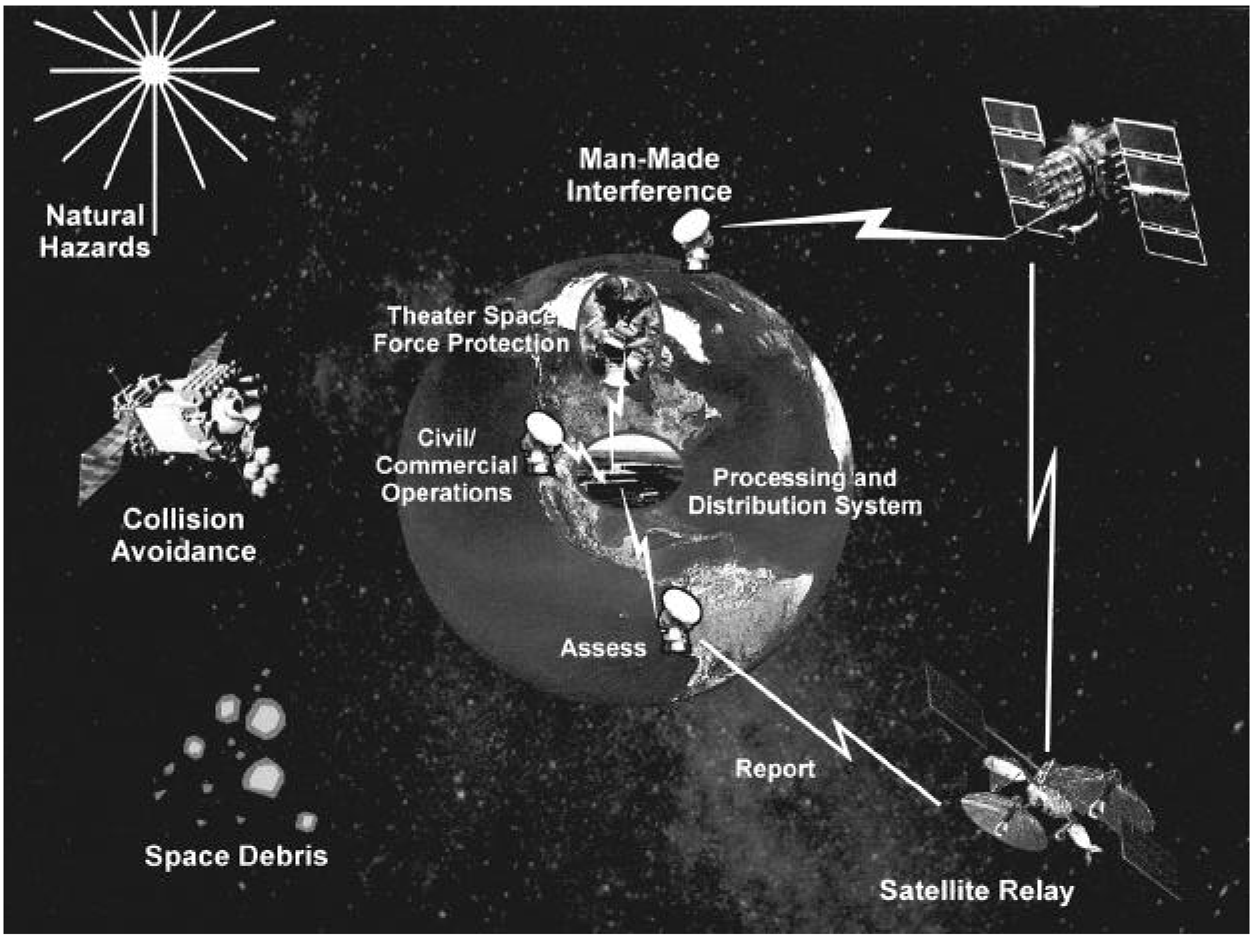
CHAPTER XIV

PROTECTION OF SPACE ASSETS

A. DESCRIPTION

Protection of Space Assets is a crucial warfighting and peacetime national objective because space products and services are integral to joint warfighting capability and an increasingly important part of our national politics, economics, and culture. Protection includes both active and passive defensive measures to minimize threats (natural and manmade) to space systems, including space platforms, links, launch, and ground segments. This concept is depicted graphically in Figure XIV–1.



Source: ***USSPACECOM Long Range Plan, 1998*** **(Reference 31), Figure 5–12.**

Figure XIV–1. Concept—Protection of Space Assets

In a broader context, Protection of Space Assets is one of four key objectives identified by U.S. Space Command (USSPACECOM) that must be achieved to gain control of space. The other three are surveillance of space, prevention, and negation. While protection of existing space assets is currently one of the warfighter's highest priority space objectives—and is being highlighted for that reason in the JWSTP—surveillance, prevention, and negation are all closely related to protection and require sustained, long-term R&D efforts that complement protection R&D programs. Because of this interrelationship, an understanding of Protection of Space Assets in the context of these three objectives is important. A detailed discussion of this subject is presented in Section E.

B. OPERATIONAL CAPABILITY ELEMENTS

There are five operational capability elements (OCEs) or goals associated with Protection of Space Assets:

Detect and Report Threats/Attacks. Our space systems must have sensors to detect attacks and quickly report anomalies or suspicious events. In addition to manmade events, we need an ability to identify environmental phenomena that can impact the operation of space systems.

Identify, Locate, and Classify Threats. Accurately determining threat or attack sources is necessary to determine appropriate countermeasures. At the core of this capability is a robust battle management apparatus managed by trained personnel who can receive, process, correlate, fuse, and disseminate information rapidly and unambiguously to system operators and warfighters.

Withstand and Defend. Both passive and active means are needed to counter attacks on key space systems and preserve vital space system functions. Civil and commercial systems critical to military operations may also require the same degree of protection as national security systems.

Reconstitute and Repair. Should defensive measures fail, an ability to recover lost functionality through direct intervention or redundant architectural schemes will be needed.

Assess Mission Impact. Anomalies caused by external forces must be accurately assessed to allow proper action by operators.

C. FUNCTIONAL CAPABILITIES

The five principal OCEs associated with Protection of Space Assets are enabled by the functional capabilities described below:

- *Hardening/Shielding of System Components.* To withstand attacks and enhance survivability, electronic components and processors must be hardened against natural and manmade radiation sources. Also, sensitive components (e.g., external wiring, exposed pressurized volumes such as batteries or propellant tanks, propellant lines, exposed optical surfaces, control momentum wheels) must be shielded against damage from impact with meteoroids or orbital debris. Sensors must also be protected against potential threats, including lasers. Shielding can also be accomplished through active responses such as maneuvering.
- *Developing Robust Battle Management*. Effective battle management is fundamental to our ability to protect critical space assets. Besides identifying the source and nature of threats, battle managers will also develop and disseminate a common operating picture, status of forces, planning tools, and decision aids. Battle management also implies the development of dynamic modeling and simulation capabilities for wargaming, testing, and exercising in joint and combined operations.

- *Improving System Maneuverability.* In addition to hardening and shielding programs, improving the maneuverability of space systems increases their survivability by making them more difficult for potential adversaries to locate, track, and target. Maneuverability also contributes to enhanced surveillance, assured access, and negation.
- *Attaining Adequate Force Protection.* While hardening, shielding, and system maneuverability all apply to the space platform itself, force protection encompasses the links between space and ground nodes, security of the ground nodes themselves, and protection of personnel. Sufficient resources must be invested to prevent single-point failures in space system architectures.
- *Developing Adequate Defensive Information Operations.* Technologies to reduce susceptibility to jamming, as well as schemes to improve denial and deception and protect true capabilities, are important adjuncts to a meaningful development program for Protection of Space Assets.
- *Threat Warning and Assessment Reporting.* Detecting, providing warning of, and assessing the effects of threats and hazards is key to enabling the decision for an appropriate response. Technologies that enable a decisionmaker to understand the probability and impact of a threat or attack, or even confirm its existence, are key. Tasks to achieve this capability include tracking, characterization, classification, and cataloging. Areas of concern include proximity of other bodies, radio frequency (RF) interference, RF weapons, directed-energy weapons, kinetic effects, and information operations directed against command and control systems.
- *Space Weather Sensor Systems.* Natural hazards can be as effective as manmade hazards for disabling space systems. Knowledge and warning of space weather events will enable appropriate action for protecting space systems and contribute to threat warning and assessment.
- *Mobile Mission Processors.* One way to reconstitute and repair ground stations is to have backups. Mobile stations have several advantages and may be less costly and more easily protected than alternative ground stations. Multimission mobile stations, which can take advantage of standard interfaces and processing, are especially attractive.
- *Diagnostics and Repair Technology.* The "repair" option demands a relatively intelligent way to quickly diagnose and respond to on-orbit or remote problems. The current deliberate "anomaly resolution" procedures, while well tried, are very time consuming.
- *Quick Launch Recovery.* Reconstitution and repair of launch capabilities should also be considered in light of the relative vulnerability of our launch capabilities.
- *Modeling and Simulation.* For training and planning purposes, modeling and simulation is well understood, but not well applied to space. For the purposes of battle management and decision aids, modeling and simulation still need considerable development for space systems (satellites, links, command functions, launch facilities).

Table XIV–1 shows the correlation between the functional capabilities discussed above and the five OCEs outlined in Section B for Protection of Space Assets. While advancements in all functional capability areas lead to improved operational capabilities, developing robust battle management and improving system maneuverability have an especially strong impact on achieving these goals.

Table XIV–1. Functional Capabilities Needed—Protection of Space Assets

	Operational Capability Elements				
Functional Capabilities	Detect and Report Threats/Attacks	ID, Locate, and Classify Threats	Withstand and Defend	Reconstitute and Repair	Assess Missions Impact
1. Hardening/Shielding of System Components	○	○	●	○	○
2. Developing Robust Battle Management	●	●	●	●	●
3. Improving System Maneuverability	○	●	●	●	○
4. Attaining Adequate Force Protection	●	●	●	○	○
5. Developing Adequate Defensive Information Operations	○	○	●	○	○
6. Threat Warning and Assessment Reporting	●	●	○		○
7. Space Weather Sensor Systems	●	●			○
8. Mobile Mission Processors			○	●	
9. Diagnostics and Repair Technology				●	●
10. Quick Launch Recovery			○	●	
11. Modeling and Simulation		○	○	○	●

● Strong Support ○ Moderate Support

D. CURRENT CAPABILITIES, DEFICIENCIES, AND BARRIERS

While the primary threats to our space systems are to ground nodes and links (electronic warfare or direct attack), many long-term shortfalls exist in our ability to protect space systems. These shortfalls and the key technologies needed to address them are summarized in Table XIV–2. OCEs include 2020 metric goals (in parentheses) taken from the *USSPACECOM Long Range Plan, 1998* (Reference 31).

Table XIV–2. Goals, Limitations, and Technologies—Protection of Space Assets

Goals	Functional Capabilities	Limitations	Key Technologies
Operational Capability Element: Detect and Report Threats/Attacks			
Detect and report threat or attack to owner/ operators in near-real time (NRT) (all assets of national interest) Detect/track with precise • Size low-Earth-orbit (LEO)/geosynchronous Earth orbit (GEO) (1 cm/10 cm) • Location LEO/GEO (10 m/100 m)	Develop robust battle management Attain adequate force protection Provide threat warning and assessment reporting Develop space weather sensor systems	Inability to determine if a satellite is under attack Inability to contact any satellite at any time Many coverage gaps Limited cross-cueing and target tipoffs Large minimum size for cataloging orbital debris Shortfalls in capabilities for operating through disturbed environments No automated assessment systems onboard satellites	Standard adaptive communications interface Space-based surveillance: onboard processing, cryocoolers, vibration suppression, satellite crosslinks Robust command/control Forecast disturbed environments impacting operations Advanced processing techniques and data fusion Space-based relay of mission data Mass storage Active high-resolution imaging Adaptive optics Nonlinear optical phase conjugation Small, low-power radio frequency (RF) and directed-energy (DE) detectors Lightweight attack sensors Onboard intrusion detection/characterization
Operational Capability Element: Identify, Locate, and Classify Threats			
Provide real-time characterization of high-interest objects (100%) Detect/track with precise • Size LEO/GEO (1 cm/10 cm) • Location LEO/GEO (10 m/100 m) Perform timely surveillance of high-interest objects (HIOs) (NRT) Perform space cataloging/monitoring (NRT) Identify, locate, and classify source with high confidence (seconds) Perform combat assessment against adversary space system (limited target set, NRT)	Develop robust battle management Improve system maneuverability Attain adequate force protection Provide threat warning and assessment reporting Develop space weather sensor systems	Imaging capability marginal Characterization untimely Data accuracy limitations, especially angular data Limited computational/storage capacity Large minimum size for cataloging orbital debris Shortfalls in capabilities for operating through disturbed environments Extended time and inaccurate assessment of satellite anomalies High volumes of precise information needed Inability to contact any satellite at any time	Space-based surveillance: onboard processing, cryocoolers, vibration suppression, satellite crosslinks LIDAR/LADAR/laser sensors Active illumination Advanced hyperspectral sensors (electro-optical, bistatic, infrared) Advanced human–machine interfaces Knowledge-based engineering Mass storage Forecast disturbed environments impacting operations Advanced modeling and simulation Space-based relay of mission data Artificial intelligence Natural/manmade threat warning and assessment reporting package demonstrations Advanced processing techniques and data fusion Nonlinear optics Active high-resolution imaging Adaptive optics Nonlinear optical phase conjugation Advanced/improved application software

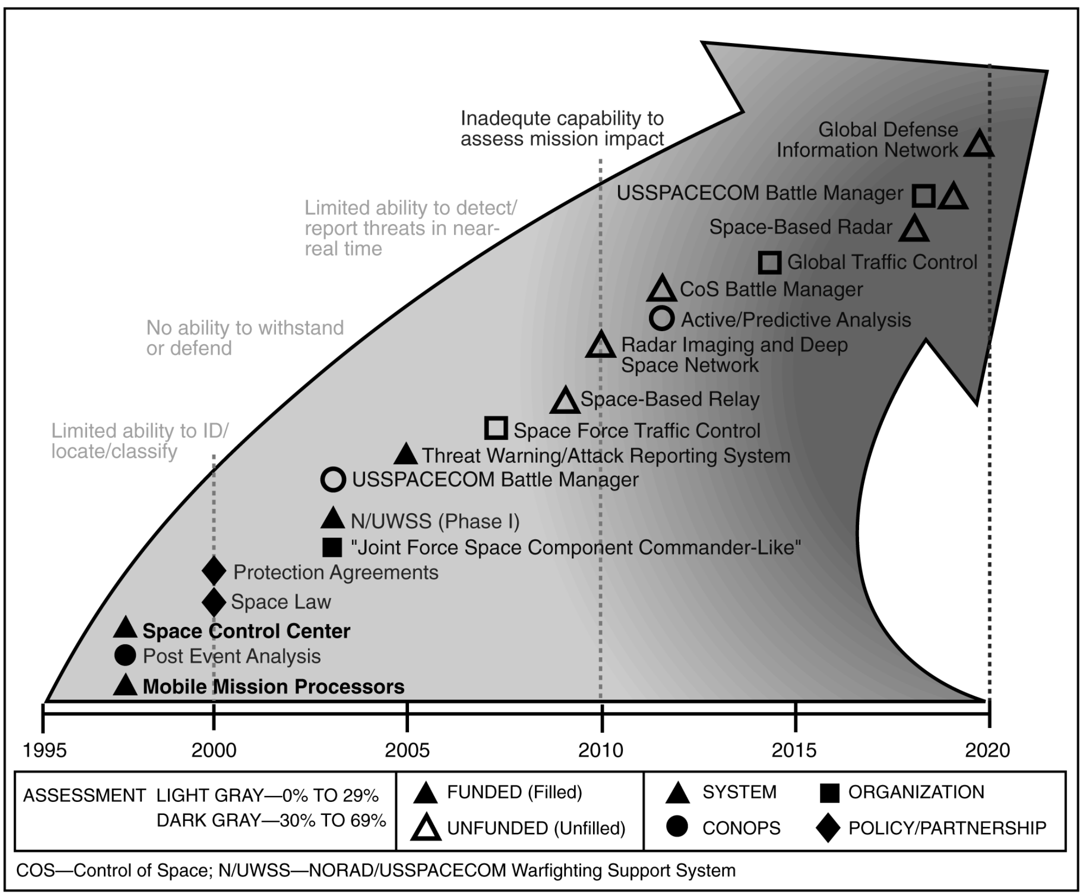
Table XIV–2. Goals, Limitations, and Technologies—Protection of Space Assets (continued)

Goals	Functional Capabilities	Limitations	Key Technologies
Operational Capability Element: Withstand and Defend			
Withstand and defend against threats (100%)	Provide hardening/shielding of system components Develop robust battle management Improve system maneuverability Attain adequate force protection (protect personnel and infrastructure) Develop adequate defense information operations	Dependence on overseas ground stations Satellites designed for natural environment only Limited onboard detection and protection capabilities No self-defense capability onboard satellites No independent Satellite Detection System (SDS) or defensive satellite (DSAT) capability Shortfalls in simulation/test capability Shortfalls in design methods Limited ability to validate hardening Critical infrastructure vulnerabilities need to be identified and redressed New generations of microelectronics inherently more susceptible to radiation hazards Satellite debris creation avoidance Smaller satellites more vulnerable to small orbital debris and meteoroid impact Inadequate orbital debris shielding/avoidance Limited backup command and control/processing	Advanced modeling and simulation Onboard protection suite package for satellites Onboard self-shielding, hardening, diagnostics, and maneuvering Mobile robust/agile satellite processors Knowledge-based engineering Enabling technology for radiation-resistant microelectronics Design protocols for testable hardware Techniques for hardening commercial off-the-shelf technologies/systems Balanced hardening against multiple hazards Onboard diagnostics Kinetic energy antisatellite (ASAT) system High-power microwave Advanced laser technologies Coherent RF and IR electronic attack techniques Space maneuver vehicles (SMVs) Fuel, propulsion, power, avionics Radiation-resistant microelectronics Technologies for system hardening and hardening validation Antiterrorism technologies Space-based command and control/processing
Operational Capability Element: Reconstitute and Repair			
Reconstitute and repair space services (days/hours) Perform employment on demand against adversary space system (limited target set, all nodes, minutes)	Develop robust battle management Improve system maneuverability Develop mobile mission processors Improve diagnostics and repair technology Provide quick-launch recovery	Shortfalls in simulation/test capability Critical infrastructure vulnerabilities need to be identified and redressed Shortfalls in design methods Replenishing satellites is expensive Replenishing satellite constellations is not timely	Onboard diagnostics Advanced modeling and simulation Mobile robust/agile satellite processors Knowledge-based engineering Design protocols for testable hardware Survivability assessment technologies Fuel, propulsion, power, avionics

Table XIV–2. Goals, Limitations, and Technologies—Protection of Space Assets (continued)

Goals	Functional Capabilities	Limitations	Key Technologies
Operational Capability Element: Assess Mission Impact			
Assess mission impact/disseminate (seconds)	Develop robust battle management Improve diagnostics and repair technology Provide modeling and simulation	High volumes of precise information needed Need for validation of the survivability of systems and critical ground-based infrastructure Modeling and simulation to determine impacts of outages Onboard diagnostics are limited	Advanced processing techniques and data fusion Advanced modeling and simulation Space-based relay of mission data Artificial intelligence Knowledge-based engineering Mass storage Improved simulations Advanced human-computer interfaces Advanced/improved application software

Based on *USSPACECOM Long Range Plan, 1998* (Reference 31), programmed and planned systems will move us on a path toward achieving each of the OCEs, but very slowly. At current investment levels, protection will remain inadequate in 2010 and be only marginally acceptable by 2020 (Figure XIV–2). There are two reasons why progress in this area must be



Source: *USSPACECOM Long Range Plan, 1998* (Reference 31), Figure 5–15.

Figure XIV–2. Assessment of Protection

emphasized. First, many of the technologies affecting protection (e.g., shielding, onboard maneuvering, onboard diagnostics) are currently immature, suggesting that advancements will be unpredictable and require several development paths to ensure success. Second, progress also depends on advancements in related areas such as surveillance and battle management that face extremely complex challenges in their own right.

A growing recognition for the need for space control is forcing DoD to look seriously at the need for CONOPS development and organizational changes that could add impetus to technology programs. Our increasing reliance on civil, commercial, and international space systems will lead to the development of partnerships, laws, and agreements to protect these assets. The combination of growing manmade threats (orbital debris and antisatellite systems), the harsh space environment (there will be peaks in the solar activity cycle in 2001 and 2012), and the need to ensure that space services are available on demand may force industry to devote more attention to protection as well and accelerate technological development.

E. TECHNOLOGY PLAN

The Defense Technology Objectives (DTOs) listed below address deficiencies in all of the operational capability elements outlined in Section B and represent a meaningful approach to the development of space protection capabilities. The list is divided into two sections. In Section 1, the DTOs specifically falling under the Protection of Space Assets area are shown. Section 2 lists DTOs belonging to other technology areas that have a strong linkage to space protection activities. The listing should not be considered all-encompassing. For example, efforts being conducted in Chemical/Biological Warfare Defense and Protection, and Counter Weapons of Mass Destruction, as well as Combating Terrorism relate directly to Protection of Space Assets because of the vulnerability of ground sites, but were not addressed here because they are discussed in Chapters XII and XIII. Detailed descriptions of the DTOs can be found in *Defense Technology Objectives of the Joint Warfighting Science and Technology Plan and the Defense Technology Area Plan* (Reference 6), and the *Defense Technology Area Plan* (Reference 3).

1. Space Protection DTOs

- *N.01, Space Radiation Mitigation for Satellite Operations*, will establish the relationship between the space radiation environment, satellite anomalies, and satellite systems' degradation or failures. It will also develop techniques and instrumentation to mitigate these effects or to provide alerts for hazardous space environments. The benefits will include improved spacecraft reliability and availability, extended mission duration, and increased space system autonomy.
- *N.02, Compact Environmental Anomaly Sensor II ACTD*, will develop miniaturized environmental sensors for integration on critical satellite systems for launch into geosynchronous orbit prior to Solar Max. This will maximize the availability of the space system to the warfighter. These sensors will provide warnings of dangerous space environmental conditions to allow for safe spacecraft operations, reduce anomaly resolution time, and decrease satellite downtime.
- *N.03, Space Environments and Hazards*, will develop and distribute the technology and understanding needed to predict natural and weapon-induced hazards to space systems and provide protection against these hazards. This encompasses both the

physical threats to space systems and to their missions (e.g., propagation of RF signals through disturbed environments).

- *N.04, Satellite Passive Protection*, will develop and demonstrate, by 2005, passive technologies for satellite onboard laser protection (e.g., IR surveillance and launch detection systems) against ground-based lasers threats (dazzle and damage). Concepts include antijam and damage protection materials and devices. Analysis tools to demonstrate the impact of ground-based lasers on surveillance systems will be developed. Computer animation techniques will provide these tools with graphics user interface. Hardware and software will be developed to trigger dazzle protection devices with prior knowledge of ground-based laser wavelengths. Where possible, agile laser filters will be developed and used. Laser damage protection devices will be demonstrated using ground simulations.

2. Related DTOs

- *A.13, Satellite C^3I/Navigation Signals Propagation Technology,* will provide reliable, real-time specifications and forecasts of ionospheric conditions and disturbances, and their effects on communications, surveillance, and navigation systems, including the Global Positioning System (GPS).
- *NT.01, Nuclear Operability and Survivability Testing Technologies,* will provide the means to validate the survivability and operability of military systems in a proliferant nuclear threat environment.
- *NT.02, Electronic System Radiation Hardening,* will develop enabling technology to support the fabrication of radiation-hardened electronics and photonics, and develop test/design protocols to validate system survivability using above-ground tests.
- *NT.05, Balanced Electromagnetic Hardening Technology*, will develop and demonstrate innovative and affordable technologies and methodologies for integrated hardening and testing of military systems against high-power microwave and high-altitude electromagnetic pulse effects.
- *NT.06, Survivability Assessments Technology*, will perform operability, survivability, vulnerability, and connectivity assessments for current and proposed systems in combined nuclear effects environments.
- *NT.09, Nuclear Phenomenology*, will develop and provide prediction tools for nuclear weapon effects phenomenology and its interaction on systems to understand the nuclear weapon-related free field; provide nuclear weapon target interaction lethality information; and provide nuclear weapon phenomenology information to the warfighter in usable form.
- *SE.37, High-Density, Radiation-Resistant Microelectronics,* will focus on high-performance, extremely dense, radiation-resistant microelectronics. Space applications, which presently dominate requirements for radiation-resistant microelectronics, need to operate reliably after exposure to natural and nuclear radiation.
- *SP.20, Spacecraft Propulsion/IHPRPT Phase I,* will develop and demonstrate advanced satellite propulsion technologies for orbit changes, orbit maintenance, and de-orbit maneuvers of military and commercial satellites. The technologies demonstrated

here will provide critical enabling technologies for a follow-on DTO. The successful demonstration of IHPRPT spacecraft propulsion component objectives will increase satellite on-orbit life by 25 percent and either increase satellite payload by 10 percent or increase the number of repositioning maneuvers by 200 percent.

Currently, one Advanced Concept Technology Demonstration (ACTD) directly supports Protection of Space Assets (Figure XIV–3). Table XIV–3 measures the relevance of the technology demonstration and the remaining DTOs to the Protection of Space Assets OCEs.

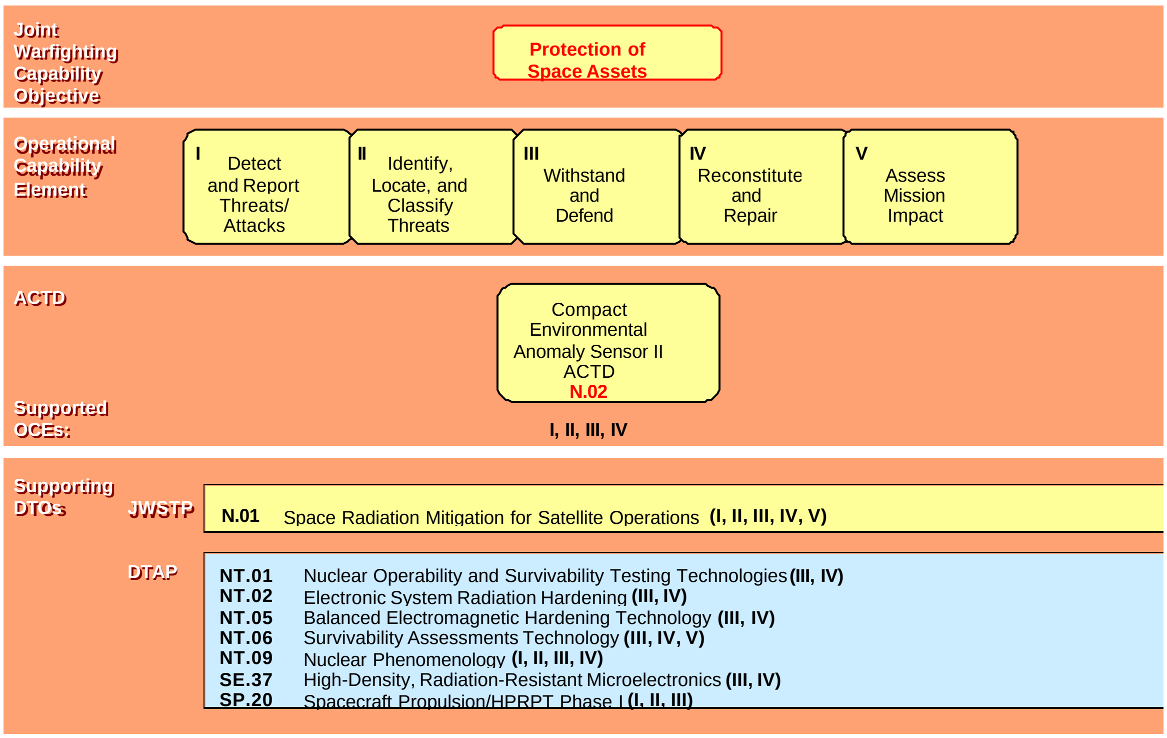


Figure XIV–3. Technology to Capability—Protection of Space Assets

To achieve the desired level of protection for our critical space assets, a multiphased approach is envisioned. First, the specific technology efforts listed above must be supported. This will result in onboard satellite protection systems, more durable electronics, greater maneuverability, and improved threat warning and attack reporting. Second, a comprehensive effort to improve space surveillance and situational awareness is required. At a minimum, this should entail incremental improvements to the existing space surveillance network, an improved ability to track small objects in space, and better data fusion and display capabilities to support battle management. Finally, a coherent technology effort across all four space control elements (surveillance, protection, prevention, and negation) must be pursued because such a strategy is mutually supportive and facilitates development in each individual area.

As noted previously, technology activities enhancing protection both influence and are influenced by technology programs in surveillance, prevention, and negation. This interrelationship is depicted in Table XIV–4.

Table XIV–3. Demonstration Support—Protection of Space Assets

Demonstration	Operational Capability Elements: Detect & Report Threats/Attacks	Identify, Locate, & Classify Threats	Withstand & Defend	Reconstitute & Repair	Assess Mission Impact	Service/ Agency	DTO	Type of Demonstration: ACTD	ATD
Space Radiation Mitigation for Satellite Operations			●	●		Air Force	N.01		
Compact Environmental Anomaly Sensor II ACTD	●	●	○	●		Air Force	N.02	X	
Space Environments and Hazards	●	○				DTRA	N.03		
Satellite Passive Protection		○	●		○	Air Force	N.04		
Nuclear Operability and Survivability Testing Technologies			●	●		Joint	NT.01		
Electronic System Radiation Hardening			●	○		Joint	NT.02		
Balanced Electromagnetic Hardening Technology			●	●		Joint	NT.05		
Survivability Assessments Technology			●	○	●	Joint	NT.06		
Nuclear Phenomenology	○	○	●	●		Joint	NT.09		
High-Density, Radiation-Resistant Microelectronics			●	○		Air Force	SE.37		
Spacecraft Propulsion/IHPRPT Phase I	○	○	●			Air Force	SP.20		

● Strong Support ○ Moderate Support

Table XIV–4. Interrelationships of Space Control Operational Capability Elements

Space Control OCEs	Protection of Space Assets	Surveillance of Space	Prevention	Negation
Surveillance				
1. Detect	●	●	○	●
2. Track	●	●	○	●
3. Characterize	●	●	○	●
4. Classify	●	●	○	●
5. Catalog/Monitor	●	●	○	●
6. Disseminate/Distribute	○	●	○	○
Protection				
7. Detect/Accurately Report	●	○		
8. Identify, Locate, and Classify	●	●	○	○
9. Withstand and Defend	●	○	○	○
10. Reconstitute/Repair	●			
11. Assess Mission Impact	●	○		
Prevention				
12. Detect Use	○		●	○
13. Assess Mission Impact	○		●	
14. React Timely and Flexibly	○		●	
Negation				
15. Identify Target	○			●
16. Perform Weaponeering	○			●
17. Execute Operations Cycle	○			●

● Strong Support ○ Moderate Support

A number of conclusions can be drawn. First, support to protection-related activities impacts every space control area to some degree. The same can be said of surveillance, which has very broad impact because each space control area depends heavily on, and is enhanced by, accurate situational awareness. Finally, technology investment and development in all four areas results in a complementary program that affords the best way to support future warfighting and national security requirements. For this reason, key DTOs supporting surveillance, protection, prevention, and negation are listed below.

Surveillance of Space. Surveillance of space is critical to every aspect of space control. It includes the ability to detect, track, identify, monitor, and characterize objects and events in space. At the heart of adequate surveillance is a robust battle management capability. Technological programs in sensors, radars, data processing, and data fusion are particularly critical as are efforts to enhance tactical displays and man-machine interfaces. DTOs that relate to surveillance of space include:

- D.03, Discriminating Interceptor Technology Program
- D.05, Advanced Space Surveillance
- HS.06, Joint Cognitive Systems for Battlespace Dominance
- HS.13, Human-Centered Automation Testbed
- HS.21, Decision Support Systems for Command and Control
- HS.23, Immersive Interfaces and Visualization Techniques for Controlling Unmanned Vehicles
- HS.28, Distributed Mission Warfighting Training Techniques and Technologies
- SE.33, Advanced Focal Plane Array Technology
- SE.38, Microelectromechanical Systems
- SE.58, Lookdown Bistatic Technology
- SE.59, Low-Light-Level Imaging Sensors
- SE.61, Multiphenomenology Sensor Fusion for ATR and Tracking
- SE.65, Long-Wavelength and Multispectral, Large-Area, Staring Focal Plane Arrays
- SE.67, Hyperspectral Applications Technology

Prevention. Prevention addresses measures to preclude an adversary's ability to use U.S. or allied space systems for hostile purposes. Technologies and techniques that interrupt data dissemination, deception, and encryption must be better understood and developed to provide usable tools to warfighters. DTOs that relate to prevention include:

- IS.38, Antenna Technologies
- IS.50, Advanced Intelligence, Surveillance, and Reconnaissance Management

Negation. Negation includes development of measures to disrupt, deny, degrade, or destroy hostile space systems or services. A range of technologies should be pursued to support any decision that might be made to develop counter space weapons. DTOs that relate to negation include:

- WE.22, High-Power Microwave C^2W/IW Technology
- WE.41, Multimission Space-Based Laser
- WE.43, Advanced Multiband Infrared Countermeasures Laser Source Solution Technology

Figure XIV–4 is a technology roadmap for Protection of Space Assets. This figure—coupled with enhancements, surveillance of space, prevention, and negation—represents an overall strategy to achieve space control.

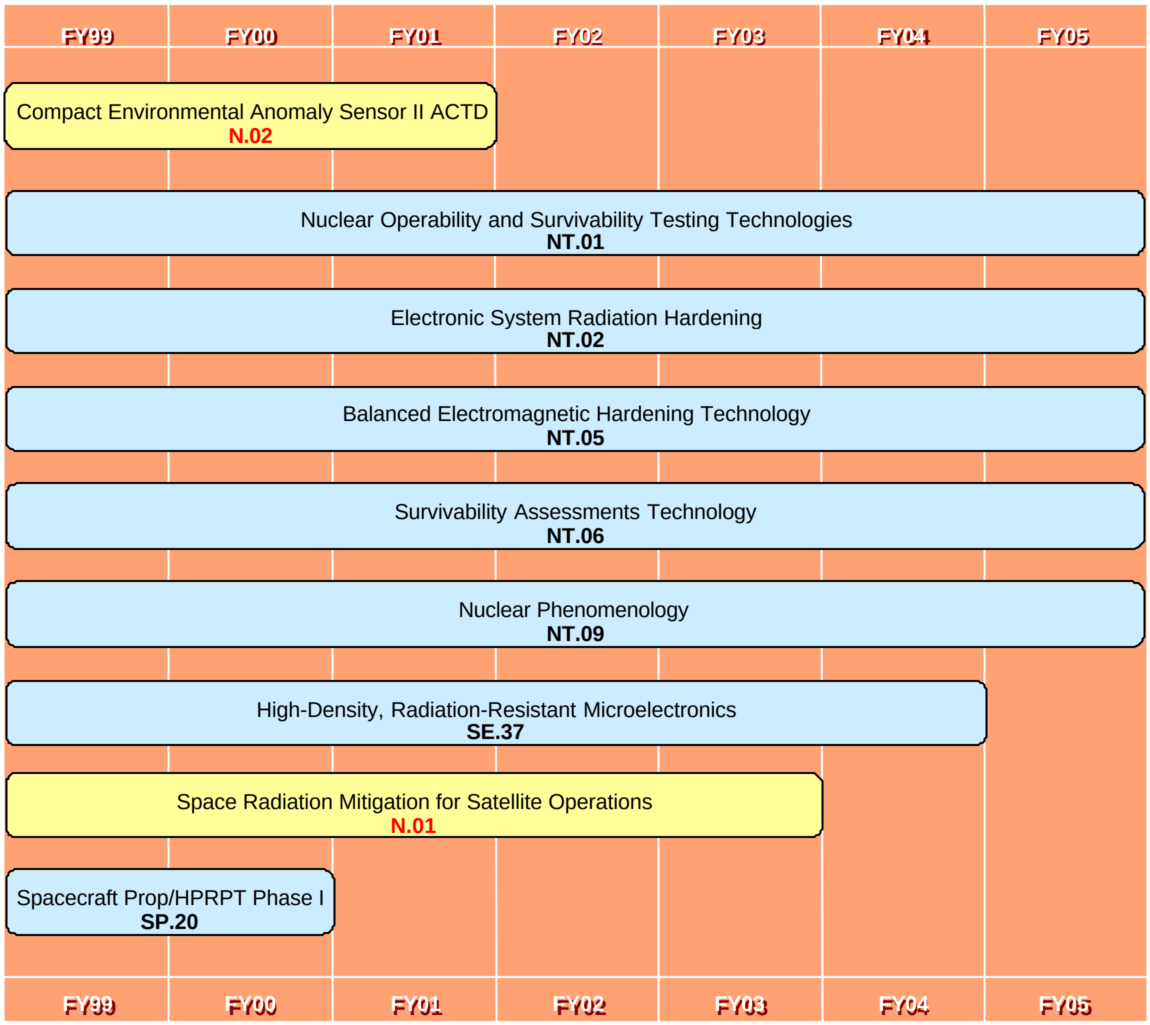


Figure XIV–4. Roadmap—Protection of Space Assets

F. SUMMARY

Protection of Space Assets is critical to warfighting success because of the military's growing reliance on space products in support of joint operations. While the current investment strategy does not resolve all deficiencies, it puts DoD on a solid path toward obtaining essential space protection capabilities.

Figure VIX–5 shows how increasing warfighting capabilities are achieved through incremental advances in demonstrated technology in Protection of Space Assets.

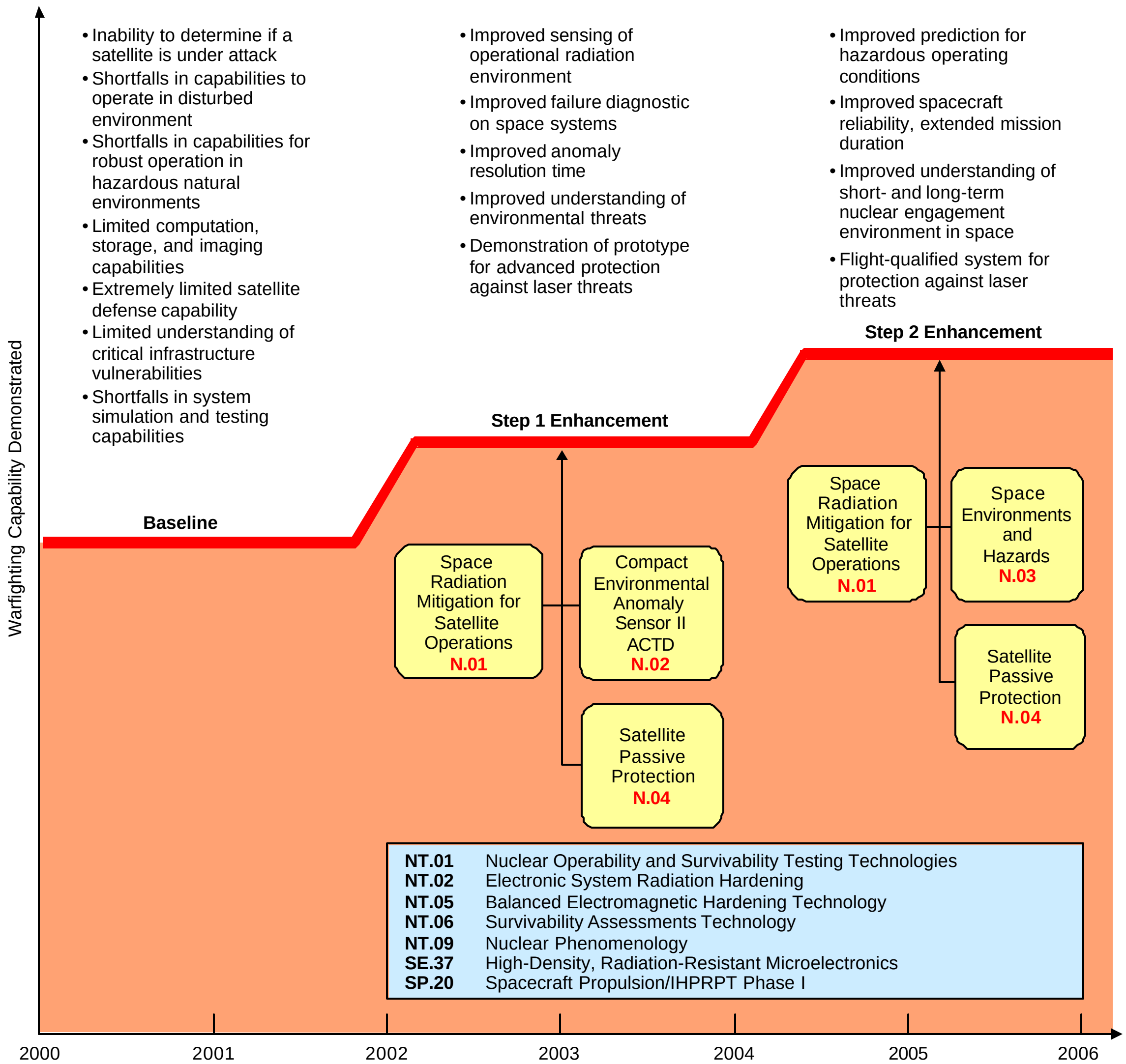


Figure VIX–5. Progress—Protection of Space Assets