APPLICATION OF SPACE AND REMOTE SENSING TECHNOLOGY TO THE VERIFICATION OF WEAPONS SYSTEMS FOR USE IN OUTER SPACE

A Study Carried Out For
The Arms Control and
Disarmament Division of
The Department of External Affairs

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FOREWORD

This study presents an overview analysis of the effectiveness of space technology and remote sensing applied to arms control verification of anti-satellite weapon systems. In doing so the Study Team have been guided by statements of Canadian Foreign Policy made by principal Canadian officials in International Assemblies and has been cognizant of the desirability of demonstrating possible Canadian initiatives which would prove beneficial also in the national context.

Through assessments of possible configurations, character and capability of anti-satellite systems, and by constraining the scenario for verification missions to a scope which generally conforms to the capabilities of the political process, the Study Team has concluded that there is a role for remote sensing from spacecraft in this mission. This is to say that verification of space craft from spacecraft could prove to be a very effective system. The technology requirements for such a verification system can be met without serious challenge to the restricted intellectual and proprietary technological rights areas of the US and USSR.

On this basis the Study team has suggested in outline the possible configuration, roles and tactics of such a spacecraft and has outlined the capabilities of the Canadian Space Industry in the production of such a first-generation Surveillance and Verification system. From this it is possible to suggest positions which might be taken by Canadian Diplomatic officials in international meetings which would constitute a practicable first step in the anti-satellite weapons verification process and which could comprise specific Canadian contributions to that process.

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CHAPTER 1

INTRODUCTION

1.1 Background

Over the last five years increasing attention has been accorded to the subject of Arms Limitation and the problem of Verification of Arms Limitation Agreements which might be executed either through bilateral arrangement between the United States and the USSR or those in a broader basis under the aegis of the United Nations. In this context there has been considerable emphasis placed upon the reservation of the "use of outer space for peaceful purposes." There have been a number of treaties which have attempted to achieve this objective including the 1963 Partial Test Ban Treaty and the 1967 Outer Space Treaty. SALT I and II, the ABM Treaty and multilateral treaties such as the 1979 Moon Treaty all have significance in this respect.

Negotiations between the United States and the Soviet Union on the anti-satellite aspects of the Use of Outer Space which began in Helsinki in 1978 and were continued in Berne and Geneva are now in abeyance. Even so, the motivation for seeking verifiable and comprehensive limits on anti-satellite capabilities and use is strong. Non-peaceful uses of outer space, referred to by many as the "militarization of outer space" has been given increased attention in UNCOPUOS and its sub-committees.

The arms control aspects of the outer space issue are likely to assume increasing stature particularly in the Committee on Disarmament (CD) and the 40 member nation group have agreed to address this issue. Canada has been active in promoting outer space for peaceful purposes. Significant addresses on this subject have been delivered by the Prime Minister at UNSSOD II and by the Canadian Ambassador at UNGA 35 and 36. During the last session of the CD Canada tabled an initial working paper to define the issues. The Department of External Affairs now requires further definition of the outer space subject in terms of technology factors and issues together with Canadian expertise in addressing some of these through applications of "space technology." The initial requirement is for an overview report from which specific issues and initiatives might be identified for deeper study.

1.2 Purpose of the Study

Stemming from the comments of the Prime Minister at UNSSOD II which focussed sharply upon the deployment of anti-satellite weapons or anti-satellite laser systems in space this study comprises an overview of what would be required to conduct verification of possible arms control agreements on the limitation of all weapons for use in outer space using satellite and space technology. In this context attention is directed to the possible character of weapons systems involved, the application of remote sensing space-borne technologies for detection and verification, together with the potential capabilities and involvement of Canadian Industry and Canadian Space Technology. Major issues and possible areas of initiative which could lead to more specific substantial contributions to Canadian Foreign Policy objectives, through relevant research by the Canadian Space Industry, are addressed.

1.3 Objective of the Study

The objective of this study and its general parameters are as follows:

Objective:

To study and identify problems relating to verification of existing and projected weapon systems for use in outer space, whether space-borne or land based, and to analyse the application of space technology, remote sensing techniques, and arms control methodology to the verification process.

General Parameters:

- the weapon systems for use in outer space may be nuclear, electronic or chemical and may be space or land based;

- verification requirements might involve confirming reduction of weapon systems scale, discovery of violations, assessment of readiness status, detection of pre-launch preparation, confirmation of launch and post launch surveillance;

- surveillance might be focussed upon any phase of the weapon systems process most easily detected - pre-production, production, deployment, operational testing, and operational capability;

- verification may be effective in terms of the weapon system itself or elements of its command, control, and support systems;

- different remote sensing techniques and methods both within state-of-the-art and soon to be within state-of-the-art which may be particularly effective on specific elements of the weapon system and its deployment/configuration should be assessed.

1.4 Conduct of the Study

The study was conducted as a team effort comprising members of PHILIP A. LAPP LIMITED and of SPAR AEROSPACE LIMITED. In the course of the study there were discussions with other relevant individuals and agencies both inside and outside Government. In addition to the technological aspects of space borne detection and surveillance some attention was given to international strategic/political factors insofar as these were considered to impinge upon possible technical solutions and options. A bibliography of major study and reference materials is attached as Annex B to this Report.

The Report is organized into 7 Chapters as follows:

Chapter 1 - Introduction

Chapter 2 - Threat Configurations

In this Chapter the Study Team has considered the basic form of anti-satellite weapons and the platforms on which they can be based in terms of the stages of their life cycle.

Chapter 3 - Remote Sensing

In this Chapter classifications of remote sensing are outlined along with their applicability to the various features of possible anti-satellite satellite systems.

Chapter 4 - Detailed Analysis of the Applicability of Remote Sensing in Verifying Compliance or Contravention of Agreements

In this Chapter the data on major features of anti-satellite weapons are combined with the current capabilities of remote-sensing technology in order to establish the applicability of particular remote sensing techniques. The Chapter includes a summary of major conclusions relevant to the scenario outlined in Chapter 1.

Chapter 5 - Candidate Spacecraft and Missions for Anti-Satellite Weapon System Verification from Space

Based upon the analysis of Chapter 4 this Chapter suggests the possible configurations, character and capability of a verification satellite.

Chapter 6 - Canadian Capabilities

This Chapter outlines Canadian Space Industry capabilities in meeting the requirements for the system postulated in Chapter 5.

Chapter 7 - Summarization of Findings and Conclusions

This Chapter summarizes findings and conclusions on the application of space technologies in this mission and suggests initiatives that might be feasible in the Canadian context.

1.5 Parameters and Factors Affecting Arms Control Verification Missions

In the course of the study it became apparent to the team that the feasibility of applications of space technology in the verification and detection mission would be determined by the scope of and character of the mission being envisaged. This is to say that the broader the mission scope and the greater the resolution demands, coupled with broad and comprehensive roles, a satellite or satellite group dedicated to detection and surveillance of anti-satellite systems could present severe challenges to current technology. This would represent a very long lead-time in achievement, and still not provide a totally effective and reliable instrument. It was noted also that such a broad and comprehensive surveillance system (such as the 1981 postulation of an International Satellite Monitoring Agency) could present problems in acceptance by such major players as the United States and the Soviet Union. Without undertaking deep excursions into political and strategic areas which are beyond our primary and established expertise, we attempted therefore to constrain the study to fit within a scenario which we believe might be realistic in the context of the United Nations. The emphasis was on optimal technological solutions and options within the range of technology available for such a mission in a realistic timeframe, and within the practical bounds of the political process.

The suggested scenario in its simplest form is developed by considering the following technological and political factors in combination:

1. The full range of technology for totally effective broad-based surveillance, detection and verification of possible threats to peace that may be introduced into space from both space and earth platforms is generally the property of the United States and the Soviet Union and is unlikely to be available to third parties or international groups for deployment in this mission;

2. Although such technology could be replicated over time, the cost would be prohibitive and there would always be a considerable technology "lag";

3. It is highly probable that effective surveillance and verification capability will be an essential condition to the execution of arms limitation agreements relating to outer space. On this basis applications of existing technology will be crucial;

4. The most realistic role for the United Nations in arms control verification in outer space would be one which involves surveillance activities which the one major power cannot impose upon the other without provocation and retaliation. This notion is in harmony with the traditional United Nations "peace keeping" role. This is to say that the United Nations might fill the "no-man's land" in outer space between the two major contenders.

Interestingly, when we look more closely at the "no-man's land" concept in outer space environment as a plausible scenario, and postulate the most effective technological content and capability of a feasible surveillance and detection satellite in this role, we find that the configuration and deployment of a particular satellite is within the generally available space technology not only on a world basis but in Canada itself. This is to say that the current broadly available space technology is consistent with verification of anti-satellite weapon systems deployed in space in a limited and plausible mission role consistent with the probable capability of the political process.

In the course of the study the team established additional perceptions upon the utilization of space technology and remote sensing in arms control verification:

1. Applications of space technology, while extremely useful and perhaps essential, do not in themselves constitute a totally effective verification system. Therefore such utilization of technology would, for best effectiveness, be an element of a broader based more diversified system;

2. Surveillance, interrogation and verification of potential threats to peace based in outer space is effective from another space-borne satellite and less demanding technologically than surveillance from earth, or air-based platforms;

3. Surveillance from space of earth-based threats is highly demanding technologically and from a cost-effectiveness point of view less productive than several other methods;

4. Surveillance from space of anti-satellite weapon systems deployed in space is a less complex and demanding task when the space population has been classified and verified and the mission has reached a more or less steady state operation of monitoring new arrivals to the environment.

On the basis of the foregoing perceptions and the most plausible mission for the United Nations (or other third party agency) this study has reviewed configurations of threat, utilization of remote sensing devices and techniques and has postulated achievable peace-keeping responses. It is hoped these might enable Canadian diplomatic officials to establish valid positions in the anti-satellite weapons context which are in harmony with Canadian Foreign Policy objectives and which also might prove beneficial to National economic and industrial objectives.

CHAPTER 2

THREAT CONFIGURATIONS

2.1 Introduction

The first step in a review of the technical problems associated with verifying conformity with or violation of arms control agreements is to prepare an accurate list of the various ways an anti-satellite weapon can be configured as a threat. Preparation of this list is a straightforward exercise in identifying the basic forms or genre of the weapons themselves and the choice of platforms on which they can be based, or from which they can be launched. This list then becomes the foundation upon which is built the analysis of what is distinctive about each threat configuration so that effective surveillance and detection methods can be identified. This chapter begins with the preparation of such a list and concludes with a review of the distinctive features and observables during the various phases of each weapon's progress toward an operational status.

2.2 Anti-Satellite Weapons

Weapons that can be used against satellites can damage or interfere with a satellite's operation by exploding in the vicinity of it, by hitting it physically, by temporarily jamming its communications and sensing channels or, finally, by striking it with a destructive beam of energetic particles or laser energy.

For the purposes of this study we divide these weapons into two major classes. The first class we label as "Delivered Energy" weapons. The second class we label "Directed Energy". The purpose in making this distinction has partly to do with delivery time. Energy from a directed energy weapon travels to a target at or near the speed of light; delivered energy weapons require propulsion and ballistic trajectories, or both, to reach a target in space. In the latter case, time in the order of minutes is required for this traversal of the platform - target distance. Because the "reaction time" for the two classes are vastly different, the associated control, guidance, and steering technology is vastly different also.

Another fundamental division occurs because of the basic physical nature of the weapons. Weapons in the delivered energy class damage a target by releasing large amounts of energy at or in the immediate vicinity of a target. The energy is 'stored' in a carrier until it reaches the target.

Weapons in the directed-energy class have their energy created at a local source; it is then directed or 'beamed' to the target. No physical carrier is needed, the energy is, as it were, its own carrier.

Finally, the configuration of the two classes of weapons and their "mother" platforms can differ in ways that matter in terms of verification in and from space. Beam weapons at terrestrial sites will probably always have distinctive support facilities characterized by uniquely shaped buildings whereas conventional anti-satellite weapons resemble other classes of missiles and rockets more than they differ from them.

Each of these two anti-satellite weapon classes has two subsets. Under delivered energy weapons we include nuclear and chemical explosives and simple non-exploding projectiles. An example of the latter would be a 'ramming' satellite or passive projectiles ejected from a mother satellite. The fragile mechanical nature of satellites makes them vulnerable to this type of encounter unless elaborate protective measures have been taken to 'harden' the satellite against such attacks. We shall label this member of the subset under delivered-energy weapons as a residual kinetic energy weapon because the damage is done when the energy of the projectile is absorbed by the target. As a point of interest, hardened satellites normally require more powerful rocket launchers because of the extra weight of thicker external surfaces or more robust components.

Directed energy weapons, like delivered energy weapons can appear in two formats. First there is the laser or particle beam weapon powerful enough to damage delicate components such as solar arrays or optical sensors on a satellite, or even damage the satellite's main structure. One is more destructive than the other but they both leave the target disabled. Second, there is the directed-energy beam that can interfere with one of a satellite's key functions while the beam is on. When the offending beam is turned off the satellite can resume normal operations. Included in this second class are all common forms of jammers, whether they operate in the radio wave, microwave, or optical region of the spectrum. It may be noted that this is the only instance in which radio wave and microwave electromagnetic (EM) beams will be discussed in the context of weapons. Note also that, although electronic countermeasures (ECM) is normally associated with the use electromagnetic (EM) jammers, ECM is too specialized a subject to be included in an overview of the kind being undertaken here.

2.3 Platforms for Anti-Satellite Weapons

For this study of anti-satellite weapons we identify the three platforms that can carry and maintain a weapon in a state of readiness for use against a satellite. The three platforms are another satellite, an aircraft, or a terrestrial site. An anti-satellite missile carrying an explosive charge is, technically speaking a platform also, but a missile is customarily lumped as part of the weapon, with the base from which it is launched being called the platform. Mobile terrestrial, and ocean-going (surface or sub-surface) platforms are special cases of terrestrial platforms, but for practical reasons this study concentrates on fixed earth platforms. The practical reasons pertain to the almost insuperable problem of verifying the existence of anti-satellite weapons on these special platforms. Current thinking (resulting from this study) is that verification from space of arms control agreements respecting weapons on mobile or ocean-going platforms will require such elaborate cooperative measures that the space element in the verification exercise may not be crucial and may not be cost-effective. Furthermore, technological advances are and continue to be such that the necessity to support some types of anti-satellite weapons from large, complex fixed terrestrial sites is slowly yielding to sophisticated, mobile platforms. Realistically, these mobile weapon systems can only be identified with confidence as anti-satellite weapons during the early test and proving-out phases and then only if tested against satellites.

2.4 Platform/Weapon Combinations or Threat Configurations

It is beyond the scope of this study to prepare a detailed technology forecast with respect to the practicality and timing of every possible combination of all anti-satellite weapons and weapon platforms. The weapons in particular have an almost infinite range of power, lethality, flexibility and adaptability. To give meaning to the study, we have restricted our attention to the two major weapon classes and their subsets. From a reading of the available unclassified literature, discussions with technical experts, and professionnal judgement we conclude that all weapons in these classes are reasonable candidates, technically speaking, for testing at the full-scale level in the 1980's and the first half of the 1990's. Some could even be in service by that time. The various feasible combinations of platforms and anti-satellite weapons are given in Table I. The variety of combinations is illustrated in Figure I.

WEAPON / PLATFORM	DELIVERED ENERGY		DIRECTED ENERGY Lasers, Particle and Electromagnetic Beams	
	CHEMICAL OR NUCLEAR	RESIDUAL KINETIC	DESTRUCTIVE OR PERMANENTLY DISABLING	JAMMERS
TERRESTRIAL	GROUP 1.1 FEASIBLE	IMPRACTICAL	GROUP 1.3 FEASIBLE	GROUP 1.4 FEASIBLE
AIRCRAFT	GROUP 2.1 FEASIBLE	IMPRACTICAL	GROUP 2.3 FEASIBLE	GROUP 2.4 FEASIBLE
SATELLITE	GROUP 3.1 FEASIBLE	GROUP 3.2 FEASIBLE	GROUP 3.3 FEASIBLE	GROUP 3.4 FEASIBLE

TABLE 1

FEASIBLE ANTI-SATELLITE WEAPON/PLATFORM COMBINATIONS

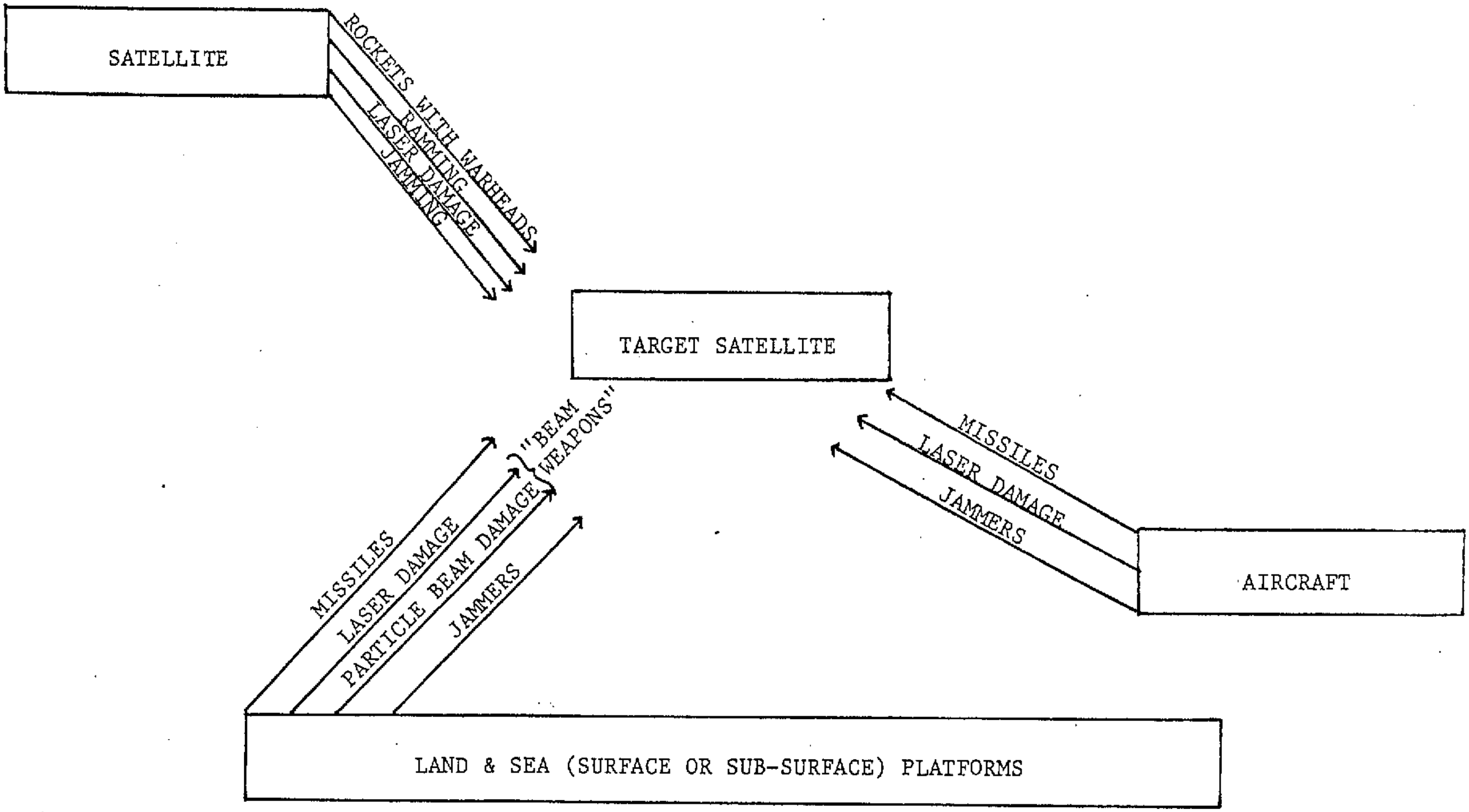

FIGURE I

PLATFORMS ON WHICH ANTI-SATELLITE WEAPONS CAN BE SITED

The selected combinations are, by group:

Group 1.1: Ground-Based Delivered Energy Weapons with Nuclear or Chemical Explosives;

Group 1.3: Ground-Based Directed Energy Weapons with Destructive Power;

Group 1.4: Ground-Based Directed Energy Weapons for Jamming;

Group 2.1: Aircraft-Based Delivered Energy Weapons (Missiles) with Nuclear and Chemical Warheads;

Group 2.3: Aircraft-Based Directed Energy Weapons with Destructive Capability;

Group 2.4: Aircraft Based Directed Energy Weapons for jamming;

Group 3.1: Satellites Carrying Delivered Energy Weapons with Explosive Chemical and Nuclear Warheads;

Group 3.2: Satellites for Ramming or Ejecting Passive Projectiles;

Group 3.3: Satellites Carrying Directed Energy Weapons with Destructive Power;

Group 3.4: Satellite Carrying Directed Energy Weapons for Jamming.

Group 1.1: Ground-Based Delivered Energy Weapons with Nuclear or Chemical Explosives:

Anti-Satellite missiles and rockets are member of this group. These systems exist today and are believed capable of intercepting satellites in Low Earth Orbit (LEO). We exclude from this group multi-stage rockets that launch "killer" satellites into stable orbits for later use. Killer satellites are covered in Group 3.1.

The main characteristic of Group 1.1 systems that might be observed remotely are the launch complexes, and the trajectories of the missiles during tests. The trajectory and track of an anti-satellite missile under test might, for example, take it close to an already orbiting satellite as a test of its guidance or homing subsystem. It might also have to have a brief 'chase' history. These trajectories would last several minutes, thereby allowing radar detection, direct visual observation of the missile during flight, infrared observation of engine plumes and the terminal explosion, if one occured, and, possibly, monitoring of telemetry, command, and tracking signals. All of these observations could be made from space. The launch complex can be observed from space during inactive periods but might present interpretation problems leading to ambiguities in conclusions. In the context of verification from space, the credibility of the analysis would therefore be a major problem - How would one prove that any, or all, or none of the weapons were anti-satellite?

<u>Group 1.3: Ground-Based Directed Energy Weapons with Destructive Power:</u>

Anti-satellite lasers and particle beam weapons are members of this group. The beam-launching complexes for these weapons have distinctive features, such as large particle accelerator facilities, or, for a laser, a large optical focussing system, in the order of metres diameter. Therefore, the end use, unless hidden, will always be obvious. The end-use of the facility would be unambiguous both during tests and during post-test inactive periods. The particle-beam weapon facility would be more complex than the facility for a destructive laser. Certain classes of lasers require relatively inconspicuous hardware for creating the primary laser beam. For example, a chemical laser's largest components in the laser section are storage tanks for hydrogen and flourine. However, the beam-expanding optics are a necessary and distinguishable feature. Excellent reviews of the technical details of directed-energy weapons are given in Ref. 15, 16, 36 and 37.

Group 1.4: Ground-Based Directed Energy Weapons For Jamming:

Radio-wave, microwave and optical jammers are members of this group. Radio wave and microwave jammers are not necessarily distinguishable from normal communications hardware but an analysis of, for example, the strength of their emissions during testing would reveal whether or not they might be jammers. Optical jammers would have beam-expanding optics similar to the destructive laser systems, but the power level would be much lower. A ground- based optical jammer could resemble an astronomical optical telescope both in its outward features and in its siting, since both require cloud-free conditions during use. Correct interpretation of remotely sensed data acquired from space would depend on observing the facility during tests of its aiming and jamming capabilities. Since these tests would normally be carried out with a cooperative satellite, detection of a test in progress to verify the facility's purpose would require foreknowledge and careful planning. Realistically, a cooperative arrangement with the country doing the testing might be necessary to remove ambiguities in the interpretation of the remotely sensed data. Conceivably, such cooperation might be forthcoming as a way of establishing that the facility was only a jammer, not a destructive weapon.

Group 2.1: Aircraft-Based Delivered Energy Weapons (Missiles) with Nuclear and Chemical Warheads:

As the title suggests, air-to-space missiles are members of this group. Discernible characteristics of these systems are associated with what they do rather than what they look like because their mission differs from that of other military aircraft.

Efficient launching of air-to-space missiles requires a vertical orientation and possibly a high vertical velocity component at high altitude on the part of the aircraft because the aircraft is essentially replacing the first booster stage of a more conventional rocket launcher.

Aerobatic manoeuvers of this type during training and testing would distinguish the weapons from missiles to be used against ground or air targets. The trajectory and track of the missile during tests would also be unique because of extra propulsion for a chase mode plus evidence of homing on an already orbiting satellite, as is the case of anti-satellite missiles launched from land bases.

During inactive periods, the aircraft could not be readily differentiated from others as to function by remote sensing from space.

Group 2.3: Aircraft-Based Directed Energy Weapons with Destructive Capability:

In principle, both destructive lasers and particle-beam weapons are members of this group. However, while lasers may be practicable for the forseeable future, particle-beam weapons on aircraft do not appear practical in the time frame of interest. Notable features about an aircraft/laser system would be the large size of the aircraft needed to carry a large heavy payload and the presence of discernible beam-expanding optics in the order of a metre diameter. The aircraft would compare in size to a large military transport-aircraft. Advances in technology might permit a laser weapon to be mounted externally at 'hardpoints'. Tests of such a system against targets in space would be conspicuous when viewed from a space platform with remote-sensing capability. During transmission, scattering of such a powerful beam might cause visible and IR radiation to be emitted in all directions along the column of the beam and this would be generally visible.

Group 2.4: Aircraft-Based Directed Energy Weapons for Jamming:

Radiowave, microwave and optical jammers can be carried in an aircraft. The distinctive permanent feature of a laser weapon system would be the presence of a focussing mirror up to 1 metre diameter. Antennas for radiowave and microwave jammers can be conspicuous because they are externally mounted and frequently are present in large numbers. Furthermore these weapon platforms are seldom silent, so the jamming emissions tend to be distinctive. A radar antenna would probably be protected by an optically opaque radome on the nose of the aircraft and could not be seen. Monitoring the power and variety of the emissions during a test could distinguish normal communications-level power from jamming-level power. Note that when a test is finished there is no remaining evidence in space because nothing has been damaged.

Group 3.1: Satellites Carrying Delivered-Energy Weapons with Explosive Chemical and Nuclear Warheads:

These are the 'killer' satellites referred to in Group 1.1.

Satellites that are themselves orbiting nuclear or chemical bombs and satellites that are platforms for rockets with explosive warheads are members of this group. For completeness, we include satellites that are capable of re-entry for an attack against terrestrial targets. The latter require special materials to permit re-entry without damaging the explosive payload. Observation by a space sensor while in orbit would reveal enough information about such a weapon to establish that it was in fact a nuclear weapon and whether or not it was configured for re-entry. Nuclear weapons emit radiation that can be detected at closer range; re-entry requires unique materials that could be observed in space at close range. Such a weapon platform would require extra fuel for orbit changes and chases in space. This feature might be discernible. Verification of the presence of a chemical explosive is much more difficult. It might have to be done by inference. Some of the analysis would be based on observations of what the satellite didn't do. It is reasonable to believe that a satellite whose legitimate purpose is reconnaissance, or remote sensing, or communications, or navigation, or scientific research, or some combination of these can be correctly identified as to its purpose. It follows that satellites that cannot be categorized into such peaceful roles are capable of hostile actions. This deductive method has frequently been used in the past to identify the purpose of Soviet satellites.

Group 3.2: Satellites for Ramming or Ejecting Passive Projectiles:

Satellites in this group could take on many configurations, but, as for the satellite with explosives, much can be learned from close observations. Inspection in space might reveal the presence of the large amounts of fuel and high-thrust engines needed for chase. Mechanisms for firing projectiles might be present. The ramming function would require quite extraordinary manoeuvering and propulsion features which could be verified from space with reasonable accuracy.

Test phase and 'readiness' checking would be especially useful for verifying such a satellite's main purpose.

Group 3.3: Satellites Carrying Directed Energy Weapons with Destructive Power

Systems in this group are self-evident. They are the particle beam and laser beam weapons. As in the case of the aircraft, however, it is doubtful if particle-beam weapons on satellites will reach maturity before the next century, so the discussion is limited to destructive laser weapons. Large aperture optics are required to focus a beam in the IR, optical and ultraviolet spectrum. Typically, a mirror system similar to that of an astronomical telescope, the main mirror being several metres in diameter, would be required. These optics would be a distinguishing characteristic of the satellite. The primary power for the laser while unique for certain types of lasers need not be for others, so consistent verification by this parameter depends on the particular system being used. Whether directed against terrestrial or space targets, the test phase in the development of such a weapon would be conspicuous from an observation platform in space. Early testing ground-to-space would also be conspicuous because the beam would disturb the atmosphere as in the case of ground-based system described earlier.

A potentially special member of this group is reviewed in Reference 27 of the Bibliography list. This weapon, an x-ray laser, is unique for two reasons. First it is a beam weapon, with characteristics similar to a laser, but it operates at x-ray wavelength. Wavelength is a determinant in the size of focussing optics, so by virtue of the very short wavelength of an x-ray laser any focussing hardware is orders of magnitude smaller in size from that required for laser beams in the optical spectrum. In fact, in the configuration discussed in Reference 27 focussing hardware is not needed, the x-ray laser is self-focussing. Therefore, the major distinctive features of optical lasers noted above do not apply. The second unique feature is the fact that the x-ray energy for the laser originates in a nuclear explosion in the device itself; the platform is destroyed on firing. The weapon may be envisaged as directing the x-ray energy of a nuclear explosion (energy of the order of 10^{12} joules) to a remote target, the target being damaged by the shock or impulse of the x-ray beam. According to the article it is entirely practical to direct the weapon towards a number of targets simultaneously by placing a series of laser rods, which resemble spokes of a wheel, around a very low yield nuclear warhead and aiming the rods at targets. Because it has no focussing optics and is relatively small in size - the rods might vary from 1 to 3 metres in length - such a weapon would be difficult to verify except by close visual inspection of the rods and measurements of nuclear emission.

Groups 3.4: Satellites Carrying Directed Energy Weapons for Jamming

Anti-satellite weapons in this group might be easily confused with satellites for normal communications. Verification by remote-sensing would require analysis of what the system did over long periods of time and how consistent this activity was with that of, say, a legitimate communications satellite. The orbit of such an anti-satellite system could conceivably be different from that of a conventional or peaceful satellite because of the need to optimize the jammer's position, with time. However, highest confidence would be put on the analysis of remotely sensed data taken during simulated or actual anti-satellite jamming tests.

The detection-sensitive characteristics of the ten threat configurations noted in ten of the previous subsections are summarized in Table II.

2.5 Multifunction Satellites

The previous paragraphs have dealt with a particular weapon on a particular platform. Practically speaking, for the case of satellite platforms at least, it might prove advantageous to combine two weapons on a single satellite. For example, a platform with a large electrical power supply and adequate propulsive fuel could support rockets with warheads and jammers. Various combinations could be made to make best use of the platform's features, be they pointing accuracy, propulsion, primary power, size, orbit altitude and inclination, or platform lifetime. The opportunity must be borne in mind when considering the most likely configuration of a space-based threat platform.

WEAPON / PLATFORM	DELIVERED ENERGY		DIRECTED ENERGY Lasers, Particle and Electromagnetic Beams	
	CHEMICAL OR NUCLEAR	RESIDUAL KINETIC	DESTRUCTIVE OR PERMANENTLY DISABLING	JAMMERS
TERRESTRIAL	GROUP 1.1 .launch complex .test trajectories and chase-in-space tracks .explosion in space possible	IMPRACTICAL	GROUP 1.3 .large, novel power facilities .disturbed atmosphere during tests .large focussing telescopes (lasers only)	GROUP 1.4 .emissions at jamming power levels .focussing telescopes for lasers
AIRCRAFT	GROUP 2.1 .missile launch at high vertical velocity and high altitude .missile trajectory & chase-in-space .possible explosion in space	IMPRACTICAL	GROUP 2.3 .1-2 m laser focussing mirrors .optical ports .disturbed atmosphere during tests	GROUP 2.4 .emissions at jamming power levels .focussing telescopes for lasers
SATELLITE	GROUP 3.1 .nuclear radiation .re-entry materials .extra fuel for orbit changes .launch .on station communications	GROUP 3.2 .unusually high propulsion capability .projectile ports .launch .on station manoeuvres	GROUP 3.3 .possible high electrical primary power .focussing telescope with 1-2 metre mirrors .launch .on station manoeuvres	GROUP 3.4 .emissions at jamming power levels .focussing telescopes for laser jammer

TABLE II

DETECTION-SENSITIVE CHARACTERISTICS OF ANTI-SATELLITE THREAT CONFIGURATIONS

2.6 Verification During Stages of Development

The final element in this analysis of Threat Configurations is consideration of how sensitive an anti-satellite weapon is to remote sensing during the various phases of its life cycle. Like any other technologically sophisticated system, anti-satellite weapons progress through a number of phases in the transition from original conceptualization to deployment in a readiness state. From the point of view of verification of an anti-satellite system by remote sensing from space, these stages reduce to five distinct phases beginning with the design and build and ending at the ready (but inactive) phase. A sixth phase or status was added to the list to separate the 'ready' phase from what might be designated as 'alert' status. Significant discernible changes sometimes can occur in a transition from inactive to alert status particularly in the case of space-based systems. The six detection-sensitive phases are:

a) Design and Build,
b) Test at full-scale or full power,
c) Deployment,
d) System testing,
e) Activation of system to ready (but inactive),
f) Change to alert status.

2.6.1 Phase (a). Design and Build

Verification from space of conformity to or violation of agreements during this phase is possible for weapons requiring major civil works and/or with the construction of distinctive structures. A ground-to-space missile site is a candidate. A particle accelerator facility for a beam weapon is such a structure. Some lasers would require large power plants, others would not. In case of the weapons that can be constructed in existing laboratories and factories, however, verification from space is not possible without some form of complementary cooperation on the ground.

2.6.2 Phase (b). Tests generally of experimental models, prototypes, etc., at full-scale or full power in a highly structured test set-up, for example tests against 'dumb' targets:

The activity surrounding tests of this kind are normally very distinctive. With foreknowledge derived from non-space sources, confidence in the analysis of test data acquired remotely in and from space would be high for the systems being considered in this study. An exception is full-power tests on earth of a laser weapon to be based ultimately on a satellite platform. Such a test could conceivably be conducted 'indoors' against simulated satellite targets in vacuum chambers; it would present an impossible verification problem without cooperation.

2.6.3 Phase (c). Deployment of the first-generation system:

Deployment of anti-satellite (killer) satellites is defined as those operations associated with placing the satellites in the correct orbit. Clearly, satellite systems are highly visible in this phase. Deployment of aircraft-based anti-satellite weapons refers to the logistical activities associated with placing the aircraft at their chosen bases and constructing communications, control and any special facilities. For ground-based systems, deployment is essentially replication in more sophisticated form of the original test facility. What was verifiable during the first phase may therefore be verifiable while it is being duplicated.

During the deployment phase, a weapon's hardware and software are integrated into military practice for the first time.

2.6.4 Phase (d). System testing, using real or simulated command and control, and representative targets:

As far as practicable, all features of a system must be exercised periodically to establish confidence in the system's ability to perform at a later time if called upon to do so. Accordingly, system testing is the most revealing and distinctive phase in a weapon's development because communications, control, and simulated or real operations against coperative targets in space are involved.

2.6.5 Phase (e). Activation of the system in ready-but-inactive status:

Remote sensing during this phase is a credible verification procedure for weapons on satellites because the system can be examined periodically to detect changes in configuration for example, re-boost to overcome orbit decay of low altitude satellites. Remote sensing of earth or aircraft - based systems during this phase is not likely to be productive, in general, unless very high resolution sensors capable of observing small details such as servicing or substitutions are employed.

2.6.6 Phase (f). Change to alert status: altitude and orbit changes in satellite; visible payload configuration changes; sudden surges in communications traffic:

As for Phase (c), this status is most easily detected on weapons-carrying satellites because the changes can be observed visually at relatively close range. Furthermore, control communications with the satellite are likely to increase. The presence of these signals would be difficult to conceal. A change to alert status for aircraft-based weapons, if it involved becoming airborne would be observable from space because the aircraft would eventually be positioned at high altitude to perform their mission. Associated ground activities, for example, movements of people and logistics activity, might also be discernible and distinctive. Increased command and other communications applicable to terrestrial or airborne platforms would not necessarily be detectable from space. A change of status at a terrestrial site could go completely unnoticed at a space observation platform.

This chapter has provided an overview of threat configurations, in a context of verifying conformity to or violation of arms control agreements. From this overview it is concluded that satellites carrying weapons are the most consistently observable and verifiable threat once they pass the design and build stage. Terrestrial or airborne weapon platforms must be revealed at certain stages of their life, usually during testing phases, but at other times analysis of remotely sensed data may prove to be difficult and ambiguous. While it might appear redundant to state it because it is so obvious, it must be noted here that remote sensing of details is most effective at the closest practicable range. Therefore, in addition to the increase in the credibility of space data on satellites carrying weapons in comparison to data on terrestrial or airborne weapon platforms, highest credence can be placed on data taken at close range, on the order of a few hundred metres, because of the increased detail available. Chapter 3 will examine in more detail the response remote sensing satellites can make to these threats.

CHAPTER 3

REMOTE SENSING

3.1 Introduction

Chapter 2 has described ten anti-satellite weapons, their platforms, their characteristic features and has discussed the potential for verification at the various stages a weapon system goes through as it reaches operational capability. The anti-satellite weapons and platforms of Chapter 2 have a number of common features, though they vary in detail from one system to another. This Chapter develops a detailed list of the common features of these threats that might normally be amenable to remote sensing from space. Remote sensors themselves are then examined in the context of these features. Although the review will include all threats at all stages of development it should be borne in mind that in-orbit verification of satellite-based threats is the most productive, and furthermore, that examination at close range produces the best data set.

3.2 System Characteristics and Effects Normally Amenable to Remote Sensing

Listed below are 16 elements or characteristic features that might be discerned at one time or another by remote sensing from space:

a) platform/weapon dimensions;
b) platform configuration;
c) weapon configurations;
d) primary power;
e) one-shot versus repeater;

f) delivery system - ballistic; propulsive;
g) delivery sensing - aiming; homing, passive or active; beam-riding;
h) command and control - autonomous, self initiating; remotely triggered; readiness phase; enabled phase;
i) local emissions;
j) materials;
k) ion wake;
l) reaction to interrogation - self-protective; hostile or shy; mechanisms; action profile;
m) lifetime and lifecycle;
n) re-service and supply;
o) family concepts - distributed function; multiple systems;
p) support/logistics - personnel, civil works, basic services.

In addition to the above list, experience has shown that renewed or changed emphasis on a particular class of weapon system frequently has repercussions on the activities and flow of reports and information from the non-military R & D and manufacturing sector. This is particularly true during the design and build phase, i.e. Phase (a). We note this aspect in the interest of completeness even though the data is normally collected through reviews of the literature, attendance at conferences, public statements and the like.

3.3 Remote Sensors

Remote sensors can be classified according to what they sense, the form of their data output, their requirements and limitations for different sensing missions. Statement of the current state-of-the-art world wide, Canadian accomplishment to date, and finally, the existing Canadian know-how to develop the sensor if the need arose is included in Chapter 6.

Except as noted sensors are perceived as being used in three degrees of "remoteness" from the anti-satellite weapon: (i) proximity sensing close to a satellite, that is within a kilometer and down to a few hundred meters; (ii) distant sensing of a satellite, that is from tens to hundreds of kilometres distance in space, (iii) distance sensing of the earth, that is sensing at a hundred kilometers or more.

The sensors can be divided according to the four principal categories of what is sensed. The list with brief definitions, is:

1. Visible and infrared (VIR) sensing of scattered, reflected, and emitted optical, ultraviolet and near infrared radiation. A subcategory is radiation emitted in the far infrared, commonly referred to as Thermal IR, because the wavelength peak of the emitted spectrum is characteristic of bodies at or near room temperature.

2. Detection of Sensing reflected microwaves; i.e. RADAR.

3. Passive Electromagnetic (EM)-sensing of radar, telemetery, command tracking and all other forms of communications in the radio wave and microwave part of the spectrum. These techniques are commonly referred to as passive EM sensing to distinguish them from optical and infrared sensing.

4. Sensing of perturbations of the local environment about a satellite. This category includes detection of nuclear radiation, chemical leakage, static electric potential and electric fields, and magnetic anomolies. Certain perturbations of local environment can be 'sensed' at a distance, others require the sensor to be placed in the vicinity of the perturbation. The definition of remote sensing is somewhat strained in the latter case but the sensors are very cost-effective and are therefore included as possible candidates for a remote-sensing 'payload'.

Additional discussion of these categories is given.

3.4 Visible and Infrared (VIR)

The end product is normally an image. The images are formed by lenses or curved mirrors or by line-by-line scanning, usually of rotating or nodding mirrors. The images can be captured on film or on a fine grid of electronic light sensors. Images collected at satellites must be telemetered to ground stations, a process that can be accomplished in real or near-real time in the case of electronic sensors or in minutes in the case of film. (The film must be developed and 'read-out' by electronic scanning in the satellite. Film recovery is not considered here.)

The state-of-the-art in the formation and telemetering from satellites of images is highly developed throughout the world. With very sophisticated and expensive optics, objects down to a few centimetres size can be observed from satellites at 200 to 300 kilometres altitude. As is known from ordinary experience on earth however there is an inverse relationship between the width of the field of view of an optical imaging system and the distance between the imaging system and the object being imaged. This inverse relationship is a necessary compromise dictated by the necessity to have the image of an object at great distance be sufficiently magnified to permit it to be analysed. Consequently, optical systems such as high-power telescopes have a very limited field of view, in the order of degrees or even minutes, whereas cameras for use over short distances can have fields of view of 90^{o} and more. Imaging systems for distant objects have a second important limiting feature, in addition to narrow fields of view. To obtain enough light to make an image "visible" the cross-section of the light-collecting optics must increase dramatically. While the design and manufacture of large precision optical components is highly developed everywhere in the world, the techniques are extremely expensive when used to produce space-quality components. The state-of-the-art in this space hardware is generally associated with military missions.

In terms of remote sensing in and from space, visible, near infrared, and thermal IR optical systems hold a pre-eminent position, largely due to the compatibility of the product image to what the human eye normally perceives. However, space-based high resolution optical systems for viewing at long range, say in the order of a tens of kilometres or more, have very narrow fields of view, thus limiting what area the satellite can 'see' in the relatively brief period of each orbit. They also have very large, expensive, high-technology, collecting apertures.

3.5 Radar

Radar systems exist in several basic configurations. The most important for remote-sensing in and from space are narrow-beam, millimetric ranging and scanning radars, Synthetic Aperture Radars (SARs) and terrestrially observing Space Based Radars (SBRs) with special 'staring' modes. Signals from a scanning radar can be used to build up a high resolution image or to simply display an echo at a certain range and bearing. Scanning radars for use over ranges of a few tens of kilometres in space are reasonably well developed, as are SARs for range up to several hundred kilometres. SAR imaging technology however is much more complicated than that of the simple scanning radar and image processing time for SAR can lag in real time by several minutes. The application of SAR to high velocity targets appears to be a complex problem. Space Based Radars are also extremely sophisticated when it comes to the synthesis of staring modes for which very esoteric signal processing techniques are required. SBRs are not seen as being available for non-military use for several years. In the context of this study, a millimetric wave radar for use in a scanning mode over ranges of several tens of kilometres in space is a practical option for determining range and bearing or producing images with resolution in the order of several meters. (At closer range the image resolution improves.)

3.6 Passive Electromagnetic (EM) Sensing

Passive EM sensing has become a very sophisticated technology since World War II. Technical progress in the subject has accelerated in the past decade especially with the development of digital control and digital frequency synthesis techniques. Highly sensitive radio-wave and microwave receivers are regularly described in the literature as being able to scan large segments of the radio spectrum in seconds with high resolution, and effectively monitor signals from several sources simultaneously. Special features permit 'tagging' of signals for future reference. The principal limitation of EM sensing at a satellite is the achievment of high sensitivity and adequate directivity. Like optics, the high sensitivity needed to detect signals over long distances requires large collecting apertures, in the order of many tens of meters at longer wavelengths. Again as in optics, the 'field of view' (which is associated with the antenna beamwidth) becomes correspondingly small. The technology therefore becomes increasing awkward as the distance from the source increases. EM sensing over a few tens of kilometres is very straight forward. The case of EM sensing of signals sent into space from the ground is straightforward where the threat and the sensing spacecraft are in the same uplink beam. For command and control, satellites normally have small receiving antennas while the earth sation has large antennas and high power transmitters. Hence earth-to-space transmissions can be monitored with comparatively simple apparatus, comparable to what is needed to monitor emissions from a satellite being examined.

3.7 Perturbations of the Local Environment

Sensing in the local environment is a highly specialized and highly developed technology for the four phenomena of nuclear radiation, chemical leakage, static electric and static magnetic anomolies. Except for so-called E-Wave detection of magnetic fields, which is still in development, all sensors are reliable and generally available. Data is customarily obtained in the form of signatures.

The information is summarized in conjunction with other data in TABLE V of Chapter 6.

3.8 Conclusions

From the foregoing it is evident that the state-of-the-art is, in general, adequate for the remote-sensing applications being discussed in this study. For this mission, however, in some applications, factors such as ambiguity of targets will preclude a positive analysis of remotely sensed data, regardless of resolution, spectral purity, or anything else, because, powerful as it is, remote-sensing can approach but it can never achieve the confidence level of close on-site inspection of objects by skilled observers. This is another way of stating what had been noted earlier, that is the closer one can get the better (and frequently the easier). The next chapter concludes this detailed review by combining the features of the threats with remote sensors to separate the high-and-low probability situations.

CHAPTER 4

APPLICATION OF REMOTE SENSING TECHNOLOGY IN VERIFICATION OF THREATS

4.1 Consolidation of Data

For an analysis of the high and low probability scenarios the Chapter 2 data on all major features of anti-satellite weapons to be sensed is combined with the current capability of space-based remote-sensing technology to sense them. This is done in chart form in Tables A1 through A10 in Annex A. A separate chart has been prepared for each threat configuration group identified in Table I.

To present the information compactly, remote sensing techniques and the features of a system that can normally be sensed are presented as rows and columns respectively in each table. The intersections of the rows and columns have a meaning when we indicate at each one the phases in a weapon's development during which each (remote-sensing)/(system-characteristic) combination is valid. The question being asked when a decision to put any of the six (a) to (f) phases (given in Chapter 2) at an intersection is: "During which of the six phases of development <u>can something be learned</u> about the feature in this column by the sensing operation designated for this row? For example, at the upper left hand intersection of TABLE A1 we state that some knowledge of dimensions of a terrestrial-based anti- satellite missile site can be gained through visual observation from space when the site is being built, phase (a); when the missile is being tested (b);

when the system is deployed (c); when the system is being tested (d); when it is inactive (e); and when it changes to alert status (f). Note that we must beg the question of whether or not the sensing is adequate to constitute totally effective detection as compared to sufficient detection to merit additional investigation by other means. By identifying only those development phases where remote sensing is applicable we have in essence added a third dimension to our chart and made a rough feasibility selection. The final right hand column in the table gives the total number of 'hits' for each sensor technique at each of the phases of development. This exercise is necessarily subjective because minute details and distinctions are not appropriate to a table of this kind.

In a number of systems certain remote sensing techniques, or certain features of the system, or both, have no meaning. In these cases the appropriate row or column of the table has been left bank.

In many situations some sensors will be more effective than others; in others, use of more than one sensor will be redundant because one is sufficient; in still others the widest possible complement of sensors will be necessary to acquire even a modest data set.

4.2 Quantitative Analysis of Consolidated Data

As expected, the charts for the ten threat scenarios reveal noticeable differences from group to group in what can be sensed and in what phases the sensing can be done.

To illustrate, elimination of rows by virtue of inapplicability is evident in tables A1 through A6 for groups 1.1, 1.3, 1.4, 2.1, 2.3 and 2.4. What the tables say is that the capability to sense the perturbations in the local environment caused by the weapon-carrying platform does not apply to land and air platforms. In a similar way, elimination of columns by virtue of inapplicability indicates that reaction to interrogation, assessment of lifetime and life cycle, and in some cases estimates of primary power, cannot be done for land or air-based threats. Only a satellite can observe at close enough range another satellite to sense nuclear, chemical, or magnetic disturbances associated with the presence of weapons. Moreover only another satellite can probe for a reaction to its presence.

The numerical data in the right hand columns of tables A1 through A10 can be combined to obtain a quantitative statement of the net effectiveness of each sensor technique in each threat configuration. The procedure, the results of which are presented in Table III, is as follows. In each table the numbers in the right hand column for each row have been added together to give the total incidents of use of each remote sensing technique for all the features of each threat configuration. We have weighted the incidents of use in phases (c) deployment, (d) system test, and (e) ready-but-inactive by a factor of 2 to emphasize the importance of these 3 phases for this mission. To illustrate, the final column in Table A1 shows that visible and near infrared sensing is effective against 4 threat parameters in phase (a), 6 in phase (b), 5 in phase (c), 7 in phase (d), 3 in phase (e) and 5 in phase (f). Summing these incidents and weighting them by two in phase (c), (d), and (e) gives a total of 45. We will designate this number as the Figure of Merit (FOM) for this sensor in the context of this particular threat configuration. Summing all of the FOM's will give a TOTAL FOM for remote sensing in each threat configuration. The various totals are all given in Table III. Because of the importance of imaging systems, the individual totals are given for visual and near infrared, thermal infrared, and radar, the three imaging sensors.

Though crude and subjective, this analysis gives some insight into the universality of each particular sensing technique. As noted earlier what it does not do is reflect the criticality of any particular observation in the verification process.

Table III reveals two features. First, the overall or total Figure of Merit for sensing satellite platforms in their various stages of development is essentially double that for terrestrial or airborne platforms. Second, sensing by means other than imaging is a significant factor in sensing satellites from satellites as opposed to sensing land and air platforms from satellites.

The numbers in Table III have been used in Table IV to support a qualitative statement about the effectiveness of remote sensing in verifying compliance or detecting contravention of arms control agreements in and from space. We have somewhat arbitrarily rated a Total

WEAPON / PLATFORM	DELIVERED ENERGY: CHEMICAL OR NUCLEAR	DELIVERED ENERGY: RESIDUAL KINETIC	DIRECTED ENERGY (Lasers, Particle and Electromagnetic Beams): DESTRUCTIVE OR PERMANENTLY DISABLING	DIRECTED ENERGY (Lasers, Particle and Electromagnetic Beams): JAMMERS
TERRESTRIAL	GROUP 1.1 FOM's VIR 45 THERMAL IR 18 RADAR 48 OTHER 26 TOTAL 137	IMPRACTICAL	GROUP 1.3 FOM's VIR 53 THERMAL IR 39 RADAR 48 OTHER 17 TOTAL 157	GROUP 1.4 FOM's VIR 31 THERMAL IR 26 RADAR 24 OTHER - TOTAL 81
AIRCRAFT	GROUP 2.1 FOM's VIR 49 THERMAL IR 45 RADAR 49 OTHER 42 TOTAL 185	IMPRACTICAL	GROUP 2.3 FOM's VIR 44 THERMAL IR 42 RADAR 38 OTHER 25 TOTAL 149	GROUP 2.4 FOM's VIR 28 THERMAL IR 34 RADAR 38 OTHER 8 TOTAL 108
SATELLITE	GROUP 3.1 FOM's VIR 91 THERMAL IR 73 RADAR 76 OTHER 145 TOTAL 385	GROUP 3.2 FOM's VIR 116 THERMAL IR 81 RADAR 76 OTHER 118 TOTAL 391	GROUP 3.3 FOM's VIR 76 THERMAL IR 70 RADAR 73 OTHER 142 TOTAL 361	GROUP 3.4 FOM's VIR 75 THERMAL IR 72 RADAR 65 OTHER 122 TOTAL 334

TABLE III

QUANTITATIVE FIGURES OF MERIT (FOM's) FOR INDIVIDUAL, AND TOTAL, REMOTE SENSORS IN TEN THREAT SCENARIOS

WEAPON / PLATFORM	DELIVERED ENERGY		DIRECTED ENERGY Lasers, Particle and Electromagnetic Beams	
	CHEMICAL OR NUCLEAR	RESIDUAL KINETIC	DESTRUCTIVE OR PERMANENTLY DISABLING	JAMMERS
TERRESTRIAL	GROUP 1.1 FAIR	IMPRACTICAL	GROUP 1.3 FAIR	GROUP 1.4 POOR
AIRCRAFT	GROUP 2.1 FAIR	IMPRACTICAL	GROUP 2.3 FAIR	GROUP 2.4 FAIR
SATELLITE	GROUP 3.1 GOOD	GROUP 3.2 GOOD	GROUP 3.3 GOOD	GROUP 3.4 GOOD

TABLE IV

QUANTITATIVE ASSESSMENT OF THE EFFECTIVENESS OF REMOTE SENSING IN AND FROM SPACE IN TEN THREAT SCENARIOS

Figure of Merit below 100 as Poor; between 100 and 200 as Fair; and greater than 300 as Good. It must be understood however that for a very specific type of weapon, such as a very powerful anti-missile laser in a satellite, prospects for effective remote sensing are probably much better than good, they may be excellent. The size of the primary power supply in this case could materially influence the distinctive features of the satellite. At the other extreme, the ultimate purpose of a jammer satellite might be readily disguised by using it for normal communications.

This completes the detailed analysis of the probable effectiveness of remote sensing against ten platform/weapon threat configurations. We conclude that sensing offensive satellites is likely to be much more effective than sensing earth-bound anti-satellite weapons. Furthermore, sensing satellites with destructive, as opposed to jammer, weapons is the most effective. And finally, recalling earlier statements, sensing at close range is the most revealing, the most reliable, and the least demanding technically of the sensor. (Although achieving and maintaining proximity is costly in terms of fuel.)

Putting these conclusions into a perspective of practical policy, economics and feasibility, it can be stated that long-range sensing of satellites, air, or land platforms requires state-of-the-art technology and is necessarily limited to narrow fields of view. Sensing of satellites at close range on the other hand requires commonly available or soon to be available technology that is more modest in performance and has acceptable fields of view for the purpose.

Though price and politics militate against the former, the close-approach satellite-to-satellite scenario is still a plausible option, bearing in mind that the number of satellites to be verified is always small if verification is only required for 'new arrivals'.

The following chapter will incorporate the analysis and conclusions of this and previous chapters into how these missions might be performed by a spacecraft technologically configured to meet the essential requirements of the limited plausible scenario postulated in Chapter 1.

CHAPTER 5

CANDIDATE SPACECRAFT AND MISSIONS

5.1 Introduction

In this chapter a concept is put forward for a hypothetical, but plausible, remote-sensing satellite capable of carrying out the basic function of closely inspecting other satellites having unknown or at least questionable objectives in space. We will also remark briefly on the characteristics of a remote-sensing satellite configured for more esoteric observation from intermediate and long range. In addition to describing the key features of the 'short-range' satellite we will review possible tactics that might be involved in using it. The chapter will conclude with a brief statement about the other critical non-satellite elements of an arms control verification mission.

5.2 Background, Factors and Assumptions

The tables of the previous section analyzing the effectiveness of various space borne sensors in verification of threats to spacecraft by terrestial or spacecraft borne weapons systems show that no single sensor or combination of sensors is definitive in all pre-operational and operational phases of a program. It is clear that some sensors are more effective than others in providing diagnostics data across the spectrum of weapons which might be deployed. It is also apparent that most weapons systems are most readily identified as to purpose where system tests are being performed. Finally, satellites can in theory at least be examined at close range after they are deployed.

Examination of the nature of the most effective sensor packages suggests that it might be possible to mislead an investigation of a weapons system into the belief that the mission is totally different or non-hostile. To carry out such a deception across all phases of a weapons program is likely to seriously degrade the performance of this mission but remains a possibility. It has been assumed in this study that the satellite investigation would be only one facet of any relevant arms verification program and that other techniques would largely preclude large scale decoy or Q-ship type operations. However it may be noted that such options might be moderately effective in the early weapon system development and testing, but with the more massive quantity of data likely to be available in the deployment and operations phases, the cover is likely to be less effective.

In order to consider the nature of the spacecraft bearing the verification sensors, assumptions have been made regarding the circumstances of the investigation as discussed elsewhere. It has been assumed that the verifications are being made in a general context of non-hostility and where "world opinion" is a motivation. Thus the verification is assumed to be an acceptable rather than a hostile act, and there is no immediate urgency in the determination as to the nature of the weapon system or spacecraft being investigated.

These are critical assumptions to this section as they determine the nature and fueling of the investigating spacecraft, its acceptable operations, the duration of observations, the nature of the data backhaul and the extent of facilities and manpower for the data reduction and analysis.

While clearly it is desirable that all possible data be obtained for verification, it is also clear that a high confidence in the analysis can be developed on the basis of a relatively restricted data base. In the following, the approach is to use a minimal payload capability to (a) permit a cost effective mission concept and (b) to illustrate some of the mission constraints.

5.3 Degrees of Remoteness - Characteristics

As mentioned in relation to the sensor capability analyses, the investigation of spacecraft and weapons from space may be divide into three broad categories of remoteness with quite distinctive characteristics viz.

(a) A close approach - based on a highly manoeuverable spacecraft with a sensor payload such as to provide diagnostic information from distances in the meter to kilometer range. This is applicable only to investigations of spacecraft by spacecraft.

(b) Intermediate range - based on spacecraft to spacecraft distances of tens to hundreds of kilometers, the diagnostic techniques tend to be of higher angular resolution than (a).

(c) Long distance - operable over earth to orbit distances but also applicable to S/C to S/C investigations. The resolution and pointing demands are extreme.

The diagnostic instrumentation may be based on similar characteristics in each case but the requirements for resolution, pointing and integration/processing times will be generally vastly different as will be the spacecraft carrying the equipment. The following sections outline typical payloads and their impact on the spacecraft design.

5.4 Close Approach Mission

5.4.1 Observer Spacecraft Payload

A review of the platform/threat characteristics tabled in Chapter 4 gives some idea of a minimal spacecraft payload which might prove of interest. Assuming an ability to move a sensor payload into close proximity to another spacecraft, the principal instruments might be as follows:

(i) A conventional high quality photographic or video raster image based on visible spectrum. This would provide a great deal of information regarding design and thus purpose of a spacecraft. The nature of antennas provides data on the frequency bands utilized, the beams widths etc..

Large optical apertures are generally recognizable in even low resolution images. The shape and dimensions of the spacecraft are highly sensitive to the purpose. Secondary platforms in some cases suggest high accuracy pointing etc. etc.. The visible configuration <u>and</u> operations are probably the most significant single diagnostic distinguishing the purpose of a spacecraft.

(ii) The second item of a typical close range investigation spacecraft might be a thermal imaging subsystem. A thermal image of a spacecraft provides data as to how the spacecraft generates and utilizes its power resources. If the observations of the spacecraft cover several operational configurations then a great deal of performance data can be inferred. Thermal images would also provide substantial data on thrusting operations, i.e. on the pointing accuracies, spacecraft mass etc..

(iii) Another significant diagnostic tool, potentially critical to the observing spacecraft itself, is a high resolution radar - probably in the millimeter region of the spectrum and possibly of an imaging type.. This would provide high resolution data on the relative motions of the spacecraft, a measure of reaction to thruster operations etc..

From these data together with those on thrusters e.g., burn-time and magnitude, basic spacecraft parameters of mass and momentum can be developed. The radar is also a critical requirement for target acquisition and proximity manoeuvering.

(iv) The final candidate instrument for the limited mission observation spacecraft would be an EM receiver able to locate and characterize all target spacecraft E.M. missions and to the extent possible intercept the uplink transmissions.

Such a receiver would have the ability to analyze the signals as to Effective Isotropic Radiated Power (EIRP), bandwidth, modulation etc. Of special significance would be the Telemetry and Command (T & C) signals and their correlation to spacecraft operations.

TABLE V (page 55) summarizes the payload capabilities of the candidate spacecraft and illustrates the type of diagnostic data which might be derived from a typical mission or verification.

5.4.2 The Observer Spacecraft

The total four sensor payload for the <u>close investigation</u> spacecraft is a relatively small payload in respect to weight and power resource demands. The ability to maneuver in close proximity to a spacecraft as well as execute the requisite orbit and plane changes presupposes a major fuel load, assuming that the spacecraft is not launched on a single investigation dedicated mission. It appears that a series of satellites might be distributed amongst the principal orbits of interest e.g., synchronous equatorial, low altitude inclined. Because of the proximity of operations, the propulsion system would have to be very precise.

TABLE V

CANDIDATE SPACECRAFT PAYLOAD CAPABILITIES

1. Visual

(a) Spacecraft Characteristics
* Size
* Configuration
* Appendages
* Separable Sections

(b) Apertures
* Optical - Pointing Sensing
  Weapons
* Antennas - Frequency
  Beam widths
  T & C bands
* Pointing Characteristics

(c) Solar Panels
* Power capabilities

(d) Propulsion
* Motor/Thruster sizes
* Burn durations

(e) Thermal design
* Radiators
* Point sources

2. Thermal Images

* Power dissipation
* Power sources
* Thruster operations

3. Electromagnetic Wave

* Frequencies
* EM Electromagnetic Power radiated
* Data input/output rates
* Microwave sensing e.g. radar?

4. Radar

* Spacecraft motions in thrusting/ stationkeeping.

All observations become additionally productive where there are cross correlations between sensors and usually are more definitive where spacecraft changes in environment of operations are correlated.

The relatively low data rate associated with the sensor suggests that it would be feasible to tape record the data and thus overcome the limitations in coverage which would develop at low altitudes. For reason of the same communications limitations, it would be desirable that the spacecraft be able to operate in, or override into, an autonomous mode, both to gain maximum data and to prevent collisions or other incidents.

The spacecraft command system woud have to be secure primarily because of the problems which could occur with the extensive manoeuvering. The telemetry and data dump could be "clear" if desired, as might be required of an international system.

Spacecraft pointing requirements would be nominal because of the low angular resolution systems in the payload.

5.4.3 Summary - Close Approach

The close approach mission is potentially the most productive of definitive data, yet is based on utilization of the lowest level of sensor technology. However the inferred requirements to put the investigating spacecraft into station keeping on an unknown satellite results in either a nominal fuel load on a spacecraft dedicated to a single investigation (orbit) or a major fuel capability to provide plane and orbit changes between investigations. Based on the assumption that investigations are generally to occur in a period of "non-hostility" and the primary concern is weapons or hostile vehicles "parked in orbit" for a substantial period, it may be possible to utilize low energy high efficiency thrust techniques to move the spacecraft to successive stations for investigations.

5.5 Intermediate Range Mission

This implies a revised payload with increased sophistication. At intermediate range, the diagnostic portion of the payload might be based on the same parameters, but the resolution requirements are substantially increased, with attendant decreases in the field of view. Consequently there are also increased difficulties in acquisition and pointing which affect the vehicle requirements. The radar is probably the instrument which will provide the initial "local control" for lock-up. If the separation/approach velocities are low then instrument pointing slew rates are similarly low and no difficulties should arise. The fuel penalty has essentially been accepted. If however the investigating spacecraft has a high separation/ approach velocity, the total period for acquisition and sensing may be short and the pointing slew rates high. The design of the payload under such circumstances is much more difficult as are the demands on spacecraft stability and pointing. Clearly it is highly desirable that at least a reasonable capability to open up the range, thus saving fuel, be incorporated even in a close approach.

5.6 Long Range Mission

Long range probing operable at earth to orbit ranges or spacecraft to spacecraft at equivalent distances involves high technology in all aspects of the payload and spacecraft. The resolution demands are coupled with difficult field of view and pointing constraints. The sensor technologies may be expected to change somewhat where the measurement cannot achieve the required resolution. The spacecraft stability requirements are extreme, but maneuvering capabilities are minimal except where orbit changes are required for example for illumination. The pointing slew rates tend to be high and target acquisition problems severe.

5.7 Investigation Tactics

The question of investigative tactics is most applicable to close approach situations where greatest flexibility can be achieved. Other missions at greater range may be limited by the duration of observation available and the inability to sense certain aspects of the unknown spacecraft's operations. The specific approach will be determined by apriori knowledge of the possible missions, the fact that a launch has occurred and extensive orbit determinations from the ground. A typical scenario follows.

Assigned to interrogate a specific spacecraft, the sensor spacecraft will be manoeuvered on a minimum energy basis for a close approach station keeping.

Initial control will be from ground tracking of the two spacecraft. The sensing spacecraft will probably be given an approximate bearing and acquisition range on which it will center its millimetric radar search.

Based on ground tracking and locally acquired range data the sensing spacecraft would move into convenient range for optical measurements. During this approach the receiving equipments would search for spacecraft emissions and evidence of uplink signals addressed to the target.

The initial sensing might center on any physical characteristics or emissions considered to pose or imply a threat to the sensing spacecraft. Of particular interest would be any operations which indicated the target spacecraft was aware of the sensing e.g., shuttering, pointing changes, radar or optical ranging.

The general approach would be to obtain complete visible and thermal images of the target correlated with the target's operations. In addition, the electromagnetic spectrum emissions would be recorded.

Special reference would be made to "on board" generated emissions such as telemetry including spacecraft motion across the downlink beams to confirm beam widths etc..

Depending on the nature of the suspected mission, target spacecraft behaviour on entering eclipse could be a significant clue or confirmation. Optical data might be unavailable except as to actions leaving eclipses, but thermal images could be very revealing at entry, during and following eclipse.

In more aggressive modes, the sensing spacecraft might interrogate the target with higher power signals, optical illumination devices etc.. Less aggressive actions might be "shadowing" the solar array or confusing earth or star sensors but even these might result in loss of a spacecraft and be considered hostile.

5.8 The Total System

The spacecraft and its sensor capabilities are critical to this type of verification mission, but they are only a part of the total system. As illustrated by the review of a possible spacecraft tactical scenario, there is a very substantial support infrastructure to the spacecraft. Portions of the system are diagnostic in themselves (e.g., tracking) but we shall refer here only to the support aspects.

1. Tracking

   In order to perform the mission, and achieve an effective "encounter", the target location must be established, and the orbit accurately determined. This can be done fairly readily by optical or radar means. The secondary problem is the abundance of man made items in space. Thus in addition to the tracking equipment themselves, and the computers to determine orbit parameters from the range data, there is generally a large scale computer inventory of objects and their respective orbit parameters, identification etc..

2. Launch Vehicles

The launch of the investigative spacecraft implies availability of launch facilities, probably on a relatively short turn around call-up basis. Depending on the class of spacecraft and the intended orbit, this may not be a major hurdle. Conceivably the spacecraft could be a single visit (limited fuel) restricted payload vehicle which might be aircraft launched similarly to an anti-satellite weapon.

3. Operations & Control

The spacecraft on a verification mission must be monitored and controlled. Particularly where the scenario calls for a close approach a real time quick reaction capability may be critical to avoid "incidents".

The problem is tractable where a direct link can be maintained, but where the spacecraft operates "out of sight" of the master or slave control, other spacecraft may be required to maintain the link. Facilities similar to TDRSS in concept (but not capabilities) could be involved, further extending the system or its complexity.

4. Data Reduction

In the case of tracking and some sensor data, substantial data reduction may be required to put the information into its most useful form and to establish the cross correlations between the various sensors, tracking, spacecraft operations, environmental changes etc..

5. Interpretation

The difficulties of interpretation of the data in terms of verification of a potential weapons system cannot be underestimated. It is critically dependent on not only hard data from spacecraft and ground but also more speculative inputs from other sources, which implies substantial skills as well as background in diverse space and weapons concepts.

CHAPTER 6

CANADIAN CAPABILITIES

6.1 Introduction

Although there is no basis to presuppose a requirement for Canada to implement an arms verification space system alone, for present purposes Canadian capabilities will be reviewed in respect to all aspects or requirements of the space system described in the earlier part of this section.

6.2 Payload

A previous section has discussed the requirements and technology base for various types of sensors which could be utilized for arms control verifications from space. A summary is given in TABLE VI which also provides an overview of the status of the Canadian technology as demonstrated, or as a technology base for extension to new requirements. The overview would suggest a good basis for development of most sensor types with some lack of experience oriented to the highest resolution instruments.

In terms of present activites, the National Research Council's Canada Center for Space Science has programs in rocket payloads and low resolution optical sensing (Project Viking) which are a part of the relevant technology capabilities. Some of the technologies

TABLE VI

CATEGORIES AND OPERATING FEATURES OF REMOTE SENSING TECHNIQUES

OPERATING FEATURES / WHAT IS SENSED	PRODUCT FORMAT AND PERFORMANCE	SENSOR-TO-TARGET RANGE & PATH	REACTION OR INTERROGATION TIME	ESTIMATED STATE-OF-THE-ART	CANADIAN TECHNOLOGY BASE	CANADIAN CAPABILITY (ACCOMPLISHMENT)
A.1 Scattered, Reflected Emitted Optical and Near Infrared	IMAGES 35 mm quality, colour or B&W	Proximate	Seconds	millimetres	High	High Starlab
	2 metre resolution	Space/Space (10^4 km)		metres		
	0.5 metre resolution	Space/Earth		centimetres		
A.2 Emitted Far Infrared (Thermal)	cm resolution	Proximate		centimetres	High	High
	10 metre resolution narrow view, large optics	Space/Space		metres		
	10 metre resolution narrow view, large optics	Space/Earth		metres		
B Reflected Microwaves (radar) (See Note 1)	IMAGES metres from scanners and SAR (cms range resolution from scanners)	Proximate	Seconds for scanner and SBR. SAR requires minutes for onboard processing or wideband telemetry with faster ground processing	High	Good	Good
	tens of metres from scanners, metres from SAR	Space/Space		High	Good for hardware High for software	Fair
	metres from SAR and SBR	Space/Earth		High	High for SAR Low for SBR	High for SAR Low for SBR
C TT&C Communications Signals (Passive EM Sensing)	Spectral Signatures limited by sensitivity, dynamic range, spectral resolution, sweep rates	All	Seconds	High below 100 GHz	High	High
				High above 100 GHz including optical	Moderate	Low Not active at this time
D Perturbation of the Local Environment . Nuclear Radiation Sensing . Chemical Sensing by Mass Spectrometry . Potential and E-Field Probes	Spectral and Anomaly Signatures Sensitivity limited	Proximate only	Seconds	High	High	High
. Absorption spectra . Atomic/Molecular Emission	Sensitivity limited (coarse images obtainable)	Space/Space only	Seconds	High	High	High
. Magnetic anomaly and Magnetic Sources	0.5 γ Sensitivity limited	Space/Space only	Seconds	High	High	High
	0.5 γ E - wave technique	Space/Space only	Seconds	Uncertain	High	Low

Note 1: SBR - Space Based Radar, SAR - Synthetic Aperture Radar

within the WISP program could also be applicable to some sensing techniques. The work by NRC towards participation in the Starlab program involves many of the space optical sensor problems such as thermal control, pointing etc. which are critical to high resolution systems.

The Canadian capabilities in Radio frequency and Radar equipment are more than adequate for the types of sensor payloads envisioned here.

6.3 Spacecraft

Canadian capabilities in respect to spacecraft design and manufacturing are proven through two decades of successful programs. The Alouette/ISIS series of spacecraft is indicative of the capability to supply complex sensing spacecraft (in this case scientific observations) operating at low earth orbit typical of sensing missions. The CTS progaram demonstrated a unique Canadian spacecraft for communications from equatorial geosynchronous orbits.

Most recently Canadian capabilities have been illustrated by the CANADARM with its complex computer controlled motions and multiple interfaces to the STS Orbiter and by the successful ANIK D prime-contracted in Canadian industry. The ability to manage large space programs encompassing many disciplines and suppliers will be further demonstrated by the SBTS (Brasilsat) program.

Similarly the DOC M Sat and EM&R's Radarsat now moving through their Phase B contracts will maintain Canadian spacecraft level skills over the next half decade.

6.4 Tracking

Canadian tracking capabilites are well established in the several sub-disciplines. The Prince Albert station was designed and used for tracking of non-cooperative targets while Telesat and CRC have demonstrated skills in tracking of cooperative spacecraft in both low earth orbit and at geostationary station.

There is also experience in optical tracking from the earth which could be relevant to the needs of this program.

6.5 Launch & Launch Support

Although there is no established Canadian facility or vehicle capable of inserting spacecraft into orbit, the Churchill range work in rockets and range operations coupled with the experience gained in range operations in the course of Canadian space programs provides a sound basis for meeting requirements in this area. Certainly for smaller payloads in Low Earth Orbit even the basic launch vehicle could be developed from present Canadian vehicles.

6.6 Spacecraft Operations

The Canadian capabilities to maintain a spacecraft operation has been well established in both private and government establishments. The only distinction which would characterized the arms verification mission would be the much greater computational load associated with the manoeuvering to intercept and investigate another spacecraft.

6.7 Data Reduction and Analysis

Data reduction capabilities in Canada are very highly developed as well as being widely dispersed. Programs comparable to the verification mission might be the Landsat reduction by EM&R's Canada Center for Remote Sensing, the hardware and software developed for Sarsat's SAR, and the data processing used in the Sarsat program in Search and Rescue. There are probably several other sources of such capability within the military and security operations in Canada.

The analysis and interpretation tasks associated with the reduced data are much less well defined in terms of requirements and are probably best equated to speculative scientific investigations of complex phenomena or alternately archological detective work. Clearly a broad spectrum of weapons and space knowledge is required.

CHAPTER 7

SUMMARY OVERVIEW

For the previous chapters of this Report, the Study Team has reviewed in broad terms the range of weapon systems for use in space, their platforms and has conducted analysis of their sensitivity to remote sensing detection and determination at various stages of their life cycles.

Working from the assumption that third party surveillance and detection systems for purposes of verification will not reach a level of technological sophistication equal to that of the capability of the United States and the Soviet Union to develop and deploy, the Study has focussed upon a more limited surveillance and detection capability. This could back up possible initial steps which might be achievable by the political process in addressing this subject. On this basis the Study Team has suggesed that a considerable capability is within reach to conduct close-in verification of space-borne weapon systems from a surveillance spacecraft of relatively modest technological sophistication. Longer range space weapon verification would require higher levels of sophistication. Such a system is envisaged as being a principal element of a broader total system which would entail air and ground survey. The role envisaged for such a surveillance spacecraft is to not duplicate detection measures which the United States and Soviet Union routinely apply against each other, but to also include those actions and surveillance activities which if applied between the two major powers might constitute provocation and thus generate retaliation. The diminution of the provocation-retaliation motive between the United States and Soviet Union could be a considerable stabilizing influence in the reservation of outer space for peaceful purposes. The third party role assumes that the third party does not constitute a threat to the other parties and that they are not placed in invidious political and technological positions.

In this context, chapters 3 and 4 of the report have outlined the remote sensing information products that are relevant to the role described above and as well to some other anti-satellite systems (this is to say - other than spaceborne). From the analysis it is clear that the highest level of effectiveness at least cost and least technological problem is achieved in the close-in space-to-space surveillance role.

Chapter 5 of the report has developed the outline configuration, capability and feasibility of such a spacecraft and in Chapter 6 a summarization of Canadian Industry capability in the relevant space technology fields has been provided, also in outline. In the course of the study, it has been concluded that dedicated spacecraft would be required for such a role and that attempts to integrate existing or planned Canadian Satellites into this role would seriously detract from the primary tasks of those satellites without significant addition to the anti-satellite surveillance and detection function. Manoeuverability and on-call response is a very important capability ingredient of an anti-satellite verification satellite system.

Based upon this concept of a limited mission and in terms of the capability of Canadian Industry to meet the technology requirements the Study Team is persuaded that there is a base from which Canadian Diplomatic Officials can develop and propose Canadian initiatives (either as Canadian or in the framework of the UN and CD) which support in material terms statements made by the Canadian Ambassador and the Prime Minister referred to the Chapter 1 of this report.

We are aware that it would be impossible to make a fully developed proposal or inititative in UN & CD on the basis of this overview alone. It clearly is a multi-facted problem involving several technological and non-technological disciplines.

Areas that might be suggested for more detailed investigation could includes:

1. In the context of close-in satellite to satellite surveillance - the international legal implications including those that would pertain to a world organization;

2. Organizational support and infrastructure required for comprehensive missions of this type on an on-going basis;

3. Development of a more definitive spacecraft and mission concept for close-in and intermediate satellite to satellite surveillance missions;

4. Detailed assessment of applicable payload technologies and relevant Canadian capabilities.

* * * *

ANNEX A

DETAILED TABLES:

APPLICATION OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE / THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	abc def	abc def	a-c d-f			-bc def	-b- d--	-			-b- d--					abc d-f	465 735
Thermal Infrared	--c d--	abc def	--c d--			-	-	-			-b- d--					-	122 411
Radar-active microwave	abc def	abc def	a-c d-f			bc def	-b- def	-			-b- d--					abc d-f	464 666
Passive EM, including EMP	-	-	-		ASSUMED ONE SHOT	-b- d--	-b- d--	--- d--			-					-	020 300
Orbit Trajectory Analysis	-	-	-			-b- d--	-b- d--	-b- d--			-					-	030 300
Nuclear emissions																	-
Chemical emissions, static electric/magnetic anomoly																	-
Detect plasma anamolies	-	-	-b- d--			-b- d--	-	-			-b- d--					-	030 300

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 1.1

PLATFORM: Terrestrial

WEAPON: Delivered-energy nuclear/chemical missile

REACTION TIME: Order of minutes

TABLE A1: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE / THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distribured	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	abc def	abc def	abc d--	-b- d--		abc d-f	abc def	-			-b- d--					abc d-f	686 835
Thermal Infrared	abc def	abc d-f	-bc d--	-b- d--		-b- d--	-b- d--	-			-b- d--					abc d--	384 812
Radar-active microwave	ab- d--	abc def	abc d-f	-b- d--	ASSUMED REPEATER	abc d-f	abc def	-			-b- d--					abc d--	685 824
Passive EM, including EMP	-	-	---	-		--- d--	--- d--	--- d--			-					-	000 400
Orbit Trajectory Analysis																	-
Nuclear emissions																	-
Chemical emissions, static electric/magnetic anomoly																	-
Detect plasma anamolies	-	-	-b- d--	-b- d--		-	-	-			-b- d--					-	030 300

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 1.3
PLATFORM: Terrestrial
WEAPON: Directed-Energy, Destructive
REACTION TIME: Seconds or less

TABLE A2: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE / THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all Parameters, for each phase
Visible, Near Infrared	abc def	abc def	-b- d--			ab- d-f	ab- d-f	-									452 524
Thermal Infrared	abc d--	abc d-f	-b- d--			ab- d-f	ab- d-f	-									452 503
Radar-active microwave	ab- d--	abc d-f	-b- d--	REPEATER ASSUMED		ab- d-f	ab- d-f	-									451 503
Passive EM, including EMP																	
Orbit Trajectory Analysis																	
Nuclear emissions																	
Chemical emissions, static electric/magnetic anomoly																	
Detect plasma anamolies																	

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 1.4
PLATFORM: Terrestrial
WEAPON: Directed Energy, Radiowave, Microwave, Optical Jammer
REACTION TIME: Seconds or less

TABLE A3: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

THREAT FEATURES / REMOTE SENSING TECHNIQUE	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc d-f	-bc def	-bc d-f	-b- d--	-bc d-f	-b- d-f	-	-			-b- d--			--- -ef	-b- d-f	-bc d-f	095 928
Thermal Infrared	-bc d-f	-bc def	-bc d-f	-b- d--	-bc d-f	-b- d--	-	-			-b- d--			-	-b- d-f	-bc d-f	095 916
Radar-active microwave	-bc d-f	-bc d-f	-bc d-f	-b- d--	-b- d-f	-b- d--	-b- d--	-			-b- d--			--- -ef	-bc d-f	-bc d-f	0105 1017
Passive EM, including EMP	-	-	-b- d-f	-	-	-bc d--	-bc d--	-b- d-f			-			-	-	-b- d--	052 502
Orbit Trajectory Analysis	-	-	-b- d--	-b- d--	-b- d--	-b- d--	-				-				-	-	040 400
Nuclear emissions																	
Chemical emissions, static electric/magnetic anomoly																	
Detect plasma anamolies	-	-	-b- d--	-b- d--	-	-	-	-			-b- d--			-	-	-	030 300

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 2.1
PLATFORM: Aircraft
WEAPON: Delivered Energy Nuclear/Chemical Missile
REACTION TIME: Order of Minutes

TABLE A4: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE \ THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc def	-bc def	-b- d--	-b- d--		-b- d--	-b- d--	-			-b- d--			--- -ef	-b- d-f	-bc d-f	093 935
Thermal Infrared	-bc def	-bc def	-b- d--	-b- d-f		-b- d--	-b- d--	-			-b- d--			-	-b- d-f	-bc d-f	093 925
Radar-active microwave	-bc def	-bc def	-b- d--	-b- d--	ASSUMED REPEATER	-	-	-			-b- d--			--- -ef	-b- d-f	-bc d-f	073 735
Passive EM, including EMP	-	-b- d--	-b- d--	-		-b- d--	-b- d--	-b- d-f			-			-		-	050 501
Orbit Trajectory Analysis																	
Nuclear emissions																	
Chemical emissions, static electric/magnetic anomoly																	
Detect plasma anamolies	-	-	-b- d--	-b- d--		-	-	-			-b- d--						030 300

PHASE LEGEND
(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 2.3
PLATFORM: Aircraft
WEAPON: Directed Energy, Destructive
REACTION TIME: Seconds

TABLE A5: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

THREAT FEATURES / REMOTE SENSING TECHNIQUE	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc d-f	-bc d-f	-b- d--	-		-bc def	-	-						--- -ef	-b- d-f	-bc d-f	064 626
Thermal Infrared	-b- d--	-b- d--	-b- d--	-b- d-f		-bc def	-	-						--- -ef	-b- d-f	-bc d-f	072 725
Radar-active microwave	-bc d-f	-bc d-f	-b- d--	-		-bc def	-	-						--- -ef	-b- def	-bc d-f	064 636
Passive EM, including EMP	-	-	-	-		-	-	-b- d-f						-	-b- d-f	-	020 202
Orbit Trajectory Analysis																	
Nuclear emissions																	
Chemical emissions, static electric/magnetic anomoly																	
Detect plasma anamolies																	

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 2.4
PLATFORM: Aircraft
WEAPON: Delivered Energy Radio-wave, Microwave, Optical Jammer
REACTION TIME: Seconds

TABLE A6: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

THREAT FEATURES / REMOTE SENSING TECHNIQUE	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
REMOTE SENSING Visible, Near Infrared	-bc def	-bc def	-b- def	bc def	-bc def	-b- def	-b- def	-bc def	-	-bc def	-	--c -ef	--- -ef	--- -ef	-bc def	-bc d-f	0119 111314
Thermal Infrared	-bc def	-bc def	-b- d-f	bc def	-bc def	-b- d--	-b- d--	-	-	-bc def	-	--c -ef	--- -ef	--- -ef	-bc def	-bc d-f	0108 9911
Radar-active microwave	-bc def	-bc def	-b- d-f	--c -ef	-bc def	-b- d--	-b- d--	-	-	-b- -ef	-bc def	--c -ef	--- -ef	--- -ef	-bc def	-bc d-f	0108 91012
Passive EM, including EMP	-	--- --f	-b- def	-	-	-b- def	-b- de-	-bc def	-	-	-	--c -ef	-	-	-bc def	-bc d-f	064 667
Orbit Trajectory Analysis	-	--- -ef	--- -ef	-	-bc def	--- d--	-b- d--	-b- d--	-	-	-	-	--- -ef	--- -ef	-bc d-f	-	042 556
Nuclear emissions	-	-	--- -ef	--c -ef	-	-b- def	-	-	-bc def	-	-	-	-	-	-	-	022 244
Chemical emissions, static electric/magnetic anomoly	-	-	--- -ef	--c -ef	-	-b- def	-	-	-bc def	-	-	-	-	-	-	-	022 244
Detect plasma anamolies	-	-	-b- def	-	-	-	-	-	-	-	-bc def	-	-	-	-	-	021 222

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 3.1
PLATFORM: Satellite
WEAPON: Delivered Energy Nuclear/Chemical Explosives
REACTION TIME:
Seconds against satellite
Minutes against ground.

TABLE A7: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

THREAT FEATURES / REMOTE SENSING TECHNIQUE	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc def	-bc def	-bc def	-bc def	-bc def	-bc def	-bc d-f	-bc def	-	-bc def	-	--c -ef	--- -ef	--c -ef	-bc def	-b- d--	01112 111213
Thermal Infrared	-bc def	-bc def	-bc def	-bc def	-b- d--	-b- d--	-b- d--	-bc def	-	-bc def	-	--c -ef	--- -ef	--c -ef	-bc def	-b- d--	0 119 111010
Radar-active microwave	-bc def	-bc def	-b- d--	-bc def	-bc def	-b- d--	-b- d--	-bc def	-	-	-b- d--	--c -ef	--- -ef	--c -ef	-bc def	-b- d--	0 11 8 11 9 9
Passive EM, including EMP	-	-bc def	-bc def	-	-	-b- d--	-b- d-f	-bc def	-	-	-	--c -ef	-	-	-bc d-f	-bc def	076 757
Orbit Trajectory Analysis	-	-	-	-	-b- d-f	-bc def	-b- d--	-bc def	-	-	-		--- -e	--- -ef	-bc d-f	-	053 545
Nuclear emissions	-	--c -ef	-	--c -ef	-	-	-	-	--c -ef	-	-	-	-	-	-	-	003 033
Chemical emissions, static electric/magnetic anomoly	-	--c -ef	-	--c -ef	-	-	-	-	--c -ef	-	-	-	-	-	-	-	003 033
Detect plasma anamolies	-	--c -ef	-	-	-	-	-	-	--c -ef	-	-b-	-	-	-	-	-	012 022

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: 3.2
PLATFORM: Satellite
WEAPON: Delivered Energy Residual Kinetic
REACTION TIME: Minutes to traverse the intersatellite space

TABLE A8: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE \ THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc def	-bc def	-bc def	-bc def		-bc def	-bc d-f	--- -ef	-	--c -ef	-	--c -ef	--- -ef	--- -e-	-bc d-f	-bc d-f	0810 81012
Thermal Infrared	-bc def	-bc def	-bc def	-bc def		-bc d--	-bc d-f	--- -ef	-	--c -ef	-	--c -ef	--- -ef	--- -e-	-bc d-f	--c --f	0710 7911
Radar-active microwave	-bc def	-bc def	-bc def	-bc def		-bc d--	-bc d-f	--- -ef	-	-	--c -ef	--c -ef	--- -ef	--- -e-	-bc d-f	-bc d-f	0810 0911
Passive EM, including EMP	-	--c d-f	--- def	-		-bc d-f	-bc d-f	-bc d-f	-	-	-	--c -ef	-	-	-bc d-f	-	045 627
Orbit Trajectory Analysis	-bc def	--c ---	-b- ---	-b- d-f		bc d-f	--c -ef	-	-	-	-	-	--- -ef	--- -ef	--- -ef	-	044 357
Nuclear emissions	-	--c -ef	--c -ef	--c -ef	-	-	-	-	--c -ef	-	-	-	-	-	-	-	004 044
Chemical emissions, static electric/magnetic anomoly	-	--c -ef	--c -ef	--c -ef	-	-	-	-	--c -ef	-	-	-	-	-	-	-	004 044
Detect plasma anamolies	-bc def	--c -ef	--c -ef	-	-	-	-	-	-b- d-f	-	-bc def	-	-	-	-	-	034 345

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase

GROUP: 3.3
PLATFORM: Satellite
WEAPON: Directed Energy Destructive
REACTION TIME: Seconds or less

TABLE A9: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

REMOTE SENSING TECHNIQUE \ THREAT FEATURES	Platform/Weapon Dimensions	Platform Configuration	Weapon Configuration	Primary Power	One-shot vs Repeater	Delivery System	Delivery Sensing	Command & Control System vs Autonomous	Local (Non-EM) Emissions, Static Perturbations	Materials	Ion Wake	Reaction to Interrogation	Lifetime (life cycle)	Re-service and re-supply	Family concept (mix) distributed	Support/Logistics (Personnel)	Sensor Effectiveness, all parameters, for each phase
Visible, Near Infrared	-bc def	-bc def	-bc def	-bc def		-b- d--	-b- d-f	--c def	-	--c def	-	--c -ef	--- -ef	--- -ef	--c d-f	-bc d-f	079 10912
Thermal Infrared	-bc def	-bc def	-bc def	-bc def		-b- d--	-b- d-f	--c d-f	-	--c def	-	--c -ef	--- -ef	--- -ef	--c d-f	--c d-f	069 10812
Radar-active microwave	-bc def	-bc def	-bc def	-bc def		-b- d--	-b- d-f	--c d-f	-	-	-	--c -ef	--- -ef	--- -ef	--c d-f	--c d-f	068 9711
Passive EM, including EMP	-	-bc d-f	-bc d-f	-		-bc d-f	-bc d-f	-bc d-f	-	-	-	--c -ef	-	-	--c d-f	--c def	058 728
Orbit Trajectory Analysis	--c d--	-	-	-		--- d-f	-	-	-	-	-	-	--- e-f	--- -e-	--c d-f	-	002 323
Nuclear emissions	-	--c -ef	--c -ef	--c -ef		-	-	-	-+c def	-	-	-	-	-	-	-	004 144
Chemical emissions, static electric/magnetic anomoly	-	--c -ef	--c -ef	--c -ef		-	-	-	--c def	-	-	-	-	-	-	-	004 144
Detect plasma anamolies	-	- -ef	--c	-	-	-	-	-	-	-	--c -ef	-	-	-	-	-	004 -22

PHASE LEGEND

(a) Design & build
(b) Full-Power test
(c) Deploy
(d) System test
(e) Ready phase
(f) Red-alert phase

GROUP: [illegible].4

PLATFORM: Satellite

WEAPON: Directed Energy Radio-wave, Microwave, Optical Jammer

REACTION TIME: Seconds or less

TABLE A10: APPLICATIONS OF REMOTE SENSING TO KEY FEATURES OF ANTI-SATELLITE SYSTEMS

ANNEX B

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