Research Group for
Biological Arms Control

Aerial Surveillance and BWC Compliance Monitoring

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TABLE OF CONTENT

Tables and graphs

Executive Summary

Remote monitoring from satellites or aircraft can increase the effectiveness and efficiency of other means to verify compliance with the 1972 Biological and Toxin Weapons Convention (BWC). But aerial surveillance has little value as a stand-alone tool in monitoring the bioweapons ban.

The greatest verification synergies exist between remote sensing and on-site measures. Overhead imagery is useful in selecting inspection targets, planning on-site inspections as well as conducting investigations on the ground.

Aerial imagery can also be valuable in assessing the correctness and completeness of information on bioweapons-related activities, either declared by BWC state parties or derived from other sources.

The possible role of aerial imagery under a BWC compliance regime was thoroughly assessed by a group of scientific experts in 1992-93. Since then, the quality of commercial satellite imagery has improved dramatically, such imagery has become cheaper and is being used more widely by international nonproliferation agencies. The Open Skies Treaty has demonstrated the value of cooperative overflights as a confidence building tool. Because of the convergence of these trends, it is sensible to reassess the value of overhead imagery as one instrument in the biological weapons verification toolbox.

Representatives of 155 BWC state parties are meeting at the Sixth Review Conference 20 November – 8 December 2006 in Geneva. Delegates should consider the following steps to realise the verification potential of aerial imagery:

Establish a dialogue among technical experts to discuss new developments in verification techniques relevant to the BWC, including the role of aerial imagery.

Such a dialogue could take place in the context of the Convention as part of a new intersessional process or between interested state parties.

Mandate institutions that monitor BWC compliance to make use of aerial imagery.

UNMOVIC should be given the mandate and resources to use overhead imagery in the context of ongoing monitoring and verification activities in Iraq. UNMOVIC's broad experience in using aerial imagery to monitor biological weapons-related activities should be shared with other relevant international bodies, including a possible United Nations inspection mechanism or weapons of mass destruction unit.

Work towards an Organisation for the Prohibition of Biological Weapons with a mandate to use overhead imagery.

In the long run, an Organisation for the Prohibition of Biological Weapons with a mandate to monitor compliance with the BWC in all its aspects and the means to ensure compliance would be in an ideal position to realise the synergies between the various verification means available today, including the use of overhead imagery.

In a broader context, the following actions should be taken to realise the verification potential of aerial imagery:

Use the Open Skies Treaty as a test bed for using overflights as a confidence-building measure.

Open Skies member states should use cooperative overflights to monitor compliance with weapons of mass destruction treaties, including the BWC. They should expand the mandate of the treaty accordingly and invite states currently not party to the Open Skies Treaty to participate in such overflights.

Establish a UN satellite imagery unit.

Eventually, the challenge will be to exploit the synergies between different arms control treaties by creating a common reservoir of overhead imagery under the auspices of the United Nations.

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1. Introduction

Since the collapse of efforts to create a universal and legally-binding biological weapons verification mechanism in 2001, it has become clear that in the foreseeable future compliance with the BWC will be monitored by a mix of national and international means.

This monitoring patchwork will be less effective than a multilateral verification regime. But as long as there is no political momentum to resume talks on a compliance protocol, the challenge will be to make best use of available means at the disposal of the international community to identify and deter breaches of BWC obligations as well as to build confidence that state parties are complying with their treaty obligations.[1]

This paper looks at one piece of this verification puzzle, aerial surveillance. This may seem like an unlikely choice because detecting violations of the BWC from the air is particularly difficult. Biological weapons are small and research and development does not require large facilities which possess "fingerprints" that would make it possible to identify them from the air. Thus, aerial imagery has little value as a stand-alone tool in biological weapons verification.

There are good reasons to revisit the issue since it has been discussed by a group of verification experts from 1992-93. Commercial aerial imagery is becoming more widely available, of improved quality, easier to access and cheaper. At the same time, international organisations, including arms control institutions, are using such data for a variety of purposes, including verification of multilateral arms control accords. There are signs that the issue of the verifiability of the BWC may be re-emerging as a topic of international discussions.[2]

This paper argues that the convergence of these trends calls for a reassessment of the importance of aerial surveillance as one instrument in the biological weapons verification toolbox.

It is argued here that monitoring from satellites and aircraft can significantly increase the effectiveness and efficiency of other verification tools, in particular, on-site verification measures, used to monitor compliance with the BWC. Aerial surveillance may also increase the costs of clandestine biological weapons programmes and thereby contribute to the deterrence of BWC breaches.

Policy-makers should take steps now to evaluate more thoroughly the value of aerial imagery in the context of current and future monitoring mechanisms. They should also enable organisations involved in monitoring biological weapons-related activities to make use of the verification potential of aerial imagery.

In the short-term, aerial surveillance can aid efforts to detect, deter and investigate potential violations of the BWC in the context of a possible follow-on organisation to UNMOVIC. Having access to aerial imagery could also increase the effectiveness of a UN-based mechanism to increase transparency in biological weapons-related activities or to investigate possible breaches of the bioweapons ban.

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[1] See Trevor Findlay/Angela Woodward: "Enhancing BWC Implementation: A Modular Approach", The Weapons of Mass Destruction Commission Report No. 23, Stockholm: WMD Commission, October 2004, www.wmdcommission.org; The Verification Research, Training and Information Centre: "A new strategy: strengthening the biological weapons regime through modular mechanisms", Verification Matters, VERTIC Research Report No. 6, London: October 2006.

[2] See Trevor Findlay: "BWC 2006: Verification and the BWC: Last Gasp or Signs of Life?", in: Arms Control Today, Vol. 36, No. 7, September 2006, pp. 12-16.

In the long term, aerial imagery can and should be one of the tools available to a multilateral verification institution involved in monitoring the BWC.

This paper describes first the technical capabilities of aerial surveillance today. It then uses some historical anecdotes to illustrate the contributions of overhead imagery to monitoring the bioweapons ban. Next, the current practice of using aerial imagery and other open source information in multilateral arms control organisations is examined. The potential use of aerial imagery in the context of mechanisms to monitor compliance with the BWC is described. Finally, recommendations for policy-makers are given.

An initial draft of this paper was written in 2000 and early 2001, when BWC state parties were still engaged in negotiations on a compliance protocol. At the time, it was hoped that the paper would be published by the Verification Research, Training and Information Centre as a contribution to the talks of the Ad Hoc Group. When it became apparent that negotiations on a universal, legally-binding monitoring regime would not be finished any time soon, the initial draft went into the drawer. The current version has been updated both in terms of the technical capabilities of commercial satellite imagery and takes into account new developments in relevant international organisations. The second chapter of the paper, on the technical capabilities of commercial satellite imagery and overflights, has been written by Dr. Götz Neuneck with the assistance of André Rothkirch, both of the Institute for Peace Research and Security Policy at the University of Hamburg.

The author conducted a number of background interviews with officials from CTBTO, IAEA and UNMOVIC on current and future contributions of aerial imagery in monitoring compliance with multilateral nonproliferation agreements. In addition, several experts have commented on early drafts of the paper. The use of overhead imagery in multilateral arms control regimes is a sensitive topic. For some states "it is still a spying technology", as one official working for an international nonproliferation agency put it in an interview. Because of these and other sensitivities, all interviews were conducted on a background basis. The author would like to thank the experts that helped with the study for their time and patience. It was encouraging to see their enthusiasm for making verification more effective by using this novel verification means. All errors in the study are the sole responsibility of the author.

2. Technical capabilities of commercial satellite imagery and overflights[3]

The terms aerial imagery or overhead imagery are used here to describe all images taken from satellites or airplanes. Today, several technologies such as optical sensors or radar are used for gathering distant information from aircraft or spacecraft. Data from the earth surface may be acquired through a variety of sensor technologies. Most remote sensing techniques make use of emitted or reflected electromagnetic radiation of the object of interest in a certain wavelength domain (infrared (IR), visible light or microwave radiation). Different sensors have a different number of "wave bands" or "colour channels" of the electromagnetic spectrum.[4] The more channels a sensor has, the more detail it reveals of the observed object.

[3] This chapter has been written by Götz Neuneck of the Institute for Peace Research and Security Policy at the University of Hamburg. The author thanks André Rothkirch for comments, material and his work on satellite imagery.

[4] Multispectral sensors have between three and 15 channels. "Hyperspectral" images are based on more than 30 channels.

The resolution of a sensor is the smallest change it can detect in the quantity that it is measuring. The term image resolution describes the details an image can hold. Higher resolution of an image means a more detailed picture.[5] The resolution of satellite images depends on the instrument used and the satellite's altitude.

Cameras and digital sensors onboard satellites measure the electromagnetic radiation emanating from the observed object. Different types of sensors fulfil specific purposes. Optical sensors are powerful tools for object identification. Thermal infrared pictures can reveal heat sources such as heated buildings, turbines or changes in ground temperature. Radar sensors have the advantage of being operational 24 hours a day because they work independent of sunlight and cloud covers. Their resolution is lower than that of optical cameras. Synthetic aperture radars are emitting and measuring microwave beams and can produce high-resolution images.

In the beginning of the space age, classical film cameras and scanners with mechanical components such as rotating mirrors and cooled sensors were used for earth observation. Photo negatives had to be transferred to earth and developed. Today, digital detector cells with no mechanical scanning mechanism allow a rapid collection of data and the swift transfer to a ground station. An important progress in sensor techniques stemmed from subdividing spectral ranges of radiation into intervals of wavelength or "bands" thus creating multispectral images with more object information. Special data-processing techniques allow to filter special information out of the image data.

An observation satellite system consists of three key components:

- the spacecraft, equipped with sensors of different wavelength and a data transmitter,
- a receiving station on the ground, and
- a data-processing facility.

Important parameters for observation spacecraft are also the revisiting frequency of a satellite. A high revisiting frequency permits frequent observations and thereby the monitoring of things such as the movement of vehicles or other changes in time (vegetation, light, etc.).[6]

2.1. Commercial satellite imagery

Ever since the Soviet Union's launch of the *Sputnik* in 1957, earth observation (EO) has been used primarily for military purposes. Most remote sensing satellites are operated by national governments and used by national intelligence agencies. Access to images from such satellites is usually limited to analysts and decision-makers from the country that owns the satellite and possibly some allies. The capabilities of such national intelligence satellites are classified but it is estimated that military satellites now have a resolution in the centimetre range.[7]

State-monopoly of satellite imagery ended with the 1972 launch of *Landsat 1*, the first commercial satellite. Since then, both the quality and availability of commercial satellite imagery have increased consistently. The launch of *SPOT-1*, a joint Belgian-French-Swedish satellite in 1986,

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[5] Resolution can be quantified by saying how close lines per millimetre or pixel (digital elements) can be to each other and are still to be resolved. Spatial resolution is measured in pixels per inch.

[6] A revisiting cycle is defined by the number of days it takes the satellite to be able to image the same area. Repeat cycle refers to the number of days it takes the satellite to be able to return to the same orbital position.

[7] See Bhupendra Jasani: "Remote Monitoring from Space: The Resolution Revolution", in: Trevor Findlay (ed.): Verification Yearbook 2000. London: The Verification Research, Training and Information Centre (VERTIC), December 2000, pp. 199-213, pp. 203-204.

opened access of moderate-to-high-resolution photography to the public for commercial use. *Landsat 7*, launched in 1999, has a spatial resolution of 15 m (panchromatic).[8]

The launch of *Ikonos* by the U.S. company *SpaceImaging* in September 1999 was a breakthrough for many commercial applications. *Ikonos* has a resolution of 1 m, sufficient for detecting and identifying many militarily relevant activities. The launch of *QuickBird* in October 2001, now operated by *DigitalGlobe*, was another big step towards the application of commercial imagery for arms control purposes. The panchromatic mode of *QuickBird* has a resolution of 0.61 m and currently provides the highest quality commercial satellite imagery. The trend towards more capable commercial satellite imagery will continue. Launches of additional U.S. commercial satellites such as *GeoEye-1* or *WorldView-I*, with a resolution of 0.41 m and 0.45 m respectively, are scheduled in 2007/08.

Commercial satellite imagery has not only become better but it can be procured from ever more suppliers. *SPOT-5*, launched in May 2002 has a spatial resolution of up to 2.5 m in a panchromatic mode and 10 m in the multispectral mode. Its instruments allow three-dimensional imaging by stereoscopic views and forward/backward viewing capability of the onboard camera with a resolution of 10 m.

Other commercial EO-satellites with a comparable resolution have been launched by Israel (*EROS-A1*, 2000; resolution 1.9 m), Russia (*Resurs F-3*, *KVR-1000*, 2 m), India (*CartoSat-1*, 2005, 2.5 m), Japan (*IGS-1a*; 2003, 1 m) and South Korea (*Kompsat-2*, 2006, 1.5 m). Digital sensors are increasingly substituting analogue photography.

As more and better EO satellites are launched, coverage is also getting better. For most densely-populated areas images with a resolution of 10 m or better are available globally. Outside such areas, image resolution may vary between 100 and 500 m.

Access to such imagery is improving but still subject to various limitations. U.S. companies such as *DigitalGlobe* or *SpaceImaging* are today the only sources for satellite images with a resolution below 1 m. These companies are subject to various U.S. government restrictions, based on national security and economic considerations. The 1994 Presidential Decision Directive-23 on "Foreign Access to Remote Sensing Space Capabilities" empowers the U.S. government to delay, restrict or prohibit the sale of high-resolution satellite images.[9] This "shutter control" allows the government to temporarily restrict the collection and dissemination of imagery data of a particular geographical region if circumstances pose a risk to U.S. national security or based on international obligations and foreign policy considerations during crisis or armed conflict.

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[8] Panchromatic is a term describing a type of a sensitive black-and-white photographic film that is susceptible to all wavelengths of the visible light.

[9] In 1994 President Clinton issued PDD-23 on foreign access to remote sensing space capabilities, which makes it mandatory for all U.S. companies to acquire a U.S. government license on activities related to remote sensing space systems, technology, products, and data. Among other things, the PDD requires pre-notification of the U.S. government on any new major contract concluded between foreign customers and U.S. satellite imagery providers. See The White House: "Foreign Access To Remote Sensing Space Capabilities", Washington, D.C.: The White House, Office of the Press Secretary, 10 March 1994, http://www.fas.org/irp/offdocs/pdd23-2.htm. The executing agencies are the Department of Commerce and the National Oceanic and Atmospheric Administration. See "Application to Operate a Commercial Land Observation System", Washington, D.C., March 1994, Section B, Part 1; The guidelines for the licensing of commercial remote sensing satellites can be found at http://www.licensing.noaa.gov/. See also Laurence Nardon: Satellite Imagery Control: An American Dilemma. Paris: Ifri, March 2002, http://www.csis.org/nardon_ang.pdf.

Most sales of U.S. commercial imagery have to be approved by the National Geospatial-Intelligence Agency (NGA). Such sales have been restricted, for example, before, during and after the U.S.-led invasion of Iraq in 2003.

The "Kyl-Bingaman Amendement to the National Defense Authorization Act of 1997" also restricts the collection and release of satellite images from Israel which have a resolution "more detailed or precise than satellite imagery of Israel that is available from commercial sources".[10]

While U.S. companies dominate the commercial satellite imagery market, the United States does not hold a monopoly. Companies such as *ImageSat* (Netherlands Antilles) or *SpotImage* (France) are competing with U.S. providers. The market for commercial satellite imagery is continuing to grow, "although the pace and scope of that growth remain uncertain."[11]

Delivery times and the prices of a satellite image depend on several factors and can vary significantly. The main factors are

- the quality of the picture (geographical coverage, resolution, stereo, observation angle),
- operational factors (such as cloud coverage, location of the target area, ground station for data transfer),
- the amount and processing of data (channels, geo- or orthorectification[12])
- the license level (privat, single-user or multiple-user)[13] and
- the region and the location of the receiving station of the end-user.

On average, the price of a satellite image covering 100 km² with a delivery time between 90 to 120 days is US$3,000.[14] Archived images may be considerably cheaper and can be purchased faster than current imagery. The average price for 100 km² may be below US$2,000, and the images can be delivered within a few days, depending on the provider.[15]

Commercial satellite imagery has several strengths that make its use in the context of multilateral arms control accords attractive. Satellite imagery can be legally obtained from anywhere and its use is sanctioned under international law.[16] In addition, depending on the orbital parameters they overfly, satellites can cover huge areas in a short period of time. Satellites are following predictable periodical trajectories and allow specific revisiting cycles depending on the orbit parameters of the satellite.

Optical sensors can only be used during daytime, whereas radar satellites are independent from weather and sunlight. The sun is the major source of light for photography, and thus weather conditions and time-of-day must be optimal to create reasonable information. The satellite and

[10] U.S. Congress: "National Defense Authorization Act for Fiscal Year 1997", Public Law 104-201, Washington, D.C.: September 1996, Section 1064 (a, b), p. 2653, http://www.nps.gov/legal/laws/104th/104-201.pdf.

[11] Kevin O´Connell/Beth E. Lachman: "From Space to Information: Commercial Remote Sensing Market Factors and Trends", in: John C. Baker/Kevin M. O´Connell/Ray A. Williamson (eds.): Commercial Observation Satellites. At the Leading Edge of Global Transparency. Santa Monica: RAND Corporation 2001, pp. 71-72.

[12] Orthorectification refers to the process of removing distortions from an image so that it can be used by a mapping or geographic information system.

[13] Thus, imagery acquired under a multi-use license, to be used by several international organizations might be considerable more expensive than data purchased for use by a single end-user.

[14] Assuming an average price of US$30 per square kilometre. See table 1 for a more complete list of prices.

[15] Archived imagery is available from *Ikonos* and *QuickBird* but not from *SPOT* satellites. *Ikonos* imagery enters the archive if it is older than six months.

[16] This interpretation is usually based on the fact that no government objected to the first overflight of the Sputnik on 4 October 1957. Satellites orbit at an altitude of at least 150 km, and therefore beyond national airspace. See Jasani: "Remote Monitoring from Space", op. cit., p. 199.

the sensor-package onboard must be operated from the ground. Because the total area of the land is large and because the resolution is relatively high, the data stream which has to be transmitted from the spacecraft to the ground station is large and transmission time-consuming.

Table 1: Characteristics of some existing and planned commercial earth observation satellites

System	*Company*	*Resolution*	*Repeat/ revisit cycle*	*Status*	*Price per square km*[17]
Ikonos	*SpaceImaging* USA	1 m Pan 4 m MS	14 days/ 1-3 days	Launched September 1999	US$10-24 for Pan/MS; US$34-48 for stereo
EROS A	*ImageSat* Israel	1.9 m Pan		Launched December 2000	US$2.55-US$15.31
Quickbird	*DigitalGlobe* USA	0.61 m Pan 2.44 m MS (4 band)	20 days (max)/ 1-4 days (max)	Launched October 2001	US$16-22 for Pan/MS/color
Spot-5	*SpotImage* Neth. Antilles/ France	2.5/5 m Pan 2.5-20 m MS	26 days/ ~2 days	Launched May 2002	US$0.63-23.27 for Pan/MS; US$34-48 for stereo
Formosat-2	*NSPO* Taiwan/ *SpotImage* France	2 m Pan 8 m MS (4 bands)	?/ 1 day	Launched May 2004	?
EROS B	*ImageSat* Israel	0.7 m Pan	?	Launched April 2006	US$2.55-15.31
Kompsat-2	*KARI/EADS* Korea	1 m Pan 4 m MS (4 bands)	28 days/ 3 days	Launched July 2006	?
GeoEye-1	*GeoEye* USA	0.41 m Pan 1.64 m MS (4 bands)	?/ < 3 days	Planned Early 2007	?
WorldView I	*DigitalGlobe* USA	0.45 to 0.51 m Pan (0.5 m for non-U.S. customers) / - (?)	?/ 1.7-5.9 days	Planned Mid 2007	US$17-28
WorldView II	*DigitalGlobe* USA	0.46 to 0.52 m Pan (0.5 for non-U.S. customers) / 1.8-2.4 m MS (8 bands)	?/ 1.1-3.7 days	Planned 2008	US$17-28

Pan: panchromatic
MS: multispectral

[17] Data based on Simon Collard-Wexler/Thomas Graham/Robert Lawson/Wade Huntley/Ram Jakhu/William Marshall/John Siebert/Sarah Easterbrooks: Space Security 2006. Canada 2006, p. 8, downloadable at www.spacesecurity.org.

2.2. Overflights and the Open Skies Treaty

Airborne surveillance has its origin in military aircraft using cameras for monitoring enemy installations and activities. Today, civilian aircraft are used in many countries for fishery patrols, border surveillance or ground surveillance for mapping, traffic and environment monitoring, and geological survey. For these purposes, an optical or infrared camera shoots pictures from a free-flying platform (airplane, balloon, helicopter or unmanned air vehicle). Photography commonly takes place in the visible range of the spectrum but films that are sensitive to the very near infrared or ultraviolet allow images being taken in those spectral regions. Taken in the stereo mode, aerial imagery can provide object identification on the ground. Because aircraft can carry large payloads, they are not subject to the same restrictions as satellites in terms of collection, interpretation, storage and transfer of imagery. The resolution of air-based imagery systems depends on the cruising altitude of the observing aircraft and can reach a resolution of 0.3-3 m in a multispectral mode.

There are two main advantages of aerial surveillance over space-based imagery. A mission with aircraft can – weather permitting – be flown at any time and the resolution of imagery can be higher due to the lower flight altitude of aircraft. Aircraft, however, need permission to fly over the territory of the observed country whereas satellite imagery can be taken without the consent or even knowledge of the observed country.

The 1992 Open Skies Treaty, which establishes a mechanism for co-operative overflights among treaty members, allows the use of four types of imaging sensor technologies, which must be commercially available in all member states:[18]

- *Cameras* with a resolution no better than 30 cm.
- *Video cameras* with a resolution no better than 30 cm. The main advantage of video images vis-à-vis photography is the ability to monitor pictures in real time and to observe movement on the ground.
- *Thermal Infrared (IR) sensors* with a maximum resolution of 50 cm. Infrared sensors are useful for the collection of night time imagery, the penetration of haze and smog and the detection of camouflaged or obscured objects. Even though cloud cover degrades the capability of IR sensor, these give Open Skies aircraft an all-weather, day and night observation capability. IR sensors can be used to detect the heat of engines and monitor the operational status of facilities.[19]
- *Synthetic Aperture Radar (SAR)* with a ground resolution of less than 3 metres. SAR has an all-weather, day and night observation capability. SAR creates a three-dimensional map of the ground to the side of the aircraft and is useful for monitoring the position of ships, aircraft and vehicular activity.[20]

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[18] Treaty on Open Skies, Article IV.

[19] When analysed in the context of possible inspections under the CWC, it was concluded that infrared images could identify "cool and hot buildings, pipelines and tanks". See Amy Smithson/Michael Krepon: "Strengthening the Chemical Weapons Convention Through Aerial Imagery", Stimson Center Occasional Paper 4, Washington, D.C.: The Henry L. Stimson Center, April 1991, p. 15.

[20] Experts on the verification of the CWC concluded that SAR might reveal information about a facility such as "feed pipes, power lines, and vehicles parked around the facility". See Smithson/Krepon, op. cit., p. 16.

The treaty permits "the introduction of additional categories and improvements to the capabilities of existing categories", if agreed by all members of the OSCC. No agreement has been reached yet to add new types of sensors.[21]

Table 2: Resolution of Open Skies aircraft, commercial and reconnaissance satellites[22]

Sensor	*Optical*	*Mid-IR*[23]	*Thermal IR*[24]	*SAR*
Open Skies	0.3 m	-	0.5 m	3 m
Commercial satellites	0.6-1.0 m	-	90 m	1 m
Reconnaissance satellites	0.1-0.5 m	0.6-0.9 m	-	0.6-0.9 m

Four other categories can be used to compare aerial and space imagery.

Accessibility: Commercial imagery providers ideally offer delivery within a timeframe of five to 14 days after order placement, whereas Open Skies flights can be scheduled and carried out within less than seven days. Films can be developed within 24 hours.

Area coverage and resolution: The ground coverage of the photographic cameras is limited to 50 km on each side of the flight path, whereas the typical swath of a 1 m satellite is between 8-16 km. The resolution of the photo-cameras is 30 cm in the optical mode and pictures may be taken in stereo. Thus, Open Skies images are unmatched by existing commercial satellite images, which can reach a resolution of 60 cm at best.

Weather and other operational parameters: Aircraft can fly below cloud ceilings in case clouds block optical sensors. Infrared cameras and radar can be used irrespective of daylight.

Costs: Cost estimates show that a Open Skies flight, which collects data from 30 geographically separate sites of interest within five flight hours can lead to a total cost of about €1.400 per site, whereas the comparable satellite images might cost €2.000-4.000 per site.[25]

Table 3: Minimum resolution at which varying targets can be detected, identified and analysed[26]

Target on the ground	*Detection*	*General Identification*	*Precise Identification*	*Technical Analysis*
Vehicles	1.5 m	0.6 m	0.3 m	0.045 m
Aircraft	4.5 m	1.5 m	1.0 m	0.045 m
Nuclear weapons components	2.5 m	1.5 m	0.3 m	0.015 m
Rockets and artillery	1.0 m	0.6 m	0.15 m	0045 m
Command and control headquarters	3.0 m	1.5 m	1.0 m	0.09 m
Ports and harbors	30.0 m	15.0 m	6.0 m	0.3 m

[21] Treaty on Open Skies Article IV. See also Hartwig Spitzer: "The Open Skies Treaty: Entering full implementation at low key", draft paper, 4 March 2006, http://censis.informatik.uni-hamburg.de/openskies/OS_Artikel_Helsinki_Monitor_final_4March2006.pdf, p. 8.

[22] Based on Pál Dunay/Márton Krasznai/Hartwig Spitzer/Rafael Wiemker/William Wynne: Open Skies: A Cooperative Approach to Military Transparency and Confidence Building, Geneva: UNIDIR 2004, p. 190.

[23] Mid-Infrared sensors operate at a wavelength of at 3.5-5µm and are used to detect hot sources with a temperature of more than 800 °C, such as missile plumes.

[24] Thermal infrared sensors detect heated buildings or areas with warm surface temperature.

[25] Dunay/et al., op.cit., p. 191.

[26] Jeffrey Richelson: "The whole world is watching", in: The Bulletin of the Atomic Scientists, Vol. 62, No. 1, January/February 2006, pp. 27-35, p. 33.

3. Historical contributions of aerial surveillance to biological weapons monitoring

Aerial imagery has assisted efforts to identify or assess possible breaches of the BWC in a number of historical instances, mostly as a national technical means (NTM).[27] A comprehensive review of the role of overhead imagery in monitoring bioweapons-related activities is beyond the scope of this paper but anecdotal evidence illuminates some strengths and weaknesses of remote sensing.

3.1. The Soviet biological weapons programme

During the Cold War, the use of satellite imagery to verify compliance with arms control treaties was the prerogative of the two superpowers. The United States and the Soviet Union were the sole possessors of technical means powerful enough to directly monitor the other side. The United States observed suspicious facilities in the Soviet Union even before the BWC was negotiated.[28] The capability of U.S. spy satellites in the 1960s is roughly comparable to that of commercial satellite imagery today.

Detection of possible Soviet biological weapons capabilities presumably gained new urgency after President Nixon decided to terminate the U.S. offensive bioweapons programme in the late 1960s. The 1972 BWC was the first multilateral accord to ban an entire class of weapons. In contrast to many bilateral U.S.-Soviet nuclear arms control accords of the time, which explicitly call for non-interference with NTM, the multilateral BWC contains no such provisions.

In 1975 and 1977, U.S. newspapers alleged that the Soviet Union was breaching its obligations under the BWC by running an offensive biological weapons programme at a number of locations. These imprecise reports were based on satellite imagery coming from intelligence sources.[29] It appears that the conclusions based on the analysis of the imagery were ambiguous but crucial indicators named in the reports included "very high incinerator stacks and large cold storage bunkers" indicating "they were built for biological warfare capability".[30]

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[27] In the context of treaties, National Technical Means of verification are usually understood to encompass all means of remote sensing, such as satellites or radio antennas. "Illegitimate" intelligence means such as espionage are viewed as being outside of this definition, but they of course contribute to national assessments of other states' capabilities. There is also a large gray area between NTM and espionage to which many means of gathering intelligence belong. See for example Allan S. Krass: Verification: How Much Is Enough?, London and Philadelphia: Taylor & Francis 1985, p. 7.

[28] A list of confirmed and suspected former Soviet biological and chemical weapons research, production, storage and testing facilities - and satellite imagery of some of these sites - has been published by the U.S. nongovernmental organization GlobalSecurity.org. Some of this imagery is more than 20 years old and includes imagery from the 1950s, 1960s, and 1970s from *Corona* and *Landsat* satellites as well as the U-2 spy plane. Among the most impressive imagery is that of the former Soviet biological weapons test site Vozrozhdeniye Island in the Aral Sea. See http://www.globalsecurity.org/wmd/world/russia/cbw_fac.htm.

[29] See Michael Moodie: "The Soviet Union, Russia, and the Biological and Toxin Weapons Convention", in: Nonproliferation Review, Vol. 8, No. 1, Spring 2001, pp. 59-69, p. 61.

[30] Cited in Milton Leitenberg: "The conversion of biological warfare research and development facilities to peaceful uses", in: Erhard Geissler/John P. Woodall (eds.): Control of Dual-Threat Agents: The Vaccines for Peace Programme, Oxford: Oxford University Press 1994, pp. 77-105, p. 90. Other analysts reached similar conclusions regarding the characteristics of biological weapons activities: "There are few indicators that could be monitored by aircraft or satellites (e.g., test sites, storage areas, enlargement or modification of known facilities, aerial images of known facilities, etc.). The USA, however, was able to use overhead imaging photographs to identify specific features of Soviet BW facilities in the mid-1970s, although facilities later built were not identified." Roger Roffey: "Biological Weapons and potential indicators of offensive biological weapon activities", in: Stockholm International Peace

A 1980 *Defence Intelligence Agency* report confirms that the United States at the time did not have direct proof of Soviet biological weapons activities, though overhead imagery was apparently useful in identifying potential sites of interest.[31]

The United States government decided in 1984 to go public with allegations against the Soviet Union but no concrete evidence of Soviet BWC violations could be brought to the attention of the international community. This illustrates general problems in uncovering clandestine biological weapons programmes and the limitations of aerial imagery in that context. The largest offensive biological weapons programme ever remained in the dark despite intense efforts by Western intelligence agencies to detect direct evidence of Soviet BWC violations.[32]

After the end of the Cold War, it became apparent that this failure had been an intelligence fiasco on a massive scale. The offensive Soviet programme involved tens of thousands of staff and dozens of sites.

Following President Yeltsin's *de facto* admission that the Soviet Union had run an illegal offensive biological weapons programme, the United Kingdom, the United States and the Soviet Union/Russia agreed in 1992 on a set of trilateral inspections in order to investigate the scope of Soviet (and possible Russian) BWC violations. These inspections were not conducted in a cooperative environment. Though the political leadership in Moscow at least initially and reluctantly had agreed to allow British-American teams to visit certain facilities and sites, cooperation on the ground was at times difficult. Under such circumstances, aerial imagery was a useful planning tool to support on-site measures. According to one former British inspector involved in the trilateral process, intelligence, including satellite imagery, "helped considerably in planning (...) site visits."[33]

3.2. Uncovering Iraq's biological weapons programme: the experience of UNSCOM and UNMOVIC

Aerial imagery contributed significantly to biological weapons disarmament in Iraq. The United Nations Special Commission (UNSCOM) and the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC) are the international bodies that have the most extensive experience in verifying biological weapons disarmament. UNSCOM was initially created in 1991 with the limited task of verifying the dismantlement of Iraq's biological and chemical weapons and ballistic missile programmes after the first Gulf War. Over the course of its existence,

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Research Institute: SIPRI Yearbook 2004. Armaments, Disarmament and International Security, Oxford: Oxford University Press 2004, pp. 557-571, p. 569.

31 "In recent years the Intelligence Community has focused on a number of sites in the USSR which have been categorized as suspect BW production facilities. The controversial nature of these sites within the Intelligence Community revolved around the commonality of 'storage/bunker' areas with identical configuration at the different sites." Defense Intelligence Agency: "Foreign Technology Weapons and Systems", DST 2660P-107-80-SAO, 3 March 1980. The author thanks Milton Leitenberg for bringing the document to his attention.

32 Interestingly, some on the Soviet side seemed to be under the impression that the United States was able to detect the Soviet biological weapons programme by satellite imagery. At a news briefing about the agreement between the Soviet Union, the United Kingdom and the United States on trilateral inspections, Major-General Valentin Yevstigeneyev, then-Deputy Chief of the Defense Ministry Radiation, Biological, and Chemical Directorates admitted that there had been breaches of the BWC by the Soviet Union beginning in the mid-1970s and stated that "[d]ue to space reconnaissance, their existence at once became an open secret." Cited in Jeanne Guillemin: The Investigation of a Deadly Outbreak, Berkeley/Los Angeles/London: University of California Press 1999, p. 186. The author thanks Milton Leitenberg for bringing this episode to his attention.

33 David C. Kelly: "The Trilateral Agreement: lessons for biological weapons verification", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2002. The Verification Research, Training and Information Centre. London: VERTIC 2002, pp. 93-109, p. 104.

UNSCOM and its successor UNMOVIC took on a much larger role of identifying, locating and destroying Iraq's weapons of mass destruction (WMD) programmes.[34]

From its inception, based on UN Security Council Resolution 687, UNSCOM had been given the right to inspect any location in Iraq. The provisions for these inspections, contained in an exchange of letters between UN Secretary General Javier Perez de Cuellar and the Iraqi government, contained the right to take pertinent photographs, "whether from the ground or from the air".

UNSCOM had several sources of aerial imagery. Member states provided imagery taken during high and medium altitude overflights of surveillance aircraft to UNSCOM "on the basis of special arrangements with UNSCOM".[35] For a certain period, UNSCOM also accepted the loan from the United States of a U-2 high-altitude surveillance plane, based in Saudi Arabia and equipped with cameras for aerial photography.[36] In addition, helicopters were equipped for low altitude reconnaissance.[37] Some member states also provided photo interpreters to evaluate the imagery and two member states shared relevant satellite and aerial imagery with UNSCOM and the IAEA.[38] UNSCOM and later UNMOVIC had their own imagery evaluation unit to process specialized imagery provided by governments as well as commercial satellite imagery. These different layers of aerial imagery proved to be a strong asset in verifying Iraqi disarmament.

One of the greatest restrictions on the use of aerial imagery was its limited availability, despite the various sources for such data. In addition, imagery used was not always of the highest possible quality. The capabilities of military satellites are highly classified. In the early days of weapons of mass destruction inspections, the United States degraded aerial imagery before releasing it to UNSCOM.[39] In other cases, overhead imagery was not handed over to UNSCOM staff for independent analysis but only used to brief the Office of the Executive Chairman and chief inspectors.[40]

Assuring the authenticity of the imagery appears not to have been a problem, presumably because providers lacked a motive for supplying misleading data to UNSCOM. UNSCOM analysts also corroborated information gained from aerial imagery with evidence from a variety of other sources as a further means to ensure its veracity.

The use of aerial imagery facilitated the work of international inspectors related to biological disarmament in Iraq in several ways.[41] Overhead imagery from various sources was used to assist inspection planning. UNSCOM would use aerial imagery to determine "the status of a site, its layout and dimensions and possible function of particular structures".[42] UNSCOM and UN-

[34] The Iraq Nuclear Verification Office (INVO), a subsidiary of the IAEA, fulfilled the equivalent tasks relating to the disarmament of nuclear weapons.
[35] United Nations Monitoring, Verification and Inspection Commission: "Summary of the compendium of Iraq's proscribed weapons programmes in the chemical, biological and missile areas", United Nations Security Council, S/2006/420, New York, 21 June 2006, p. 11.
[36] See Jonathan Tucker: "Monitoring and Verification in a Non-Cooperative Environment: Lessons from the U.N. Experience in Iraq", in: Nonproliferation Review, Vol. 3, No. 3, Spring/Summer 1996, pp. 1-14, p. 4.
[37] United Nations Monitoring, Verification and Inspection Commission: "Summary of the compendium", op. cit., p. 17.
[38] Ibid, p. 11.
[39] Tim Trevan: Saddam's Secrets: The Hunt for Iraq's Hidden Weapons. London: HarperCollins, 1999, p. 88.
[40] Jonathan Tucker: "Monitoring and Verification", op. cit., p.4.
[41] The following classification is based on Trevor Findlay's analysis in Trevor Findlay: "A Standing United Nations WMD Verification Body: Necessary and Feasible", An Interim Study prepared for the Commission on Weapons of Mass Destruction, Ottawa: The Canadian Centre for Treaty Compliance, Norman Paterson School of International Affairs, Carlton University in cooperation with The Verification Research, Training and Information Centre (VERTIC), May 2005.
[42] Ibid.

MOVIC inspectors had access to databases that linked cartographic and other information. Aerial images, for example, were used to confirm whether layout or security arrangements of the facility under suspicion were suitable for biological weapons research, development or production.

In addition, the inspectors were able to monitor sites of interest over time in order to detect changes. In some cases, it was possible to use aerial imagery for the surveillance of facilities and sites before and during an inspection. Thus, UN inspectors could observe whether equipment was being removed or whether other unusual activities were taking place.

One of the most important functions of overhead imagery was to evaluate information from other sources, including from national intelligence agencies. UNSCOM analysts used photos taken by United States U-2 planes or satellite imagery to confirm information collected by sources on the ground.[43]

The value of aerial imagery was small when it could not be combined with other sources of information. Former UNSCOM inspector Tim Trevan argues that looking for biological weapons-related facilities in Iraq exclusively on the basis of aerial imagery was a "useful, but limited exercise" because biological weapons production facilities possess no unique characteristics:

> "(...) UNSCOM analysts could analyse the raw aerial photography, with no reference to other intelligence reports, and look for 'fingerprints' – the tell-tale signs that a site was a high-security military facility capable of being used for banned purposes."[44]

According to Trevan, such proxy signatures include high security, high capacity air-conditioning (associated with maintaining buildings with high containment measures), or the type and volume of traffic that comes in and out of the site.[45]

3.3. Historical lessons learned

Historical experience shows that if a state is determined to hide an offensive biological weapons programme, it can evade detection as long as access by inspectors on the ground is prevented. Not only did the large Soviet programme go literally undetected for 20 years, the offensive biological weapons programmes of Iraq and South Africa were also not identified.[46]

Despite all restrictions and limitations, aerial imagery played a crucial role in the verification of the disarmament of Iraq's biological weapons programmes. Without access to overhead imagery, UN inspections would have been less effective and efficient.

Overhead imagery has been particularly useful in combination with relevant information from the ground on biological weapons activities, gained either through national intelligence or cooperative monitoring measures, such as on-site inspections. Off-site measures can then be used for a variety of purposes, including the evaluation of data from such sources as well as preparation, planning and conduct of on-site activities.

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[43] Tim Trevan, op. cit., p. 122.
[44] Ibid.
[45] Ibid.
[46] In the South African case this is not surprising because the programme was small, involving only a few staff and was tailored mainly towards developing biological weapons for assassination purposes. See Marion Burger/Chandré Gould: Secrets and Lies. Wouter Basson and South Africa's Chemical and Biological Warfare Programme, Cape Town: Zebra Press 2002.

4. Aerial surveillance in the context of multilateral arms control and confidence building agreements

This section gives an overview over the scope and manner in which aerial imagery is used in the context of multilateral nonproliferation and arms control agreements in order to highlight some of the strengths and weaknesses as they relate to possible biological weapons monitoring mechanisms. Commercial satellite imagery is treated here as one kind of open source data. The reason for this is political: International arms control organizations encounter similar problems when using open source data and commercial satellite imagery.[47]

4.1. The Open Skies Treaty

Even though overhead imagery has been used since the Franco-Prussian War in 1870 to monitor enemy movements, airborne surveillance has not become a means of monitoring arms control agreements until the 1990s.[48] Aerial overflights as a verification mechanism were discussed during the negotiations between NATO and Warsaw Treaty Organization member states on a Treaty on Conventional Forces in Europe (CFE) in the late 1980s. A separate agreement on Open Skies, setting common standards between different states for cooperative monitoring from the air, was signed in 1992 as one result of these discussions.[49]

Open Skies is used here as a reference point because it might serve as a model for regional or global agreements on using overflights to improve transparency, including on biological weapons activities.

The Open Skies Treaty is a confidence-building regime. State parties have the right to conduct overflights over the territory of other treaty members. These overflights are used to take photographic and video imagery, and use radar and infrared sensors to survey the area overflown.

The treaty entered into force on 1 January 2002. Of the original 27 signatories all but Kyrgyzstan have ratified the accord. Membership is open for all OSCE member states and eight states have joined the regime since entry-into-force, bringing the total to 34 state parties.[50]

Russia conducted the first observation flight under the treaty in August 2002, while the United States carried out its first official flight in December 2002.[51]

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[47] On the use of open sources in arms control see Oliver Meier: "The Use of Open Source Information in Multilateral Arms Control and Disarmament Regimes", Presentation at the 3rd INMM/ESARDA Workshop on Science and Modern Technology for Safeguards, 13-16 November 2000, International House of Japan, Tokyo, Japan and Oliver Meier: "Civil Society and the Biological Weapons Convention: Creating Transparency Under Duress", in: INESAP Information Bulletin, No. 19, March 2002, pp. 14-18.

[48] Aerial surveillance is, however, extensively used to monitor compliance with regional arms accords and cease fire agreements. See J. Matthew Vaccaro: "Evolution of police monitoring in peace operations", in: Trevor Findlay (ed.): Verification Yearbook 2000. London: The Verification Research, Training and Information Centre (VERTIC), December 2000, pp. 183-195 and Trevor Findlay: "Peace operations and the military dimensions of verification", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2001, London: The Verification Research, Training and Information Centre (VERTIC), December 2001, pp. 159-172.

[49] U.S. President Dwight Eisenhower first proposed an Open Skies treaty in 1955. During the Cold War, national security imperatives prevailed over the wish for transparency. The idea was shelved until U.S. President George H. Bush formally revived it following a Canadian government's initiative in 1989. Despite the tremendous changes at the end of the 1980s, Open Skies was negotiated over the course of just three years between the member states of NATO and the Warsaw Treaty Organisation.

[50] Since the treaty entered into force, Bosnia and Herzegovina, Croatia, Estonia, Finland, Latvia, Lithuania, Slovenia, and Sweden have become state parties. Cyprus has applied for membership but Turkey has vetoed accepting them.

Under Open Skies, state parties can conduct overflights over the whole territory of any other party.[52] States are supposed to use their own aircraft for the overflight, unless the observed party insists on using its aircraft ("taxi option"). Participants from both, the observing and the observed party will take part in the observation flight.[53] There are limits on the flight distances of overflights.

Timeline for Open Skies overflights[54]	
+ 0 hrs.	Notification of inspecting state(s)
+ 24 hrs./1 day	Acknowledgement by inspected state, decision on use of aircraft
+ 72 hrs./3 days	Arrival of inspecting aircraft, inspection of aircraft and sensors, handing over of overflight plan by inspecting state(s)
+ 96 hrs./4 days	Commencement of overflight(s)
+ 120 hrs./5 days	End of overflight(s)
+ 216 hrs./9 days	Visiting team must leave host country

The information coming from the sensors is to be shared between the observing and the observed parties. Any data collected during Open Skies overflights can also be requested by other treaty members.[55]

Even though the treaty does not foresee a proper organisation to execute the treaty, it establishes the Open Skies Consultative Commission (OSCC) which is tasked both with implementing the treaty and resolving issues of compliance and concern, as well as ambiguities regarding the treaty.[56]

Open Skies was always intended to be a tool for the monitoring of arms control arrangements.[57] The Preamble notes the possibility of using Open Skies

> "to improve openness and transparency, to facilitate the monitoring of compliance with existing or future arms control agreements and to strengthen the capacity for conflict prevention and crisis management in the framework of the Conference on Security and Co-operation in Europe and in other relevant international institutions."[58]

Several member states have proposed such an expansion but there is no consensus yet to use Open Skies as a means to monitor obligations under other treaties.[59] However, information

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[51] See Arms Control Association: "The Open Skies Treaty at a Glance", ACA Fact Sheet, Washington, D.C.: July 2005, http://www.armscontrol.org/factsheets/openskies.asp.

[52] Some restrictions apply for safety reasons. Overflights may also not be conducted closer than 10 kilometres to a border with a non-Open Skies member state. Treaty on Open Skies, Article VI, Section II, para 2.

[53] Treaty on Open Skies, Article VI, Section II, para 4/G.

[54] This timeline may be shortened by mutual consent of inspecting and inspected party.

[55] This co-operative aspect of the regime is ensured by the fact that every state party can request a first-generation copy of any image acquired during any Open Skies inspection. Treaty on Open Skies, Article IX.

[56] Treaty on Open Skies, Article X. The OSCC is serviced by the OSCE Secretariat and started its operation on 2 April 1992.

[57] Peter L. Jones/Marton Krasznai: "Open Skies: Achievements and Prospects", in: J.B Poole/Richard Guthrie (eds.): Verification Report 1992: Yearbook on arms control and environmental agreements, VERTIC Yearbook, London: Verification Technology Information Centre (VERTIC), 1992, pp. 47-56, p. 48.

[58] Treaty on Open Skies, Preamble.

[59] France, Germany and Sweden proposed during the first Open Skies Review Conference in February 2005 to apply the Open Skies regime to environmental monitoring and conflict prevention and crisis management and to expand

derived from Open Skies activities has been used in the context of other verification regimes. Thus, the Opens Skies Treaty is being used for aerial verification under the 1990 Treaty on Conventional Forces in Europe. Overflights have complemented on-site inspections by covering areas that are not accessible to CFE inspectors, such as North America and Siberia and by providing a cost-effective alternative to ground inspections. Images of chemical weapon sites have also been used by national delegations to the Organisation for the Prohibition of Chemical Weapons (OPCW) in bilateral contacts. And overflights have been used to monitor conventional forces, and in particular naval forces, declared under the Global Exchange on Military Information, agreed in 1994 by the then-member states of the Conference on Security and Cooperation in Europe.[60]

4.2. The International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) uses information from open sources and satellite imagery on a regular basis to verify declarations and information collected during inspections.[61] Both feed into the State Evaluation Report on member states' compliance with safeguards.

Commercial satellite imagery is currently the only type of overhead imagery acquired by the IAEA to verify compliance of member states with their safeguards obligations.[62] It is used by the Agency

- to confirm state declared information. This applies to IAEA member states and includes the verification of design information, for example during the construction of nuclear facilities.
- to verify information declared under the Additional Protocol concerning the layout of buildings and sites related to nuclear facilities.[63] This includes the identification of differences with declared parameters, as well as the quantitative and qualitative analysis of declared information.
- in the contextof investigations, for example to assess the veracity of third party information. This is the most challenging application of satellite imagery.[64]

The Agency has negotiated arrangements with all major commercial providers of such imagery and uses various companies to acquire imagery from different parts of the world. The IAEA's Satellite Imagery Analysis Unit in the Department of Safeguards now has 15 staff, including 7 analysts. Annual costs (excluding staff costs) are about US$1 million.[65]

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the mandate of the Open Skies Consultative Commission accordingly. The proposal did not receive unanimous support by the other state parties. See Spitzer: "The Open Skies Treaty", op. cit., p. 6.

[60] Ibid.

[61] Pierre Goldschmidt: "The IAEA Safeguards System Moves Into the 21st Century", in: Supplement to the IAEA Bulletin, Vol. 41, No. 4, December 1999, S-5. Satellite imagery is processed separately from other open sources and by a different office within the Agency. Interview with IAEA official, Vienna, 21 September 2006.

[62] Informal contacts between IAEA staff and the Open Skies Consultative Commission have not yet led to any cooperation between the two organisations. Interview with IAEA official, Vienna, 21 September 2006.

[63] Such information has to be declared under Article 2 (a)iii of the Additional Protocol.

[64] Interview with IAEA official, Vienna, 21 September 2006.

[65] Ibid.

The Agency wants to expand the use of satellite imagery.[66] In October 2006, the Director General of the IAEA, Mohamed ElBaradei, in an interview with *Newsweek,* explained the rationale for maintaining and possibly expanding the use of aerial imagery:

> "To look into undeclared activity, you need satellite-monitoring imagery. We obviously cannot afford to buy as much as we want. And in many ways we rely on the good will of those who will give the imagery. But they have their own agendas. They might give me what they want to give me, and that is different from me having the independent ability to procure the imagery that I need."[67]

4.3. The Chemical Weapons Convention

The 1997 Chemical Weapons Convention (CWC) does not give the Technical Secretariat of the Organisation for the Prohibition of Chemical Weapons (OPCW) a mandate to use open sources, such as commercial satellite imagery.[68] According to the Convention, the OPCW can only request information directly related to its responsibilities.[69] The CWC limits the scope of information the Secretariat can request from state parties but it is unclear whether it *prohibits* the use of information coming neither from declarations nor from on-site activities.

Officially, the OPCW does not use open sources and there appears to be no effort to systematically evaluate open source information. The Verification Division of the OPCW does not keep information from non-official sources in its official archive but uses such data for training and background purposes. Nevertheless, open source information is used informally within the OPCW and it is common practice for inspectors to collect open source information (for example on the internet) about a facility they are going to inspect. In case of a serious compliance concern, it is conceivable "that compelling data could be acted on regardless of how it was derived or circulated."[70]

The Convention itself does envisage that the verification regime adapts to new technological challenges and opportunities in stating that the OPCW "in undertaking its verification activities, ... shall consider measures to make use of advances in science and technology."[71] The use of overhead imagery could be one such novel verification technology but the issue has apparently not been raised in OPCW policy bodies.

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[66] A working paper on the topic was presented to the Advisory Committee on Safeguards and Verification in May 2006. See Paul Kerr: "Efforts to Strengthen IAEA Safeguards Advance", in: Arms Control Today, Vol. 36, No. 6, July/August 2006, p. 46.

[67] "The Power of the Purse", *Newsweek* interview with Mohamed ElBaradei, 20 October 2006, http://www.msnbc.msn.com/id/15352550/site/newsweek.

[68] During the negotiations on the Chemical Weapons Convention, a number of studies were conducted on the usefulness of aerial imagery from overflights to verify the CWC. See for example Smithson/Krepon, op. cit.; Gregory D. Rowe: "Air Sampling Sensors, the Open Skies Treaty, and Verifying the Chemical Weapons Convention", M.A. in National Security Affairs thesis, Naval Postgraduate School, Monterey, California, December 1995.

[69] "The Organization shall conduct the verification activities provided under this Convention in the least intrusive manner possible consistent with the timely and efficient accomplishment of their objectives. It shall *request only* the information and data necessary to fulfil its responsibilities under this Convention. …", Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, Art. VIII.5. (Emphasis by the author.)

[70] John Hart: "Chemical Industry Inspections Under the Chemical Weapons Convention", Verification Matters, VERTIC Research Report No. 1, London: The Verification Research, Training and Information Centre, October 2001, pp. 24-25.

[71] Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, Article VIII, A.9.

4.4. The Comprehensive Nuclear Test Ban Treaty

The Comprehensive Nuclear Test Ban Treaty (CTBT) provides for an International Monitoring System to be set up by the CTBT Organization (CTBTO) in Vienna to monitor compliance. This system of 321 stations, using seismic, infrasound, hydroacoustic and radionuclide sensors, will monitor for nuclear test explosions globally taking place in any environment. The CTBT has not entered into force because ten of the 44 states that have to ratify the accord for it to become legally-binding have yet to do so.

Overhead imagery can be used for CTBT verification in three ways. First, member states can submit "any relevant technical information" obtained by national technical means "in a manner consistent with generally recognised principles of international law"[72] to support a request for an on-site inspection. Such data could include overhead imagery from a variety of sources.[73]

Second, the On-Site Inspection Division of the Provisional Technical Secretariat (PTS) has started to utilize satellite imagery to assist preparations for future inspections. Such data is already used in the context of OSI exercises. On-site inspections can take place only after the treaty has entered into force. Planning for OSIs is based on a global set of *Landsat* images, acquired in 2005 from the United Nations Cartographic Section.[74] This imagery is five to ten years old. Its resolution of only about 15 metres is sufficient for OSI planning. Where necessary, the imagery is combined with cartographic data and information from a geographic database, making it also a valuable tool for mapping and planning the logistics of future inspections and inspection exercises. It is also conceivable to combine these data sets with elevation maps in order to better plan overflights, which can be part of on-site inspections.[75]

Currently, one permanent PTS staff is working on satellite imagery and a consultant has been brought in to assist. The PTS has so far spent about US$150,000 for hardware and US$50,000 for software to process imagery.[76] Satellite imagery analysis requires extensive training. Maintaining the relevant expertise can be difficult, in particular in international organisations, like the CTBTO, that can employ staff generally for a maximum of seven years.

A third, more sensitive application of aerial imagery would be its forensic use to investigate a possible nuclear weapons test. Treaty negotiators anticipated such use but could not reach

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[72] Comprehensive Nuclear Test Ban Treaty, Article V (D), paragraph 37.

[73] Satellite imagery has figured prominently in discussions on the October 2006 nuclear tests in North Korea. See for example the collection of commercial images of the Institute for Science and International Security at http://www.isis-online.org/publications/dprk/.

[74] Twelve terrabytes of satellite imagery data were copied and transferred to CTBTO, basically free of charge. Interview with CTBTO official, Vienna, 20 September 2006. Information about the UN Cartographic Section can be found at http://www.un.org/Depts/Cartographic/english/htmain.htm.

[75] The CTBT is the only weapons of mass destruction treaty that gives inspectors the right to conduct overflights. Protocol to the Comprehensive Nuclear Test Ban Treaty, Part II: On-site Inspection, paragraphs 71-85 give the inspection team the right to conduct at least one overflight over the inspection area. This overflight shall be used to provide the team with a general overview and to narrow down the area for the investigation. These overflights may be subject to restrictions. During the initial overflight, passive location-finding equipment as well as still and video cameras can be used. During additional overflights (which take place at the discretion of the inspected state party), multi-spectral sensors (including infrared), gamma spectroscopy as well as magnetic field mapping equipment may be used.

[76] Interview with CTBTO official, Vienna, 20 September 2006.

agreement on whether the CTBTO should be tasked with independent assessments of suspected nuclear test explosions.[77] The CTBT thus only states that

> "[e]ach State Party undertakes to cooperate with the Organization and with other state parties in the improvement of the verification regime, and in the examination of the verification potential of additional monitoring technologies such as electromagnetic pulse monitoring or satellite monitoring, with a view to developing, when appropriate, specific measures to enhance the efficient and cost-effective verification of this Treaty."[78]

PTS staff is currently establishing the conditions to be able to use satellite data for diagnostic purposes if and when state parties decide to establish the mandate to do so. The CTBTO, which is a member of the UN family of international organisations, has already negotiated with the UN access to commercial imagery on a priority basis. Access would be granted on the same conditions that apply to humanitarian relief organisations that have such arrangements with the UN. Depending on the coordinates of the site for which imagery is requested, this could take from several days to weeks.[79]

5. The contribution of aerial imagery to monitoring compliance with the BWC

This chapter looks at the potential contribution of aerial imagery to monitoring compliance with the BWC, taking into account the technical considerations, historical lessons and political considerations outlined in the previous chapters.

5.1. VEREX: The group of scientific experts

The major groundwork of the scientific underpinning of a future BWC verification regime was accomplished from 1992-93 by the "Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint" (VEREX) which analysed 21 potential verification measures for the BWC. The technical predecessor of the Ad Hoc Group produced its final report in September 1993, after four meetings. Surveillance by aircraft as well as satellites were two of the off-site verification measures examined by the experts.

With regard to imagery collected from aircraft, VEREX concluded that such data would only have a limited usefulness in detecting violations of the Convention with the possible exception of detecting activities at open air test facilities. Experts argued that it would be difficult to draw conclusions based on air samples that could be collected during overflights. At the same time, VEREX was concerned about the legal and financial implications of overflights.[80] VEREX members were also worried about the costs and availability of high-resolution satellite imagery.[81]

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[77] CTBTO's task is limited to the technical role of providing data. Assessment and interpretation of these facts is left to state parties.

[78] Comprehensive Nuclear Test Ban Treaty, Article IV.11.

[79] Interview with CTBTO official, Vienna, 20 September 2006.

[80] Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint: "Summary Report", BWC/CONF.III/VEREX/8, Geneva, 24 September 1993, p. 13.

[81] Ibid.

The experts argued that it is improbable that non-compliant behaviour can be detected based on satellite imagery. They did however believe that such imagery could be used to validate information from other sources.[82]

5.2. The Ad Hoc Group of BWC state parties

Building on the results of VEREX, an Ad Hoc Group (AHG) of States Parties to the BWC negotiated a compliance protocol to the Convention from 1995 to 2001. In early 2001 Tibor Tóth, then-chairman of talks, tabled a draft verification protocol – called Composite Text – that was subsequently rejected by the United States.[83] Negotiations collapsed. Even though the mandate of the AHG remains in place, a resumption of these talks in the near future seems unlikely. Nevertheless, the verification issue is likely to resurface at some point in the future.[84]

The AHG envisaged three basic monitoring tools, which are part of all modern arms control verification regimes:

- mandatory declarations,
- non-challenge visits, and
- on-site investigations.[85]

An Organisation for the Prohibition of Biological Weapons (OPBW) would have implemented the verification regime. The Composite Text will be used as a reference because it represents the best available middle ground of international opinion on what a future BWC verification mechanism might look like. It also contains the core elements that are likely to be part of any future verification regime.

Declarations

Under a future verification regime, member states will probably have to declare a range of facilities that could potentially be used to research, develop or produce biological weapon agents. Under the Composite Text, past offensive and defensive biological warfare programmes, current defensive programmes, maximum and high containment facilities, vaccine and certain other production facilities as well as facilities working with listed agents would have been declarable.[86]

Aerial imagery can play a limited role in confirming that declarations are correct and complete. These are complementary, yet distinct tasks. The former restricts verification activities to declared sites and facilities, whereas the latter extends the mandate of a verification organisation to look for undeclared activities.

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[82] Ibid.

[83] Ad Hoc Group of the States Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction: "Protocol to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction" BWC/AD HOC GROUP/CRP.8, Geneva, 3 April 2001. (From here on cited as "Composite Text")

[84] See Findlay: "BWC 2006", op. cit.

[85] For a short summary of the historical background on the verification discussion see Nicholas Sims: "Verifying biological disarmament: towards a protocol and organisation", in: Trevor Findlay (ed.): Verification Yearbook 2000, London: The Verification Research, Training and Information Centre (VERTIC), December 2000, pp. 87-99.

[86] Composite Text, op. cit., pp. 18-22.

Identifying a facility's purpose during construction

Judgements about the purpose of a facility can be made based on satellite imagery collected during the construction phase. This was demonstrated in 1970 when the U.S. company *E.I. du Pont de Nemours & Co.* sued the *Christopher* brothers, a rival company, because it had used commercial satellite imagery to learn about DuPont's new method for methanol production. *Christopher* brothers did indeed use the satellite images taken during the construction of the facility to unlock DuPont's trade secret and lost the court case.[87]

A BW verification agency could use older imagery to make informed judgements about the design of a facility. Some construction sites could also be monitored to identify tell-tale signs of a BW facility.

The utility of aerial imagery to confirm the correctness of declarations is small because most relevant activities cannot be observed from outside the facility. Declarable activities that could be detectable by overhead imagery include

- the dismantlement of sites and facilities involved in past offensive programmes,
- certain elements of defensive programmes such as test sites or animal holding areas,
- activities associated with unusual outbreaks of disease.

<u>Visits</u>

There was broad agreement in the AHG that declarations should be followed up by non-challenge on-site activities, called visits. Such inspections would not be used to clarify a specific non-compliance concern but serve to increase trust in compliance. The Composite Text foresaw different types of visits:

- *Randomly selected visits* to confirm the information contained in declarations on the ground.
- C*larification visits* to clarify possible questions arising from declarations.
- *Assistance visits* to help with implementation of verification provisions.[88]

Aerial imagery may be used in several ways to assist with these activities. It could have a role in selecting the facilities to be inspected. Overhead imagery might reveal features that are not consistent with a state's declaration. For example, large storage areas, exhaust pipes or other external features at a declared facility might be indicators for a production capability that is inconsistent with the declaration.

Overhead imagery could also be used to monitor facilities that have been selected for a non-challenge inspection prior to the arrival of the inspection team. Aerial surveillance could detect (and deter) suspicious activities such as the removal of equipment. During the inspection, such imagery could serve as guide to inspectors, in particular at large sites or facilities.

<u>Challenge inspections</u>

Investigations into alleged breaches of the Convention were the most intrusive verification tool envisaged under the draft protocol. AHG negotiators foresaw two types of challenge inspections:

[87] Cited in Yahya A. Dehqabzada and Ann M. Florini: "Secrets for Sale: How Commercial Satellite Imagery Will Change the World", Carnegie Endowment for International Peace Report, Washington, D.C.: Carnegie Endowment for International Peace 2000, p. 14.
[88] Composite Text, op. cit., Article 6, pp. 25-47.

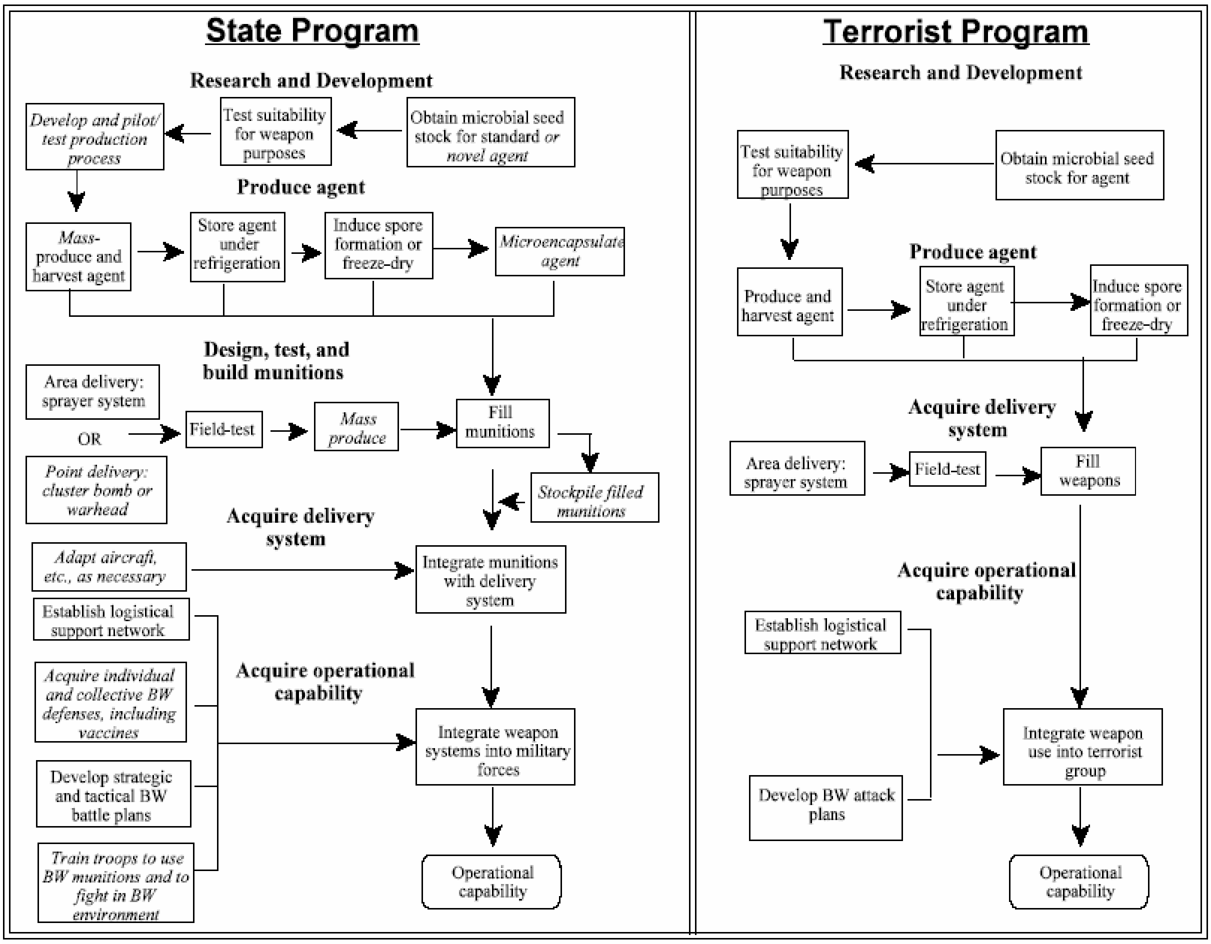
- *Facility investigations* to investigate suspicions of illicit work on biological weapons in a declared or undeclared facility.
- *Field investigations* to clarify concerns that biological weapons might have been used or in case of a suspected accidental release of an agent.

Both types of inspections would have to be launched quickly in order to find evidence of possible breaches of the Convention. The draft Protocol anticipated inspections to begin 18-96 hours after such a request had been issued.

Aerial imagery in the context of investigating breaches of the Convention can be used to detect, identify and locate clandestine activities and to assist the inspection team.

When discussing the visibility and detectability of illicit biological weapons facilities it is important to differentiate between the research, development and production phases of a weapons programme.[89] Generally, the further advanced a military programme is, the more likely it is that it will be detectable from the air.[90]

Comparison of state biological weapons of mass destruction and terrorist biological agent development[91]



[89] This argument in principle applies to both, state and terrorist programmes, though a bio-terrorist may need less steps to develop an offensive biological weapons capability than a government. See ibid.

[90] This was already the conclusion of a chapter in the 1971 SIPRI Yearbook. See "Applicability of inspection techniques to different activities", SIPRI Yearbook 1971, p. 88.

[91] Taken from Dana A. Shea/ Frank Gottron: "Small-scale Terrorist Attacks Using Chemical and Biological Agents: An Assessment Framework and Preliminary Comparisons", CRS Report for Congress, RL32391, Washington, D.C., 20 May 2004.

Facilities involved in basic research of biological weapons are difficult to identify, even when on-site access is granted. Research on biological agents can take place in small, confined laboratories that may not possess features that make them distinguishable from other chemical or biological facilities.

As one biological weapons analyst observed: "Past military BW production programs have been large, and this would still be true for possible future large-scale state programmes."[92] Thus, a military programme for the development of biological weapons is likely to require open air testing to validate that agents spread as predicted and have the desired effect on test animals.[93] Such test sites possess characteristic features which can make it possible to detect them from the air.[94] These include

- outdoor grids,
- position markers,
- animal transporters and dispersion equipment,
- grids for survival tests,
- buildings to house animals,
- refrigerated bunkers.[95]

Because most biological weapon agents are living organisms and therefore difficult to store over an extended period of time, a proliferator has to choose between having a large production capability on standby or producing biological agents and storing these in protected and air-conditioned storage site. This choice depends on the threat assessment and the characteristics of the biological agent to be produced. Historically, states with large programmes have chosen a mix of both strategies.

Indicators of facilities involved in agent production and storage that may be detectable by overhead imagery include

- refrigerated containers for storage,
- other storage/transport tanks,
- incinerators for many and large animals,
- security, including fences,
- guard towers and military presence,
- facility divided into several security zones.[96]

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[92] Ibid, p. 569.
[93] Historically, all states operating offensive biological weapons programmes have tested their weapons in the open because the development of effective dispersal techniques for biological agents is difficult to simulate "on the drawing board" or in laboratory experiments. Even the United Kingdom, which had access to test data from the U.S. biological weapons programme did want to confirm these results independently and conducted "national" tests.
[94] Since the purpose of the testing of BW is to evaluate the spread of agents, test sites typically contain collectors and/or test animals which have to be distributed over a fairly large area. Associated animal holding areas may also be observable from the air. Test assembly and spreading of the agent takes a considerable amount of time and should therefore be observable from the air. This was recognised by VEREX, which concluded that "insofar as commercially-available satellite imagery may be useful in detecting and monitoring outdoor weapon testing areas, then certain patterns of weapons testing (e.g. sensor grid layouts, animal cages) might be indicative of activities requiring clarification through other means." Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint: "Summary of the work of the Ad Hoc Group for the period 23 November to 4 December 1992", BWC/CONF.III/VEREX/8, Geneva, 8 December 1992, p. 24.
[95] Roffey, op. cit.
[96] Ibid, pp. 569-571. VEREX came to a similar conclusion and found that overhead imagery, "can detect, in certain circumstances, powerline connections between facilities; air condition machinery; steam heating or coolant conduits, even when buried underground; bunkers; effluent outlets; pipelines; setting or sewage ponds; and other general indicators of activity." BWC/CONF.III/VEREX/4, op. cit., p. 24.

Finally, biological weapons munitions filling facilities have to be constructed, maintained and operated. Such facilities can have the following characteristics associated with them which may be detectable from the air:

- transfer of weapons or agents in special containers or lorries,
- weapons, munitions, missiles, unmanned air vehicles or other means of delivery,
- equipment for biological weapons defence and biological weapons-protected buildings.[97]

To be sure, none of these pointers is a sufficient or necessary indicator for an illicit bioweapons activity. In combination, they might, however, raise suspicions about activities at specific locations. And masking all these activities will at the very least raise the cost of any clandestine biological weapons programme.

<u>The Organisation for the Prohibition of Biological Weapons and aerial imagery</u>

Given the potential contributions of aerial imagery to monitoring compliance with the BWC, a future OPBW should be given the mandate to make use of such information. The organisation could have the right to consider such imagery in the context of consultation and clarification procedures and facility or field investigations. Member states could use satellite imagery to back-up compliance concerns.[98]

From a verification point of view, it would also make sense to grant the organisation a pro-active role in using aerial imagery.[99] The organisation could be mandated to request or acquire aerial imagery, if it believes that such information is helpful in fulfilling its mandate. For example, the secretariat could ask member states or international organisations to supply imagery about a region, site or facility of interest. The secretariat could also acquire imagery from commercial providers. It might also use imagery that is already publicly available at no cost, such as the images that have been made available on the internet. A future organisation could also be given the right to interact with international or regional organisations during the fulfilment of its verification mandate. Lastly, the organisation could be given the mandate to request an overflight to clarify compliance concerns.

5.3. A United Nations monitoring mechanism for biological weapons

UNMOVIC is currently the only permanent, multilateral institution monitoring compliance with the ban of biological weapons but its mandate is limited to Iraq. The Commission's current tasks with regard to biological weapons are twofold. UNMOVIC still has to verify the complete disarmament of Iraq and has to establish a regime for the ongoing monitoring and verification (OMV) of Iraq.

Aerial imagery has only a limited role to play in verifying biological weapons disarmament. The dismantlement of test ranges and facilities can be observed and verified from the air, in particular the destruction of large sites and facilities. Aerial imagery is also being used to assess the status of

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[97] Roffey, op. cit., pp. 569-571.

[98] The Composite Text did not foresee a role for the Technical Secretariat in receiving or processing information, unless the data came from declarations or was collected during on-site activities.

[99] The Composite Text did not provide for use of overflights or satellite imagery. The only role of aerial surveillance envisaged was in the context of voluntary "orientation overflights" during challenge inspections: "Upon the request of the investigation team, the receiving State Party may provide an overflight over the investigation area or the facility to be investigated during the investigation for the purposes of providing the investigation team with a general orientation of the investigation area or the facility to be investigated. If the receiving State Party is unable or does not agree to provide an orientation overflight, this fact shall not be recorded nor be commented upon in the final report." Composite Text, op. it. , Annex on Investigations (Annex B)/ A. General Provisions, paragraph 56.

former biological weapons facilities.[100] In order to provide the high level of assurance required to certify complete disarmament, such off-site measures would need to be supported by on-site verification activities.

Aerial imagery can play a valuable role if and when Iraq inspectors will be able to resume their on-site activities. One UNMOVIC official pointed out that "inspection planning is really where satellite imagery is most useful" in particular in places like Iraq where good maps are hard to find.[101] Thus, inspectors could build on past successes. Linking aerial imagery to information about specific locations, sites and facilities has made it easier for inspectors to find their way on the ground, identify relevant places for inspection and has generally improved the effectiveness and efficiency of inspections.

Aerial imagery should also continue to play a role under a future OMV regime. This was recognised as early as April 2000 by the then-Executive Chairman of UNMOVIC. Hans Blix, wrote in a report on future requirements for OMV that "[UNMOVIC] must be equipped to take photographs, both from the ground and in the air. It must be ready to conduct fixed-wing and helicopter flights throughout Iraq in its own aircraft for all relevant purposes, including aerial surveillance."[102]

Discussions on the future of UNMOVIC include the option to make use of its expertise in the context of controlling weapons of mass destruction in other countries. Some states, like Iraq itself and the United States, would like to terminate the life of the institution. Others, including the European Union, would like to preserve UNMOVIC's core competencies, to be used possibly as part of a UN-based inspection mechanism. Because the OPCW and the IAEA already monitor the ban on chemical weapons and nuclear nonproliferation, most believe that UNMOVIC's future lies in the monitoring of nonproliferation and disarmament of biological weapons and ballistic missiles.

Currently two staff at UNMOVIC are working part time on the analysis of aerial imagery.[103] Annual costs according to one expert are US$250,000.[104] UNMOVIC continues to acquire images from a variety of sources, including from commercial satellite providers.[105] Since there is currently no prospect of inspectors returning to Iraq, UNMOVIC does not purchase imagery on short-notice. Thus, for a large part of its verification activities it can rely on archival imagery.

Giving a future UNMOVIC the capability to acquire, process and analyse overhead imagery would considerably improve its effectiveness. UNMOVIC has developed a couple of unique assets in working with such imagery. It has used aerial imagery from national and commercial sources, fuses such data with cartographic and other databases to be used in non-cooperative environments and has combined on-site and off-site verification measures in novel ways.

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100 UNMOVIC has acquired imagery of almost all of the 411 sites it inspected between November 2002 and March 2003. Early Spring 2005, UNMOVIC reported that a large portion of the sites being monitored were being razed and looted. See United Nations Monitoring, Verification and Inspection Commission: "Twentieth quarterly report on the activities of the United Nations Monitoring, Verification and Inspection Commission in accordance with paragraph 12 of Security Council resolution 1284 (1999)", United Nations Security Council, S/2005/129, 28 February 2005, pp. 2-3.

101 Telephone interview with UNMOVIC officials, 19 October 2006.

102 United Nations Monitoring, Verification and Inspection Commission: "Organizational plan for the United Nations Monitoring, Verification and Inspection Commission prepared by the Executive Chairman", United Nations Security Council, S/2000/292, 6 April 2000, p. 5.

103 Telephone interview with UNMOVIC officials, 19 October 2006.

104 Findlay: "A Standing United Nations WMD Verification Body", op. cit., p. 17.

105 UNMOVIC has access to some imagery acquired by the IAEA via the Iraq Nuclear Verification Office. UNMOVIC is also using open source imagery, for example from Google Earth (earth.google.com).

UNMOVIC is also cooperating with other international organisations in making use of overhead imagery, including the Iraq Nuclear Verification Office (INVO) at the IAEA[106], the United Nations Geographic Information Working Group, and the Department of Peacekeeping Operations.[107] There is no other international arms control organisation that combines this diverse set of competencies with regard to aerial imagery.

5.4. A UN mechanism to investigate violations of the BWC

In 1988, the UN Security Council (UNSC) authorized the UN Secretary General (UNSG) to investigate alleged breaches of the 1925 Geneva Convention, which prohibits the use of biological and chemical weapons. Since then, this mechanism has been activated four times[108], albeit with mixed results. It is doubtful that the UNSG would currently have the means to quickly launch an investigation into cases of suspected biological weapons use. Rosters of experts, lists of laboratories and equipment as well as inspection manuals have not been updated since 1989.

In the run-up to the Sixth BWC Review Conference, November-December 2006, several observers have proposed to modernize this mechanism in order to improve the international community's ability to investigate possible violations of the BWC.[109] A number of state parties have supported similar ideas at the 2004 meeting of experts under the new intersessional process.[110]

Such an expansion of the mandate of the UNSG mechanism would very likely necessitate the creation of an UN "inspection unit" to be backed by a supporting infrastructure, based on a core group of experts plus a larger standby capacity. The unit would have to maintain the necessary elements of a stand-by inspectorate and could be established within the UN Department for Disarmament Affairs (UNDDA) or at the UNSG offices.[111]

Enabling this unit to make use of aerial imagery would improve the effectiveness and efficiency of any such mechanism. Imagery could be generally useful in preparing the logistics of possible investigations into alleged use.[112] Current satellite imagery can be used to assist with the planning and conduct of a specific investigation, after such an inspection has been requested. If biological weapons have actually been used, it might be possible to detect unusual activities such as roadblocks or other security measures. Satellite pictures can also be used to generate maps against

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[106] INVO has access to aerial imagery acquired by the IAEA, which may share it with UNMOVIC. Telephone interview with UNMOVIC officials, 19 October 2006.

[107] Findlay: "A Standing United Nations WMD Verification Body", op. cit., p. 30

[108] In Southeast Asia and Afghanistan (1980-82), during the Iran-Iraq war (1984-1988), In Mozambique (1992) and in Azerbaijan (1992).

[109] See Una Becker/Harald Müller/Carmen Wunderlich: "While Waiting for the Protocol: An Interim Compliance Mechanism for the Biological Weapons Convention", in: Nonproliferation Review, Vol. 12, No. 3, November 2005, pp. 541-572; Barbara Hatch Rosenberg: "Enforcing WMD Treaties: Consolidating a UN Role", in: Disarmament Diplomacy, No. 75, January/February 2004, http://www.acronym.org.uk/dd/dd75/75bhr.htm; Trevor Findlay: "Preserving UNMOVIC: The Institutional Possibilities", in: Disarmament Diplomacy, No. 76 March/April 2004, http://www.acronym.org.uk/dd/dd76/76tf.htm.
Though the BWC does not explicitly prohibit the use of biological weapons it is widely assumed to cover such cases.

[110] See The Verification Research, Training and Information Centre: "A new strategy", op. cit.

[111] Thus, Germany proposed in 2004 that state parties designate inspectors and train them, make available equipment for such inspections, designate suitable laboratories to analyse samples taken during on-site inspections. See United Nations involvement in investigating the possible use of biological weapons, Working Paper submitted by Germany, Meeting of Experts, 19-30 July 2004, MSP/2004/MX/WP.10, Geneva, 15 July 2004. See also Becker, et al., op. cit., p. 557.

[112] The PTS' preparations for OSIs under the CTBT could serve as a model because low-resolution imagery would be sufficient for this task.

which to plot reported cases of infection. Such maps, in combination with meteorological data from the time of the outbreak, may be useful in identifying the source of the outbreak.[113]

Because investigations into alleged uses of biological weapons could take place anytime-anywhere and would need to be launched quickly, within a few days, requirements on access to satellite imagery would be high. Fast access to such imagery could be arranged on the same priority basis that is granted to humanitarian relief organizations under UN arrangements. Member states should also pledge to provide an inspection unit with current imagery, if needed.

Taking air-samples during investigations into the possible use of biological weapons is not a useful verification technique. Biological weapons agents settle down quickly, making detection by collecting air samples unlikely, unless the aircraft is flying through the area shortly after the release. Because of the dangers of exposure to biological weapons agents if an aerial investigation is conducted shortly after a suspected biological weapons attack, the use of unmanned aerial vehicles could be considered.

Some also have proposed to expand the mandate UNSG mechanism to not only investigate the possible use of biological weapons but also to confirm information declared under the CBMs,[114] and to extend the UNSG's authority to investigate "issues related to producing, developing, or stockpiling biological or toxin weapons."[115] Under such scenarios, access to commercial satellite imager would yield many of the same advantages that were described previously with regard to checking the correctness and completeness of declarations under a biological weapons verification mechanism and to detect clandestine activities.

5.5. Confidence Building: Open Skies

One of the potentially useful applications of aerial imagery in monitoring biological weapons related activities is the building of confidence that a state is honouring its commitments under the BWC. Under certain conditions, overflights may be one way to dispel suspicions about illicit activities.

The Open Skies m echanism could help to clarify suspicions about illicit biological weapons activities. Aerial imagery can provide a state accused of breaching the bioweapons ban with an opportunity to demonstrate its compliance by inviting a clarification overflight. During such an overflight, it could attempt to demonstrate that the information on which the allegation is based does not match reality. It could do this for example be showing that a location under suspicion is unsuitable for a BW facility.[116]

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[113] In 1992 a team of independent scientists investigated the cause of an outbreak of anthrax in the city of Sverdlovsk in 1979. The team bought a 1988 SPOT satellite photo of the city which was used as a map on which to plot the spread of the disease. Eventually, this was important in order to identify the likely source of the outbreak. See Matthew Meselson/et al.: "The Sverdlovsk Anthrax Outbreak of 1979", in: Joshua Lederberg (ed.): Biological Weapons: Limiting the Threat. BCSIA Studies in International Security, Cambridge, Massachusetts and London: The MIT Press, 1999, pp. 193-209.

[114] See Rosenberg, op. cit.; Becker/et al., op. cit., p. 557.

[115] The Verification Research, Training and Information Centre: "A new strategy"op. cit., p. 17.

[116] The facility under suspicion could, for example have insufficient power lines to be production site or not be connected to the infrastructure of the country. A study looking into the credibility if wide-area environmental sampling as a means to complement nuclear safeguards use three criteria to focus the area under investigation when searching for clandestine facilities: existence of a nearby transportation network (i.e. road or rail) within a distance of 1 km, existence of a main electrical power supply within 10 km, existence of a population centre (at least 5,000 population) within 20 km. The study argued that "if any of these criteria were not met in a given area, then it was considered that the existence of an undeclared facility would be unlikely …". "IAEA Use of Wide Area

6. Conclusion and recommendations

Verification has three functions. It aims to detect breaches of an arms control norm, deter violations and build confidence among parties to an agreement. Measured against these goals, aerial imagery is of limited value as a stand- alone tool to identify clandestine biological weapons-related activities. Detection, in most circumstances, requires more information than can be gleaned from overhead imagery. This also limits the deterrence value of aerial imagery. A determined proliferator is likely to be able to hide an illicit biological weapons programme from aerial surveillance. Aerial monitoring, however, will make it more difficult and costly to hide a bioweapons programme, in particular a large military programme involving dedicated facilities or outdoor testing facilities. Co-operative overflights can be useful confidence building-tools, in particular in case of the alleged use of biological weapons or if a state is suspected of running a large offensive biological weapons programme.

The greatest value of aerial imagery lies in its synergy with other verification means. Combining aerial imagery with other on-site and off-site monitoring measures can increase the overall effectiveness and efficiency of biological weapons verification.

The added value aerial imagery brings to monitoring efforts has most clearly been demonstrated in the context of on-site inspections. Overhead imagery can be used during all phases of on-site inspections. It can be used to plan inspections by giving inspectors a precise image of the area and the site to be visited. Aerial observation of the site to be inspected can reveal suspicious activities before on-site measures commence. Modern databases make it possible to link aerial imagery to data from cartographic databases and other information. The resulting map, in combination with data from global positioning system, is a valuable instrument to guide inspectors on the ground. Post-inspection imagery can help to make sure that no unusual activities take place after the inspectors have left.

Overhead imagery can also be used to assess the correctness of information from other sources about activities related to biological weapons. BWC state parties are obliged to declare certain activities in their annual confidence-building measures and there is a growing amount of open source information available that can be used to monitor the BWC. Overhead imagery can place such information in a broader context and thus evaluate its veracity.

Overhead imagery has significant technical limitations. Commercial satellite imagery today still does not provide global coverage and acquiring an image from a particular location can take weeks, if not months. Governments still control access to such imagery. The U.S. government can restrict the release of commercial imagery sold by U.S. companies, which produce the vast majority of such data. Shutter control, limited availability and time delays seriously limit the value of satellite imagery in a multilateral biological weapons verification context.

Despite these restrictions, aerial imagery is already a potent verification means and it can help to better connect the various elements in the verification chain.[117] This is particularly true in the context of a multilateral verification regime. Information managed by an international agency is perceived to be authentic, unbiased and impartial. Aerial imagery, if it comes from a neutral source and is procured and analysed in a transparent manner, is seen as objective, technical information.

Environmental Sampling In The Detection of Undeclared Nuclear Activities", Member State Support Programmes to the IAEA, STR-321, Vienna: IAEA, 27 August 1999, pp. 20-21.

[117] A 1991 study on the usefulness of overflights (aerial inspections) under the CWC reached similar conclusions. See Smithson/Krepon, op. cit., pp. 26-27.

Table 4: The usefulness of overhead imagery in different verification activities

Verification activity	*Examples*	*Value of aerial imagery*	*Type of imagery best suited*	*Requirements*	*Most likely source*
Confidence-building	Clarification of concerns about use	High	Overflights	Fast access	Cooperative overflights
Confirming correctness of declarations/CBMs	Confirming site and facility layout	Moderate	High-resolution satellite	Wide geographic coverage	CSI, NTM
Confirming completeness of declarations/CBMs	Identify undeclared sites and facilities	Low	High-resolution satellite	Fast access and wide geographic coverage	NTM
Preparing on-site inspections	Logistics	Very High	Satellite (low-resolution sufficient)	Wide geographic coverage	CSI, UN databases
Assisting field inspections	Establish inspection perimetre, observe ground activities, guide inspectors	High	High-resolution satellite, overflights	Fast access and wide geographic coverage	CSI, UN databases
Assisting facility inspections	Establish inspection perimeter, observe ground activities, guide inspectors	High	High-resolution satellite, overflights	Fast access and wide geographic coverage	CSI, NTM (overflights)

CSI: Commercial Satellite Imagery
NTM: National Technical Means

There is currently a lack of political will to improve multilateral monitoring of the BWC by realising the opportunities associated with novel verification technologies such as aerial imagery. There are several steps BWC state parties can and should take to exploit the potential of aerial imagery for monitoring of the bioweapons ban.

In the short term, it will be important to take steps

- to explore the potential of aerial imagery as a monitoring means,
- to establish an international consensus on the role of aerial imagery,
- to demonstrate the usefulness of such data in a multilateral context,
- to work towards multilateral institutions to monitor compliance with the BWC.

These issues need to be considered first by representatives of 155 BWC state parties. They are meeting at the Sixth Review Conference 20 November – 8 December 2006 in Geneva and should consider the following steps to realise the verification potential of aerial imagery:

- *Establish a dialogue among technical experts to discuss new developments in verification techniques relevant to the BWC, including the role of aerial imagery.*

Thirteen years after VEREX finished its report on the value of various verification measures for the BWC, it is time to revisit the scientific and technological basis for the verifiability of the ban on bioweapons. Not only has biotechnology made remarkable progress, verification technologies have also advanced. VEREX has laid important groundwork and many of its findings are still valid but they urgently need to be updated. Such a revision needs to include an evaluation of the role of aerial imagery as an off-site measure.

Ideally, such a dialogue would take place directly among BWC state parties, for example in the context of expert group meetings, taking place between the Sixth and the Seventh BWC Review Conference. Indeed, some have suggested making scientific and technological developments an issue for discussion during a new set of meetings of state parties. This is mostly understood to involve an analysis of the implications of new scientific developments for the bioweapons ban, but discussions on this topic should be broadened to include new verification techniques.

Should it not be possible to initiate such a scientific forum in the context of the BWC, interested state parties should initiate an expert group outside the Convention. The EU, for example is in an ideal position to sponsor a group of technical experts from its member states to evaluate novel verification means and invite other state parties to join this dialogue. Such a measure would support Europe's declared goal of working towards a universal and legally-binding verification mechanism.

- *Mandate institutions that monitor BWC compliance to make use of aerial imagery.*

Several proposals have been made to boost the verification capabilities of existing international mechanisms to monitor compliance with the BWC. This relates first and foremost to the future of UNMOVIC and secondly to an updated UNSG mechanism to investigate the use of biological and chemical weapons.

The effectiveness of both mechanisms can be improved by giving them the authority and the capacity to make use of aerial imagery. UNMOVIC already possesses a wealth of experience in using overhead imagery from a variety of sources. Preserving this accumulated knowledge and maintaining the expertise is an essential element of efforts to improve BWC monitoring. UNMOVIC has already begun to share its experience with other UN organisations and this should be continued and expanded.

Things are more complicated with regard to the UN Secretary General investigative mechanism because so far it has no permanent institutional backing. Various proposals have been made to create a secretarial structure on which to base this mechanism, at the United Nations Department for Disarmament Affairs, under the authority of the UN Secretary General or the UN Security Council. Whatever its home, the new institution should be mandated to have access to aerial imagery. Data held by other UN organisations could be helpful for general preparations. CTBTO's global database could, for example, be useful in preparing future *ad hoc* on-site inspections. IAEA and UNMOVIC have arrangements for acquiring commercial satellite imagery on short-notice which could also assist investigations on alleged use of biological weapons. Open Skies member states, based on the preamble of the treaty, could offer to place their monitoring aircraft at the disposal of the United Nations if and when the UN Secretary General requests assistance in an investigation of alleged use of biological or chemical weapons.

- *Work towards an Organisation for the Prohibition of Biological Weapons with a mandate to use overhead imagery.*

In the long run, an Organisation for the Prohibition of Biological Weapons (OPBW) with a mandate to monitor the bioweapons ban in all its aspects and the means to ensure compliance would be in an ideal position to realise the synergies between the various verification means available today, including overhead imagery.[118]

Five years ago, the international community had almost reached agreement to establish an OPBW. Diplomats engaged in the Ad Hoc Group of BWC state parties, however, tried to make a compliance protocol, including an OPBW, more acceptable by watering down many of its verification provisions.[119] The OPBW would have had only a limited mandate to make use of open sources and aerial imagery. The failure of the AHG negotiations brings with it the opportunity to correct such shortcomings of the 2001 draft protocol in a future round of talks. A future organisation should have a mandate to make use of all modern verification assets, including aerial imagery.

In a broader context, the following actions should be taken to realise the verification potential of aerial imagery:

- *Use Open Skies as a test bed for using overflights as a confidence-building measure.*

Open Skies member states should agree to expand the current use of the treaty to include the monitoring of compliance with weapons of mass destruction treaties. On a national basis, overflights are already used to observe WMD-related developments, for example by monitoring Russian chemical weapon sites. Cooperative overflights under the Open Skies regime should be used for the building of confidence that member states are in compliance with their treaty obligations, including obligations under the BWC.

All OSCE member states, in particular in Central Asia, should be encouraged to join the treaty. The treaty could also serve as model for confidence-building outside the OSCE region. Thus, cooperative overflights could be one way to facilitate the building of trust among states in the Middle East or South Asia, where the proliferation of weapons of mass destruction is one reason for political conflict. Cooperative monitoring in these regions is likely to focus on nuclear and possibly chemical arms control.[120]

- *Establish a UN satellite imagery unit*

Aerial imagery, and in particular commercial satellite imagery, can be used to monitor compliance with all weapons of mass destruction treaties. Indeed, the verification value is even greater in the context of monitoring nuclear weapons and chemical weapons proliferation and disarmament than in the biological weapons context.

Eventually, the challenge will be to realise the synergies between different arms control treaties by creating a common reservoir of overhead imagery under the auspices of the United Nations. Such a UN satellite imagery unit could supply imagery to arms control organisations whenever

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118 On the problem of verification synergies see Trevor Findlay/Oliver Meier: Exploiting synergies between nonproliferation verification regimes: A pragmatic approach, VERTIC Briefing Paper 01/02, London, May 2002.

119 See Oliver Meier: "A Biological weapons protocol: verification lite?", in: Trust & Verify, No. 97, May-June 2001, pp.1-2.

120 On the role the Open Skies Treaty see for example Ernst Britting/Hartwig Spitzer: "The Open Skies Treaty", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2002. The Verification Research, Training and Information Centre. London: VERTIC, 2002, pp. 221-237.

needed. From a verification point of view, it makes little sense that CTBTO, IAEA, INVO and UNMOVIC maintain independent capabilities to procure and analyse imagery, even though many of their tasks overlap. Humanitarian organisations already have a UN-based structure available to service their needs. This model should be expanded to arms control organisations with a global reach.[121]

To be sure, the time for such UN satellite imagery unit has not yet come. BWC member states, however, should not lose sight of the goal of creating a strong and modern verification regime. Now is the time to create building-blocks that can later provide a firm basis for a universal and legally-binding compliance regime.

[121] The idea of a international satellite monitoring agency under the UN was first proposed by France in 1978. See Bhupendra Jasani: "Remote Monitoring from Space", op cit.; http://www.un.org/Depts/Cartographic/english/about.htm.

Bibliography

Literature
Arms Control Association: "The Open Skies Treaty at a Glance", ACA Fact Sheet, Washington, D.C.: July 2005, http://www.armscontrol.org/factsheets/openskies.asp.

Baker, John C./Kevin M. O´Connell/Ray A. Williamson: Commercial Observation Satellites. At the Leading Edge of Global Transparency. Santa Monica: RAND Corporation 2001.

Becker, Una /Harald Müller/Carmen Wunderlich: "While Waiting for the Protocol: An Interim Compliance Mechanism for the Biological Weapons Convention", in: Nonproliferation Review, Vol. 12, No. 3, November 2005, pp. 541-572.

Britting, Ernst/Hartwig Spitzer: "The Open Skies Treaty", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2002. The Verification Research, Training and Information Centre. London: VERTIC 2002, pp. 221-237.

Burger, Marion/Chandré Gould: Secrets and Lies. Wouter Basson and South Africa's Chemical and Biological Warfare Programme. Cape Town: Zebra Press 2002.

Collard-Wexler, Simon/Thomas Graham/Robert Lawson/Wade Huntley/Ram Jakhu/William Marshall/John Siebert/Sarah Easterbrooks: Space Security 2006. Canada: 2006 [downloadable at www.spacesecurity.org].

Day, Dwayne A./John M. Logsdon/Brian Latell: Eye in the Sky. The Story of the Corona Spy Satellites. Washington D.C.: Smithsonian Institution 1998.

Dehqabzada, Yahya A./Ann M. Florini: "Secrets for Sale: How Commercial Satellite Imagery Will Change the World", Carnegie Endowment for International Peace Report, Washington, D.C.: Carnegie Endowment for International Peace 2000.

Dunay, Pál/Márton Krasznai/Hartwig Spitzer/Rafael Wiemker/William Wynne: Open Skies: A Cooperative Approach to Military Transparency and Confidence Building. Geneva: UNIDIR 2004.

Findlay, Trevor/Oliver Meier: "Exploiting synergies between nonproliferation verification regimes: A pragmatic approach, VERTIC Briefing Paper 01/02, London, May 2002.

Findlay, Trevor/Angela Woodward: "Enhancing BWC Implementation: A Modular Approach", The Weapons of Mass Destruction Commission Report No. 23, Stockholm: WMD Commission, October 2004, www.wmdcommission.org.

Findlay, Trevor: "A Standing United Nations WMD Verification Body: Necessary and Feasible", An Interim Study prepared for the Commission on Weapons of Mass Destruction, Ottawa: The Canadian Centre for Treaty Compliance, Norman Paterson School of International Affairs, Carlton University in cooperation with The Verification Research, Training and Information Centre (VERTIC), May 2005.

Findlay, Trevor: "BWC 2006: Verification and the BWC: Last Gasp or Signs of Life?", in: Arms Control Today, Vol. 36, No. 7, September 2006, pp. 12-16.

Findlay, Trevor: "Peace operations and the military dimensions of verification", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2001. London: The Verification Research, Training and Information Centre (VERTIC), December 2001, pp. 159-172.

Findlay, Trevor: "Preserving UNMOVIC: The Institutional Possibilities", in: Disarmament Diplomacy, No. 76, March/April 2004, http://www.acronym.org.uk/dd/dd76/76tf.htm.

Goldschmidt, Pierre: "The IAEA Safeguards System Moves Into the 21st Century", in: Supplement to the IAEA Bulletin, Vol. 41, No. 4, December 1999.

Guillemin, Jeanne: The Investigation of a Deadly Outbreak, Berkeley/Los Angeles/London: University of California Press 1999.

Hart, John: "Chemical Indusrty Inspections Under the Chemical Weapons Convention", Verification Matters, VERTIC Research Report No. 1, London: The Verification Research, Training and Information Centre, October 2001.

Jasani, Bhupendra: "Civil Reconnaissance Satellites: Opportunities and Challenges", in: R. Avenhaus/N. Kyriakopoulos/M. Richard, M/G. Stein (eds.): Verifying Treaty Compliance. Limiting Weapons of Mass Destruction and Monitoring Kyoto Protocol Provisions. Berlin: Springer 2006, pp. 323-334.

Jones, Peter L./Marton Krasznai: "Open Skies: Achievements and Prospects", in: J.B Poole/Richard Guthrie (eds.): Verification Report 1992: Yearbook on arms control and environmental agreements, VERTIC Yearbook. London: Verification Technology Information Centre (VERTIC), 1992, pp. 47-56.

Kelly, David C.: "The Trilateral Agreement: lessons for biological weapons verification", in: Trevor Findlay/Oliver Meier (eds.): Verification Yearbook 2002. London: The Verification Research, Training and Information Centre 2002, pp. 93-109.

Kerr, Paul: "Efforts to Strengthen IAEA Safeguards Advance", in: Arms Control Today, Vol. 36, No. 6, July/August 2006, p. 46.

Krass, Allan S.: Verification: How Much Is Enough?. London and Philadelphia: Taylor & Francis 1985.

Krepon, Michael/Peter D. Zimmerman/Leonard S. Spector/Mary Umberger: Commercial Observation Satellites and International Security. New York: St. Martin's Press 1990.

Leitenberg, Milton: "The conversion of biological warfare research and development facilities to peaceful uses", in: Erhard Geissler/John P. Woodall (eds.): Control of Dual-Threat Agents: The Vaccines for Peace Programme. Oxford: Oxford University Press 1994, pp. 77-105.

Meier, Oliver: "A Biological weapons protocol: verification lite?", in: Trust & Verify, No. 97, May-June 2001, pp.1-2.

Meier, Oliver: "Civil Society and the Biological Weapons Convention: Creating Transparency Under Duress", in: INESAP Information Bulletin, No. 19, March 2002, pp. 14-18.

Meier, Oliver: "The Use of Open Source Information in Multilateral Arms Control and Disarmament Regimes", Presentation at the 3rd INMM/ESARDA Workshop on Science and Modern Technology for Safeguards, 13-16 November 2000, International House of Japan, Tokyo, Japan.

Meselson, Matthew/et al.: "The Sverdlovsk Anthrax Outbreak of 1979", in: Joshua Lederberg (ed.): Biological Weapons: Limiting the Threat. BCSIA Studies in International Security, Cambridge, Massachusetts and London: The MIT Press, 1999, pp. 193-209.

Miggins, Michael D.: "Whatever happened to Open Skies?", in: Trust&Verify, No. 91, May 2000.

Moodie, Michael: "The Soviet Union, Russia, and the Biological and Toxin Weapons Convention", in: Nonproliferation Review, Vol. 8, No. 1, Spring 2001, pp.59-69.

O'Connell, Kevin/Beth E. Lachman: "From Space to Information: Commercial Remote Sensing Market Factors and Trends", in: John C. Baker/Kevin M. O´Connell/Ray A. Williamson (eds.): Commercial Observation Satellites. At the Leading Edge of Global Transparency. Santa Monica: RAND Corporation 2001, pp. 71-72.

Richelson, Jeffrey: "The whole world is watching", in: The Bulletin of the Atomic Scientists, Vol. 62, No. 1, January/February 2006, pp. 27-35.

Roffey, Roger: "Biological Weapons and potential indicators of offensive biological weapon activities", in: Stockholm International Peace Research Institute: SIPRI Yearbook 2004. Armaments, Disarmament and International Security. Oxford: Oxford University Press 2004, pp. 557-571.

Rosenberg, Barbara Hatch: "Enforcing WMD Treaties: Consolidating a UN Role", in: Disarmament Diplomacy, No. 75, January/February 2004, http://www.acronym.org.uk/dd/dd75/75bhr.htm.

Rothkirch, André: Sensorik: Entwicklung, Rüstungsrelevanz und Einhegungsmöglichkeiten, unpublished manuskript, Institute for Peace Research and Security Policy at the University of Hamburg 2005.

Rowe, Gregory D.: "Air Sampling Sensors, the Open Skies Treaty, and Verifying the Chemical Weapons Convention." M.A. in National Security Affairs thesis, Naval Postgraduate School, Monterey, California, December 1995.

Shea, Dana A./Frank Gottron: "Small-scale Terrorist Attacks Using Chemical and Biological Agents: An Assessment Framework and Preliminary Comparisons", CRS Report for Congress, RL32391, Washington, D.C.: Congressional Research Service, 20 May 2004.

Sims, Nicholas: "Verifying biological disarmament: towards a protocol and organisation", in: Trevor Findlay (ed.): Verification Yearbook 2000. London: The Verification Research, Training and Information Centre (VERTIC), December 2000, pp. 87-99.

Smithson, Amy/Michael Krepon: "Strengthening the Chemical Weapons Convention Through Aerial Imagery", Stimson Center Occasional Paper 4. Washington, D.C.: The Henry L. Stimson Center, April 1991.

Spitzer, Hartwig: "The Open Skies Treaty: Entering full implementation at low key." Draft paper, 4 March 2006, http://censis.informatik.uni-hamburg.de/openskies/OS_Artikel_Helsinki_Monitor_final_4March2006.pdf.

The Verification Research, Training and Information Centre: "A new strategy: strengthening the biological weapons regime through modular mechanisms", Verification Matters. VERTIC Research Report No. 6. London: The Verification Research, Training and Information Centre, October 2006.

Trevan, Tim: Saddam's Secrets: The Hunt for Iraq's Hidden Weapons. London: HarperCollins, 1999, p. 88.

Tucker, Jonathan: "Monitoring and Verification in a Non-Cooperative Environment: Lessons from the U.N. Experience in Iraq", in: Nonproliferation Review, Vol. 3, No. 3, Spring/Summer 1996, pp. 1-14

Verger, Ferdinand/Isabelle Sourbès-Verger/Raymond Ghirardi: The Cambridge Encyclopaedia of Space: Missions: Applications and Exploration. Cambridge: Cambridge University Press 2003.

Vaccaro, J. Matthew: "Evolution of police monitoring in peace operations", in: Trevor Findlay (ed.): Verification Yearbook 2000. London: The Verification Research, Training and Information Centre (VERTIC), December 2000, pp. 183-195.

Documents

Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint: "Summary of the work of the Ad Hoc Group for the period 23 November to 4 December 1992", BWC/CONF.III/VEREX/8, Geneva, 8 December 1992

Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint: "Summary Report", BWC/CONF.III/VEREX/8, Geneva, 24 September 1993.

Ad Hoc Group of the States Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction: "Protocol to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction" BWC/AD HOC GROUP/CRP.8, Geneva, 3 April 2001.

Defense Intelligence Agency: "Foreign Technology Weapons and Systems", DST 2660P-107-80-SAO, 3 March 1980.

IAEA: "IAEA Use of Wide Area Environmental Sampling In The Detection of Undeclared Nuclear Activities", Member State Support Programmes to the IAEA, STR-321, Vienna: IAEA, 27 August 1999.

The White House: "Foreign Access To Remote Sensing Space Capabilities", Washington, D.C.: The White House, Office of the Press Secretary, 10 March 1994, http://www.fas.org/irp/offdocs/pdd23-2.htm.

U.S. Congress: "National Defense Authorization Act for Fiscal Year 1997", Public Law 104-201, Washington, D.C.: September 1996, p. 2653, http://www.nps.gov/legal/laws/104th/104-201.pdf.

United Nations Monitoring, Verification and Inspection Commission: "Organizational plan for the United Nations Monitoring, Verification and Inspection Commission prepared by the Executive Chairman". United Nations Security Council, S/2000/292, New York: 6 April 2000.

United Nations Monitoring, Verification and Inspection Commission: "Twentieth quarterly report on the activities of the United Nations Monitoring, Verification and Inspection Commission in accordance with paragraph 12 of Security Council resolution 1284 (1999)", United Nations Security Council, S/2005/129, New York: 28 February 2005.

United Nations Monitoring, Verification and Inspection Commission: "Summary of the compendium of Iraq's proscribed weapons programmes in the chemical, biological and missile areas", United Nations Security Council, S/2006/420, New York: 21 June 2006.

Working Paper submitted by Germany: "United Nations involvement in investigating the possible use of biological weapons", MSP/2004/MX/WP.10, Meeting of Experts, 19-30 July 2004. Geneva: 15 July 2004.

Acronyms

AHG	Ad Hoc Group of States Parties to the BWC
BWC	Biological and Toxin Weapons Convention
CBM	Confidence Building Measure
CFE	Treaty on Conventional Forces in Europe
CSI	Commercial Satellite Imagery
CTBT	Comprehensive Nuclear Test Ban Treaty
CTBTO	Comprehensive Nuclear Test Ban Treaty Organisation
CWC	Chemical Weapons Convention
EO	Earth Observation
IAEA	International Atomic Energy Agency
INVO	Iraq Nuclear Verification Office
IR	infrared
MS	multispectral
NATO	North Atlantic Treaty Organisation
NGA	National Geospatial-Intelligence Agency
NTM	National Technical Means
OMV	Ongoing Monitoring and verification
OPBW	Organisation for the Prohibition of Biological Weapons
OPCW	Organisation for the Prohibition of Chemical Weapons
OSCC	Open Skies Consultative Commission
OSCE	Organisation for Security and Cooperation in Europe
OSI	On-site Inspection
Pan	panchromatic
PDD	Presidential Decision Directive
PTS	Provisional Technical Secretariat (of the Comprehensive Nuclear Test Ban Treaty Organisation)
SAR	Synthetic Aperture Radar
SIPRI	Stockholm International Peace Research Institute
UN	United Nations
UNDDA	United Nations Department for Disarmament Affairs
UNMOVIC	United Nations Monitoring, Verification and Inspection Commission
UNSC	United Nations Security Council
UNSCOM	United Nations Special Commission
UNSG	UN Secretary General
VEREX	Ad Hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint
VERTIC	The Verification Research, Training and Information Centre
WMD	Weapons of Mass Destruction