CANADA

COMMERCIAL SATELLITE IMAGERY AND VERIFICATION OF THE BIOLOGICAL AND TOXIN WEAPONS CONVENTION

MAY 1993

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PREFACE

In September 1991, the Third Review Conference of the Parties to the Convention on the Prohibition of the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction decided to establish an Ad Hoc Group of Governmental Experts open to all States Parties to identify and examine potential verification measures from a scientific and technical standpoint.

The mandate stated:

" The Group shall seek to identify measures which could determine:

- Whether a State Party is developing, producing, stockpiling, acquiring or retaining microbial or other biological agents or toxins, of types and in quantities that have no justification for prophylactic, protective or peaceful purposes;

- Whether a State Party is developing, producing, stockpiling, acquiring or retaining weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.

"Such measures could be addressed singly or in combination. Specifically, the Group shall seek to evaluate potential verification measures, taking into account the broad range of types and quantities of microbial and other biological agents and toxins, whether naturally occurring or altered, which are capable of being used as means of warfare.

"To these ends the Group could examine potential verification measures in terms of the following main criteria:

- Their strengths and weaknesses based on, but not limited to, the amount and quality of information they provide, and fail to provide;

- Their ability to differentiate between prohibited and permitted activities;

- Their ability to resolve ambiguities about compliance;

- Their technology, material, manpower, and equipment requirements;

- Their financial, legal, safety and organizational implications;

- Their impact on scientific research, scientific cooperation, industrial development and other permitted activities, and their implications for the confidentiality of commercial proprietary information."

In March/April 1992, the Group held its first meeting and compiled lists of potential verification measures in the three broad areas of development, acquisition or production, and stockpiling or retaining. The lists, containing twenty-one potential verification measures, were considered indicative and requiring further discussion.

In November/December 1992, the Group held its second meeting and concluded the general "examination" phase of the twenty-one measures. This established a consensus baseline representing a factual description of the examination from which to move forward to the more detailed "evaluation" phase. Although certain initial efforts were made with regard to evaluation of certain measures, it was recognized that a good deal more detailed work would need to be done in preparation for the next Group meeting, May/June 1993.

Moderators and Rapporteurs were requested to continue to assist the Group in its work. Rapporteurs were requested to prepare introductory papers on their respective measures to facilitate their evaluation.

This introductory paper entitled "Commercial Satellite Imagery and Verification of the Biological and Toxin Weapons Convention" constitutes fulfilment of the Rapporteur's task with regard to that potential verification measure.

INTRODUCTION

This discussion will only consider the potential application of commercial satellite imagery, since not all countries have access to the imagery/information supplied by National Technical Neans (NTM). It will not be possible to use commercial satellite imagery to detect in the first instance, or conclusively investigate, facilities which may be involved in biological and toxin weapons (BTW) related activities. Since BTW facilities can be contained within a single building without necessarily having any externally visible indicators, sensors which have no capability to "see" within such buildings will not be very useful in detecting them. The main potential application of commercial satellite imagery will likely be to prepare site plans or "image maps" to familiarize on-site inspection teams with the external layout of locations to be inspected.

A PRIMER ON COMMERCIAL SATELLITE IMAGERY

A brief introduction to typical civilian applications of commercial satellite imagery can provide some insight into the potential for such systems for the tasks being considered here. Typical applications are those which benefit from the broad area coverage which is provided by commercial satellite imagery. These include, for example, agricultural crop yield forecasting, land use studies, forest cover mapping, geological structure mapping and production of digital elevation models for mapping. They primarily involve mapping large-scale features, ones which are several tens or hundreds of metres in size rather than looking at smaller man-made features of site specific areas such a military facilities.

Commercial satellite imagery is available in two primary forms: **photographic** and **digital. Photographic** products include positive or negative transparencies and prints. Prints are required for field use but it is normal practice to purchase transparencies from the imagery supplier so that prints can be produced later as required, using either an in-house photographic laboratory or a company offering photographic laboratory services. The photographic laboratory must be able to work with large-format transparencies and prints: a survey photographic capability is required, not a 35-mm photographic reproduction capability. Interpretation of the imagery can be done using the naked eye or a simple handheld magnifying lens. Interpretation results and labelling can be added onto a print prior to use in the field. If many copies are required, the labelled print with the interpretation results can be photographically reproduced by the photographic laboratory.

Digital products are purchased on a computer-compatible tape or CD-ROM. A digital image analysis system is required to use this data. These computer systems are able to enhance features, correct for distortions in the image data (such as those introduced by elevational variation), and perform automated "interpretation." If image products are to be taken out in the field, equipment to write digital data onto photographic-quality hard copy will also be required.

Commercial satellite imagery (both photographic and digital) is available with several levels of geometric quality. The imagery collected by satellite sensors does not have the same planimetric accuracy as a cartographic map. There are systematic distortions introduced by the orbital characteristics of the satellite and by the sensor. There are also distortions introduced by "natural" sources such as the variations introduced by terrain relief. These distortions can be corrected so that imagery can be purchased as "raw" uncorrected data, with some of the geometric distortions removed, or fully-corrected imagery which has the same cartographic accuracy as a topographic map. Of course, corrected imagery is more expensive to buy than uncorrected imagery.

There are various commercial remote sensing satellites which have been designed to meet the data requirements for a multitude of applications. Lower-resolution systems, such as weather and oceanographic satellites which can have spatial resolutions on the order of several kilometers, have no potential value for BTW-related tasks. Only the higher-resolution systems will be considered in this discussion.

Current **optical** systems include the Landsat Thematic Mapper (TM), SPOT, and several systems operated by Russia from which imagery is being commercially distributed. These all have sensors operating either in the visible, near-infrared or thermal infrared wavelengths.

The Landsat Thematic Mapper sensor has six spectral bands in the visible to middle infrared, and also a thermal infrared band. The six visible to middle infrared bands have 30 metre resolution, the thermal band has 120 metre resolution. Table 1 provides technical specifications for the Thematic Mapper. There is a large historical archive of data providing global coverage. For BTW-related applications, however, the imagery provided by Landsat's TM sensor will be of marginal value due to its 30 metre spatial resolution.

Table 1. Characteristics of the Landsat Thematic Mapper (TM).

Band	Spectral Sensitivity	Spatial Resolution
1	0.45 to 0.52 μm	30 m
2	0.52 to 0.60 μm	30 m
3	0.63 to 0.69 μm	30 m
4	0.76 to 0.90 μm	30 m
5	1.55 to 1.75 μm	30 m
6	10.4 to 12.5 μm	120 m
7	2.08 to 2.35 μm	30 m

Repeat cycle	16 days
Swath width	185 km

The SPOT satellite uses two High Resolution Visible (HRV) sensors to provide multispectral images with an approximate spatial resolution of 20 x 20 metres, or panchromatic images with approximate 10 x 10 metre spatial resolution. Panchromatic imagery would be more suited, but still quite limited, for BTW-related purposes because of its higher spatial resolution. Table 2 provides technical specifications for each of the sensors. SPOT Image maintains an extensive archive of data which has been acquired, from which customers may select imagery to meet their needs. If there is no suitable imagery in the archive, a customer can submit a programming request to have imagery acquired to suit their specific requirements.

Russian satellite imagery is being offered on a commercial basis by Central Trading Systems in Arlington, Texas. Imagery are available which have been acquired using several camera systems, including the KVR-1000, KFA-1000, KATE-200 and MK-4. Digital imagery, known as "DD-5", is also available. This imagery is produced by scanning photographic film; much of it obtained using the KVR-1000. Table 3 provides technical specifications for each of the products.

The most notable characteristic of these imagery, particularly those acquired by the KVR-1000, is the high spatial resolution. KVR-1000 imagery would be of particular interest for preparing site diagrams because of the exceptionally fine spatial resolution provided by the KVR-1000. Figure 1 shows an example of imagery acquired using the KVR-1000. The two metre spatial resolution provided by this imagery is presently the finest which is available commercially. Using this imagery, it would be possible to prepare site diagrams with considerable detail and with confidence.

There is reportedly a large archival data bank of imagery acquired after 1989. According to literature from Central Trading Systems, archival data can normally be delivered directly from Moscow within 10 to 14 days of the order and new imagery can be acquired and delivered to a customer in 45 days. Central Trading Systems states that data are available for all parts of the world except Russia. Recent

Table 2. Characteristics of the SPOT system.

Band	Spectral Sensitivity	Spatial Resolution
P	0.51 to 0.73 μm	10 m
XS	0.50 to 0.59 μm	20 m
	0.61 to 0.68 μm	20 m
	0.79 to 0.89 μm	20 m

Repeat cycle	26 days with possibility of viewing location up to 12 times in a single orbit due to pointable sensors
Swath width	60 km (nadir) to 80 km (extreme off-nadir), 117 km when both sensors in twin-vertical, nadir pointing position

Table 3. Characteristics of Russian Satellite Imagery Products Available

KVR-1000	resolution	2 m
	original scale	1:220,000
	swath width	40 km
KFA-1000	resolution	4 to 7 m
	original scale	1:220,000 to 1:280,000
	swath width (using 2 cameras)	120 km
	spectral sensitivity	0.56 um to 0.67 um 0.67 um to 0.81 um
KATE-200	resolution	15 to 30 m
	original scale	1:1,000,000
	swath width	180 km
	spectral sensitivity	0.50 um to 0.60 um 0.60 um to 0.70 um 0.70 um to 0.85 um
MK-4	resolution	6 m
	original scale	1:650,000 to 1:1,500,000
	swath width	120 km to 270 km
	spectral sensitivity (3 channels of the listed possibilities)	0.400 um to 0.700 um 0.460 um to 0.505 um 0.515 um to 0.565 um 0.580 um to 0.800 um 0.635 um to 0.690 um

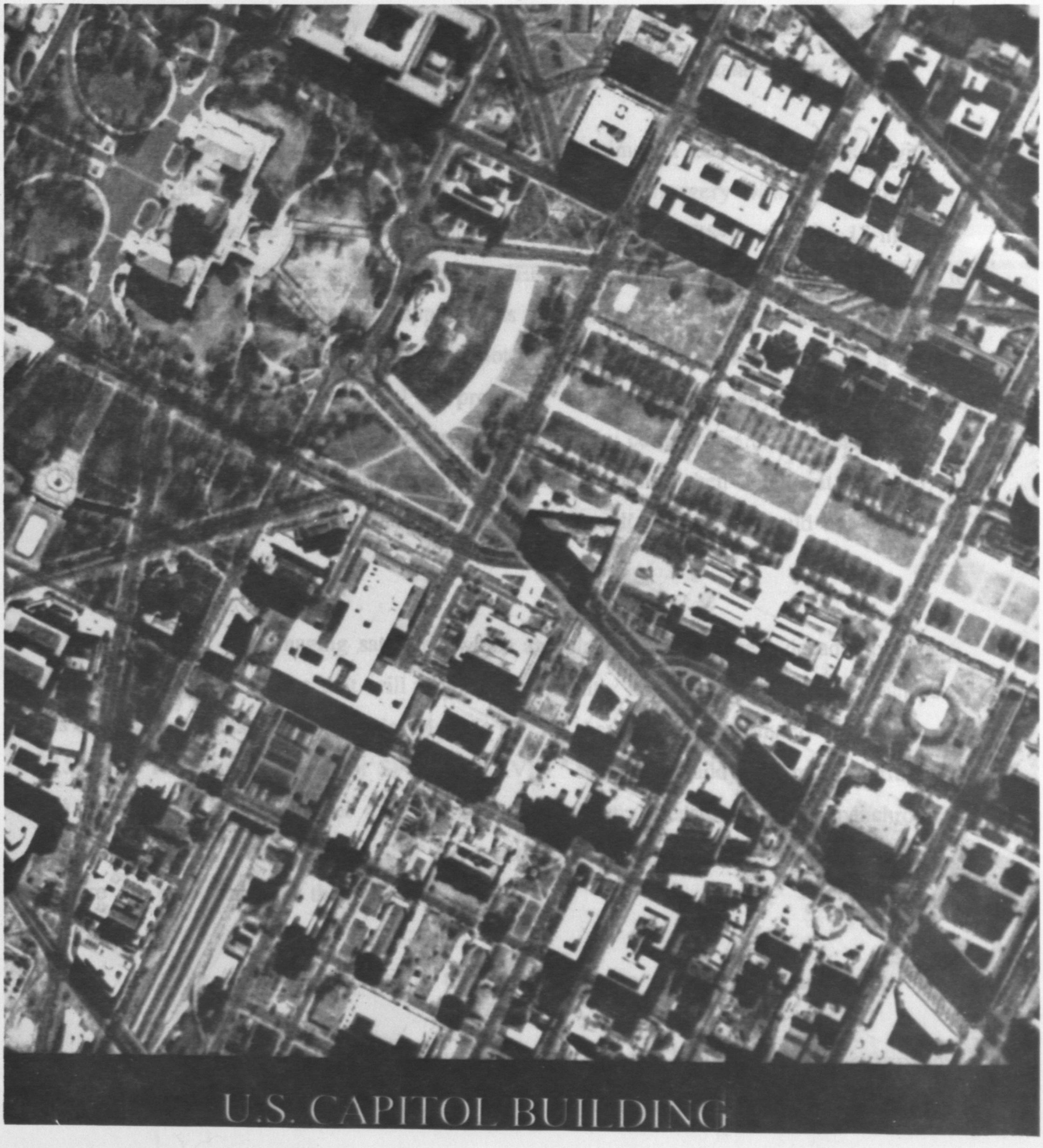

Figure 1. Recently high resolution Russian imagery has become commercially available. This KVR-1000 image of the Washington area has approximately two meter spatial resolution and has redefined the possible uses of commercial satellite imagery.

orders, however, of politically sensitive areas outside of Russia have been rejected because of fear of mis-use of the information gained from the data.

There are commercial and experimental satellites which provide relatively high resolution synthetic aperture radar (SAR) imagery with <30 metre resolution such as the European Remote Sensing Satellite (ERS-1) and the 18 metre resolution Japan Earth Resource Satellite (JERS-1). Optical systems are more likely to be of some use for BTW-related applications than these sensors. Certain man-made features such as roads and buildings are not evident in ERS-1 imagery and, as a result, these imagery would not be useful for preparing site diagrams or any other BTW-related application. Even radar-imaging systems that do show cultural features, such as the Russian ALMAZ system (which recently ceased operations when it fell out of orbit), do not show enough detail for preparing site diagrams and, therefore, would not be as useful as optical systems.

Imaging satellites which are planned for the next decade are not likely to produce systems that will provide significantly improved capabilities. Landsat 6 is to carry an Enhanced Thematic Mapper (ETM) having a panchromatic band with 13 x 15 metre resolution. Plans for SPOT-4 "HRVIR" sensors, to add a 20 metre infrared (1.54 to 1.75 micron) channel and changes to the spectral sensitivity of the panchromatic 10 metre sensor, will not likely alter the utility of the imagery for BTW-related tasks. There are also plans for the following satellites:

- ALMAZ-3 (Russian) to carry a 15-metre resolution S-band SAR;

- two China/Brasil Earth Resources Satellites (CBERS-1 and CBERS-2) which are to include a 19.5 metre High Resolution CCD Camera (HRC);

- the NASA Earth Observing System EOS-AM 1 is to carry a 3-channel Visible Near Infrared (VNIR) subsystem on the Advanced Thermal

Emission and Reflection Radiometer (ASTER) sensor which will have 15 metre resolution;

- two more European Remote Sensing Satellites (ERS-2 and ERS-3) with a similar sensor payload to ERS-1 with the addition of a Global Ozone Monitoring sensor;

- up to four Japan Earth Resources Satellites (JERS-2A and 2B, JERS-3A and 3B), all with an 18-metre resolution L-Band SAR and optical sensors with spatial resolutions of 15 metres or greater;

- Radarsat, a Canadian satellite to carry a multimode C-band SAR, will have a "high resolution" mode providing 10 metre, 1 look imagery.

LIMITATIONS AND STRENGTHS OF SATELLITE IMAGERY

Limitations

The major limitation of commercial satellite imagery is spatial resolution. Most of the relatively high resolution commercial satellite imagery provides sufficient information to detect buildings but very little detail regarding those buildings can be interpreted. If the facility is a single building, then the imagery will be of marginal use. It will show how many other large-sized buildings are around the building of interest and the road network in the area, but it will not reveal much about the actual building itself other than its general size and shape. If the facility is large, encompassing many large buildings, then the imagery may be more useful since it will provide information regarding the layout of the buildings, roads and other large features in the overall facility.

This general comment on limitations needs to be qualified somewhat in that the 2-metre resolution Russian KVR-1000 imagery which has recently become available presents new opportunities for commercial satellite imagery applications requiring high spatial resolution. This level of resolution represents a five-fold increase over the 10-metre resolution of the SPOT PLA sensor. It is possible to discern much more spatial information using this imagery. As seen in Figure 1, considerable information can be gained from this data, for example, building detail, roads and streets, and general infrastructure.

Using this imagery, it would be possible to prepare site diagrams showing considerable detail. Obviously, however, it is still not possible to see inside buildings, so even this imagery has very limited potential for the direct detection or investigation of suspected BTW facilities. Furthermore, this imagery is not yet widely available, and it must still be demonstrated that the quality and delivery of the imagery can be supplied consistently enough to meet the demands of an operational program.

Delivery of commercial satellite imagery could be another significant limitation. Normal delivery usually takes a few weeks from when the imagery is ordered. Rush orders can be made with some imagery suppliers to cut the delivery time to less than a week, but this service is more expensive. For some imagery applications, such as sea ice monitoring and weather forecasting, special facilities have been set up to provide rapid delivery of imagery including satellite downlinks for image data and specialized image processing systems. A facility such as this would not be practical in this context because of the high cost of establishing and maintaining such a capability. In general, routine use of commercial satellite imagery is most feasible for those applications which do not require imagery delivered in less than a few weeks.

If a programming request is required, the "end user" of the imagery cannot dictate when the imagery will be acquired. The satellite orbit and sensor characteristics limit the opportunities for collecting imagery to specific times. Satellite scheduling may reduce the opportunities to acquire imagery of a particular location, for example when there are conflicting programming requests. Finally, satellites which have optical sensors cannot acquire useful imagery if the target location is cloud-covered at the time of the satellite overpass.

Strengths

Commercial satellite imagery is collected remotely and its acquisition is non-intrusive. The territory of the country being imaged does not have to be entered to collect the imagery.

Imagery can be collected, processed and interpreted in advance of an on-site inspection to help familiarize inspection teams and to assist in planning (for example, in relation to perimeter security during the inspection by knowing how many roads leave the facility). If commercial satellite imagery were to be used to prepare for inspections, adequate information security would be required to ensure that the locations of the sites being prepared did not become known.

At least to the level of interpreting the layout of visible buildings and roads, satellite imagery can be used with a minimal amount of training.

Confidentiality of commercial information is not likely to be a major problem. The level of detail provided by the imagery is unlikely to reveal information regarding legitimate facilities which would be considered sensitive. Political sensitivities are another matter, however, as witnessed by the fact that recent requests for information of North Korea and Yugoslavia have been rejected, presumably due to sensitivity concerns.

Commercial satellite imagery, in general, is available to anyone willing to pay for it. If anyone else can buy it, it would be difficult for a country to raise an objection to such imagery being used in relation to the BTWC.

ABILITY TO DIFFERENTIATE BETWEEN PROHIBITED AND PERMITTED ACTIVITY

Commercial satellite imagery has no independent capability to differentiate between prohibited and permitted activity. Even the two-metre Russian KVR-1000 imagery will not reveal direct information about what is occurring inside of a building.

However, when used in conjunction with other means, commercial satellite imagery might be able to contribute indirectly to the differentiation of prohibited and and permitted activities. For example, secured perimeters can be detected using commercial satellite imagery in some circumstances. Identification of the presence of a secured perimeter might suggest that a facility may be sensitive or may contain dangerous materials. However, legitimate facilities also have secured perimeters, so such interpretations can do no more than support other, more direct evidence that a particular facility is being used for prohibited activities.

ABILITY TO RESOLVE AMBIGUITIES ABOUT COMPLIANCE

Commercial satellite imagery has no independent capability to resolve ambiguities about compliance. Evidence based upon interpretation of commercial satellite imagery may, itself, be ambiguous. However, it could be used in conjunction with other methods, for example to help familiarize on-site inspection teams with the area of a planned inspection, in the effort to help resolve ambiguities about compliance.

TECHNOLOGY, MANPOWER, MATERIAL AND EQUIPMENT REQUIREMENTS

The assessment of these requirements depends upon whether it is decided to use photographic or digital products. Photographic products can be used with a minimal investment in technology, manpower and equipment. Image interpretation required for the purposes here could be done using a simple magnifying glass; expensive interpretation equipment would not be necessary. Map cabinets would be required to archive copies of negatives and prints.

A considerable investment would be required if it were considered necessary to have an in-house photographic enlarging and printing capability. Survey-quality photographic equipment is expensive, but it must be used if one is to maintain the geometric quality of the imagery when it is photographically enlarged. A complete photographic capability including required processing, printing and enlarging equipment would cost approximately $30-60,000 CDN.

Instead, photographic printing might be "contracted out" rather than trying to develop and maintain an in-house capability. This approach would likely be much cheaper than the in-house approach. A potential problem would be maintaining the confidentiality of the locations being investigated. Personnel involved in work at the photographic laboratory could be required to get a security clearance. Another security measure might be to trim photographic negatives to remove any annotation or similar coordinates which could identify the location of an image would be removed.

Digital products would require access to digital image analysis equipment (in-house or through consultants), hard copy output devices (e.g. film writers) and the expertise to use this equipment. This equipment is relatively expensive and, for this application, there would be little or no advantage to using a digital product. Ultimately, the required final product will likely be a photographic print which has some features indicated and annotated. For this, there is no real requirement for digital imagery.

Since a "map" product would likely be required, consideration should be given to ordering geocoded imagery rather than the uncorrected products. Geocoded imagery can be purchased from imagery suppliers in either photographic or digital format. Geocoded images will typically cost about the same as an uncorrected image but geocoded images will cover a smaller area. However, since the locations of interest will be limited in area compared to the total area covered by an image, the reduced coverage of the geocoded imagery is not really much of a disadvantage.

FINANCIAL, LEGAL, SAFETY AND ORGANIZATIONAL IMPLICATIONS

Financial Implications

Assuming, for example, that SPOT satellite images in negative format were to be utilized for data interpretation and analysis, the representative cost per site, assuming one geocoded image per site, would be approximately $4,000.00 CDN.

If satellite data interpretation is conducted using digital data, then the cost for data production and interpretation would increase in relation to the additional capital expenditures and personnel costs. The cost for a computer-based data processing workstation and related image processing software would be approximately $25-35,000 CDN. Image production capabilities would be considerably more expensive, with digital printers costing approximately $50-100,000 CDN. Printing the processed imagery on a medium for later use can be done on a commercial basis, costing approximately $500 - 1000 CDN per scene, depending on colour or black and white requirements. Although more expensive, such an approach would provide more flexibility, and perhaps more security, in the conduct of inspection preparations, operations and analysis.

Legal Implications

Commercial satellite imagery is available to all nations over most areas of the globe. Legal implications are not an issue here.

Safety Implications

There are no safety implications with using satellite imagery for the verification of the BTWC.

Organizational Implications

If satellite imagery is to be utilized for verification of the Biological and Toxin Weapons Convention, there are two options open for organizing such an application. Nations could purchase, process and interpret the data themselves within already existing organizations; or, an organization such as a BTWC Secretariat could be established. In both cases, any imagery purchased would remain under the control of the organization.

Regardless, if data interpretation and analysis is conducted using geocoded photographic products with the photographic printing contracted out, there would be minimal or no organizational implications. Arranging for imagery coverage for one site (ordering the imagery and then arranging for photographic prints to be made) would entail two or three days of one person's time. If a more complex digital interpretation facility were established, then a computer analyst and photo interpreter would be required, in addition to capital equipment mentioned earlier.

IMPACT ON SCIENTIFIC RESEARCH, COOPERATION, INDUSTRIAL DEVELOPMENT AND OTHER PERMITTED ACTIVITIES AND IMPLICATIONS FOR CONFIDENTIALITY OF INFORMATION

One might expect a positive "spillover" effect from research into the use of commercial satellite imagery as an application of remotely sensed data for arms control purposes.

Cooperative research studies have been conducted by scientific, commercial, and university organizations, with the results and conclusions of the studies shared and presented in international conferences and symposia. While research into using satellite imagery for verification of the BTWC has been very limited to date, there has been a considerable amount of multi-lateral cooperation in other similar areas.