, and thus cooperative verification methods will have to be included in all multilateral limitation agreements.

Cooperative verification is required when activities take place inside and do not produce strong signatures. Of course, the respective rights and obligations have to be written into the agreements and their verification protocols, and compromises between the protection of sensitive information and the transparency needed for effective verification have to be found. There are several possible methods:

- on-site inspections with technical equipment where appropriate in laboratories or at test sites.
- overflights, which can give valuable information on the purpose of installations (structure, security/protection features, power supplies, effluents). They do not suffer from the absentee problem of satellites, can often monitor below the clouds, and are cheaper.
- remote and medium-range sensors, which can gain relevant information from a distance, avoiding intrusion into sensitive areas:
- radar for monitoring flight tests of aircraft and missiles; laser radar for high-energy laser facilities; seismic and other sensors for underground explosions; seismic and acoustic sensors for artillery test ranges or for characteristics of land or air vehicles.²¹
- inside sensors, which can detect chemical or biological substances or can record personnel activities, etc.²²
- use of RD&T choke points: sites where solid fuel for ballistic missiles is handled; wind tunnels; accelerators; test ranges, etc.

These methods could be worked out with participation of scientists of the (former?) military-scientific establishments.

INTERNATIONAL CONVERSION

Scientists and engineers who have worked in the R&D of weapons have some knowledge about how to destroy these weapons and manage their elimination. Various international projects have been proposed that would offer an opportunity for some of them to convert their know-how and capabilities to remove the heritage of the Cold War:

- build-up of an international agency to monitor and organize the dismantlement and destruction of nuclear weapons and the safe storage of weapons-grade nuclear material;²³
- 'Vaccines for Peace' to convert national R&D on biological weapons to international R&D for protection and prevention;²⁴
- build-up of an International Agency for Ballistic Missile Disarmament (IABMD) to control the global elimination of ballistic missiles (ZBM: Zero Ballistic Missiles)."
- as a long-term project, the creation of a World Space Agency to promote international civilian use of rocket and space technology ('Rockets for Peace').²⁶

In all these proposals the problem of renewed use for military purposes should not be ignored. The implications of the 'Atoms for Peace' proposal are known: the spread of nuclear technology for seemingly 'peaceful purposes' was used by many countries as a means to build capabilities for nuclear weapons. To avoid this kind of re-conversion stringent controls that can guarantee civilian use need to be established within states. To facilitate this task, it should be considered whether certain civilian technologies with an inherent potential for military use should be placed under international control, at least partly. The concept of the International Atomic Energy Agency (IAEA) - to help in building civilian national nuclear capabilities of all kinds, capabilities that also have military impact, and to control them afterwards by international inspection by the same organization - can be questioned. The pros and cons of this approach, which combines contradictory goals, need to be carefully examined for other fields of R&D.

A World Space Agency, in particular, could make available useful applications of space flight by putting existing technical resources into an international pool to be used by countries without their own national capabilities. An essential precondition, however, would be that all partners of this pool (including the greater powers) put their capabilities under international control to avoid their military use. This would be important to achieve the deal between disarmament and technological

cooperation on a non-discriminatory basis that originally was intended by the Nuclear Non-Proliferation Treaty.

The United Nations could help in promoting the conversion of resources from the military R&D sector to useful civilian applications on the national, regional and global level. The 'Dortmund Declaration,' which comprises the results of the first UN Conference on Conversion held in February 1992 in Dortmund, Germany, states that 'the transformation of military related science and technology activities has to be addressed as a central area of conversion policy.'²⁷ Appropriate science and technology are required to respond to the world's economic, financial, social and environmental needs. In particular, there is a growing need for continued scientific assessment of global environmental hazards. The available 'peace dividends' expected from the disarmament and conversion process could be used to strengthen international scientific programs towards matching these needs. As part of this process, the transformation of military-related R&D, including know-how, people, technologies, equipment and institutions, could be a cornerstone of successfully implementing conversion strategies.

A recent UN study gives a first broad assessment of opportunities, possibilities and limitations of applying military-related resources, including technologies, for environmental protection and disaster relief.²⁸ Environmental strategies require a comprehensive set of measures, including protective measures for damage prevention and control; restorative measures for repair and rehabilitation; and remedial measures for environmental compliance and development of ecologically benign and energy-efficient technologies.²⁹ According to the study, advanced research and technology, which are necessary for responding effectively to the environmental challenge, are available in the civilian and the military sector, but are not sufficiently oriented towards environmental goals. Besides R&D on energy, environmental clean-up, and waste management, information and communication technologies (e.g., sensors, computers, networks, models) in the military sector are seen as highly relevant for conversion.³⁰

Some of the limitations of this approach have already been pointed out in the UN Study:

In general, the nature of the civilian sector and its call on resources and technologies are quite different from the demands of the defense sector. Not only are the techniques, technologies, capital, equipment, and human capital and experience different, but so are the appropriate managerial talents, design emphases and end use of civilian products.³¹

The scientific capabilities offered by defense-related institutions should be adequate to the needs in terms of physical-technical characteristics, costs and desirability. For instance, sensors should be similar in frequency, covered area, resolution and availability; communication systems in the number of channels, connectivity, data rate/information flow; computers in storage capacity, speed or compatibility; models in topic, size, adequacy and relevance. In general, technological requirements are less demanding for environmental purposes (and many other civilian sectors) compared with military characteristics, which often may be overspecified, too complex or not cost-effective.³²

CONCLUSION

Conversion implies change, sometimes reversal, in the trajectory of technological development towards more useful ends. Not all the military R&D complex can be converted to useful civilian purposes. If it is maintained despite serious doubts in its civilian utility, this may be an indicator of continued military interests. Conversion should diminish the utility of certain military options and improve those of non-military ones. A successful conversion of R&D, including preventive arms control, could serve as a model for international cooperative regimes to promote, transfer, and control science and technology in the civilian sector.

NOTES

1. See, e.g., K. Macksey, *Technology in War* (New York: Prentice Hall, 1986).
2. Important qualitative steps are marked by the fission and fusion bombs, ballistic missiles, multiple independently targetable reentry vehicles; see, e.g., B.T. Feld, T. Greenwood, G.W. Rathjens, and S. Weinberg, eds., *Impact of New Technologies on the Arms Race, A Fug-wash Monograph* (Cambridge, MA: MIT Press, 1971); F.A. Long and J. Reppy, eds., *The Genesis of New Weapons*, (New York: Pergamon, 1980); and M. Thee, *Military Technology, Military Strategy and the Arms Race* (New York: St. Martin's, 1986). This process has gone on into the present; see e.g.: U. Albrecht and M. Thee, eds., *Military Use of R&D: The Arms Race and Development*, Special Issue, Bulletin of Peace Proposals, vol. 19, no. 3/4, 1988; and W.A. Smit, J. Grin, and L. Voronkov, eds., *Military Technological Innovation and Stability in a Changing World* (Amsterdam: VU Press, 1992).
3. See, e.g., J. Rotblat, ed., *Scientists, the Arms Race and Disarmament* (Paris/London: UNESCO/Taylor & Francis, 1982); Thee, *Military Technology*.

4. Of course, quantitative and qualitative aspects are intimately connected. In order to use quantitative limits, one normally needs qualitative definitions of what constitutes the system to be counted. On the other hand, qualities to be limited generally have to be defined in quantitative terms, e.g., by calibers, payloads or maximum ranges.
5. See, e.g., W.E. Odom, *America's Military Revolution - Strategy and Structure after the Cold War* (Washington DC: American University Press, 1993); National Academy of Sciences, *Strategic Technologies for the Army of the Twenty-First Century* (STAR 21) (Washington DC: National Academy Press, 1992).
6. W. Liebert and G. Neuneck, 'Civil-military Ambivalence of Science and the Problem of Qualitative Arms Control,' in *Controlling the Development and Spread of Military Technology - Lessons From the Past and Challenges for the 1990s*, ed. H.G. Brauch, H.J. van der Graaf, J. Grin, and W. Smit (Amsterdam: VU Press, 1992).
7. See the contribution by W. Smit in this volume.
8. Cf. 'Annex on the Protection of Confidential Information, Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction,' in *Geneva: Conference on Disarmament*, CD/I 170, Appendix, 1993.
9. See, e.g., J. Alic, L. Branscomb, H. Brooks, A. Carter, and G. Epstein, *Beyond Spinoff-Military and Commercial Technologies in a Changing World* (Cambridge, MA: Harvard Business School, 1992); National Academy of Sciences, *Strategic Technologies*, pp. 28-29. Furthermore, the STAR 21 report states that 'there is a surprisingly wide agreement' among the different U.S. critical technology lists, whether they refer to long-term national security or to the economic prosperity of the United States (pp. 281-82).
10. But note that there can be wider national security motives to agree to R&D limits, e.g., for reasons of stability, non-proliferation, economic savings. See also W. Smit, 'Conditions for Constraining Military R&D,' in *Verification After the Cold War - Broadening the Process*, ed. J. Altmann, T. Stock, and J.-P. Stroot (Amsterdam: VU Press, 1994).
11. For more details see, e.g., W. Liebert, 'How Should We Proceed with the Nuclear Non-Proliferation Treaty?' 44th Pugwash Conference on Science and World Affairs, Towards a War-Free World, Kolymbari, Crete, Greece, 30 June-6 July 1994.
12. See the relevant chapters in Altmann et al., *Verification After the Cold War*.
13. For a few early proposals, see 'Restricting Research and Development -Comments by J. Prawitz,' and 'Summary of Discussion,' in *Impact of New Technologies on the Arms Race*, ed. Feld et al. More recent proposals are discussed in W.A. Smit, 'Controlling Military Technological Innovation -The Role of Verification,' in *Unconventional Approaches to Conventional Arms Control Verification: an Exploratory Assessment*, ed. J. Grin and H. van der Graaf (Amsterdam: VU Press, 1990); W. Smit, 'Steering the Process of Military Technological Innovation,' *Defense Analysis*'1-A (1991), pp. 401-415;

Brauch et al., eds., *Controlling the Development and Spread of Military*

- Technology*, especially chapters 4-10; and W. Smit, 'Conditions for Constraining Military R&D,' J. Altmann, 'Verifying Limits on Research and Development - Case Studies: Beam Weapons, Electromagnetic Guns,' and W. Liebert, 'Verifying R&D Limitations - Relevance for Preventive Arms Control and Non-Proliferation,' all in *Verification After the Cold War*, ed. Altmann et al.
14. Liebert and Neuneck, 'Civil-military Ambivalence of Science.'
 15. See D. Fenstermacher, 'The Effect of Nuclear Test-ban Regimes on Third-Generation-Weapon Innovation,' *Science and Global Security* 1, no. 3-4 (1990), pp. 187-223.
 16. See A. Schaper, 'Arms Control at the Stage of Research and Development? - The Case of Inertial Confinement Fusion,' *Science and Global Security* 2, no. 4 (1991), pp. 279-99; and A. Schaper, W. Liebert, W.A. Smit, and B. Elzen, 'Redirecting and Constraining R&D: the Case of Laser Fusion, Laser Isotope Separation, and the Use of Highly Enriched Uranium,' in *Controlling the Development and Spread of Military Technology*, ed. Brauch et al.
 17. M. Kalinowski, 'Military and Dual-Use Research Aimed at Circumventing a Ban on Underground Nuclear Testing,' in *Against Proliferation - Towards General Disarmament*, ed. W. Liebert and J. Scheffran, Proceedings, First Conference of the International Network of Engineers and Scientists Against Proliferation (INESAP) (Munster: Agenda, 1994).
 18. See M.A. ter Borg and M.J.W. Tulp, *Defence Technology Assessment-Improving Defence Decision Making* (Amsterdam: Nederlandse Organisatie voor Technologisch Aspectenonderzoek NOTA, 1987); W. Smit, 'Defence Technology Assessment and the Control of Emerging Technologies,' in *Non-Provocative Defence as a Principle of Arms Reductions*, ed. M. ter Borg and W.A. Smit (Amsterdam: VU Press, 1989); and H. van der Graaf, 'Past Attempts to Control Military R&D and Weapon Innovation,' in *Military Technological Innovation and Stability*, ed. Smit et al.
 19. Liebert and Neuneck, 'Civil-military Ambivalence of Science.'
 20. See Altmann, 'Verifying Limits on Research and Development'; Schaper, 'Arms Control'; Schaper et al., 'Redirecting and Constraining R&D'; and Liebert, 'Verifying R&D Limitations.'
 21. T.H. Braid et al., 'Laser Brightness Verification,' *Science and Global Security* 2:1 (1990), pp. 59-78; P. Richards, 'Verification of a Comprehensive Test Ban Treaty - A Seismological Overview' in *Verification After the Cold War*, ed. Altmann et al.; and Canada, Department of External Affairs and International Trade, 'Non-Seismic Technologies in Support of a Nuclear Test Ban,' (Ottawa, May 1993); J. Altmann, 'Verification Techniques for Heavy Land Vehicles Using Short-Range Sensors,' in *Verification of Arms Reductions - Nuclear, Conventional and Chemical*, ed. J. Altmann and J. Rotblat (Berlin: Springer, 1989); and J. Altmann, 'Intermediate-Range Sensors for Verification and UN Peace-Keeping,' in *Verification After the Cold War*, ed. Altmann et al.

22. The verification annex of the CW Convention mentions continuous monitoring instruments and on-site instruments in several contexts; see 'Verification Annex, Convention.' The report of the verification experts for the BW Convention includes continuous monitoring by on-site instruments among the potential methods; see A. Bovallius and R. Roffey, 'Evaluation of Efficiency of Verification Methods for the BWC,' in *Verification After the Cold War*, ed. Altmann et al.: and 'Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific Standpoint,' Report, BWC/CONF.3/VEREX, Geneva, 24 September 1993.
23. See 'Verifying the Dismantlement of Nuclear Warheads,' Federation of American Scientists (Washington, DC, June 1991).
24. See E. Geissler and J. P. Woodall, eds.. *Control of Dual-Threat Agents: The Vaccines for Peace Programme* (Stockholm/Oxford: SIPRI/Oxford University Press, 1994).
25. For a discussion of this proposal see 'Revisiting Zero Ballistic Missiles -Reagan's Forgotten Dream,' *F.A.S. Public Interest Report*, May/June 1992.
26. J. Pike, 'New Regimes for Rockets,' in *Against Proliferation.*, ed. Liebert and Scheffran.
27. See: A. Brunn, L. Baehr and H.-J. Karpe, eds.. *Conversion: Opportunities for Development and Environment* (Berlin: Springer, 1992), p. xviii.
28. United Nations, Office for Disarmament Affairs, 'Potential Uses of Military-Related Resources for Protection of the Environment,' Study Series 25, 1993.
29. United Nations, 'Potential Uses,' p. 15.
30. On the latter point see J. Scheffran, 'Environmental Applications of Military Information and Communication Technologies,' in *Conversion*, ed. Brunn et al.
31. United Nations, 'Potential Uses,' p. 18.
32. See J. Scheffran, 'Opportunities and Conditions for Conversion of Military Science and Technology,' Paper presented at the Hong Kong Conference on International Cooperation to Promote Conversion From Military to Civilian Industry, 7-10 July 1993, Darmstadt: IANUS Working Paper 8/1993.