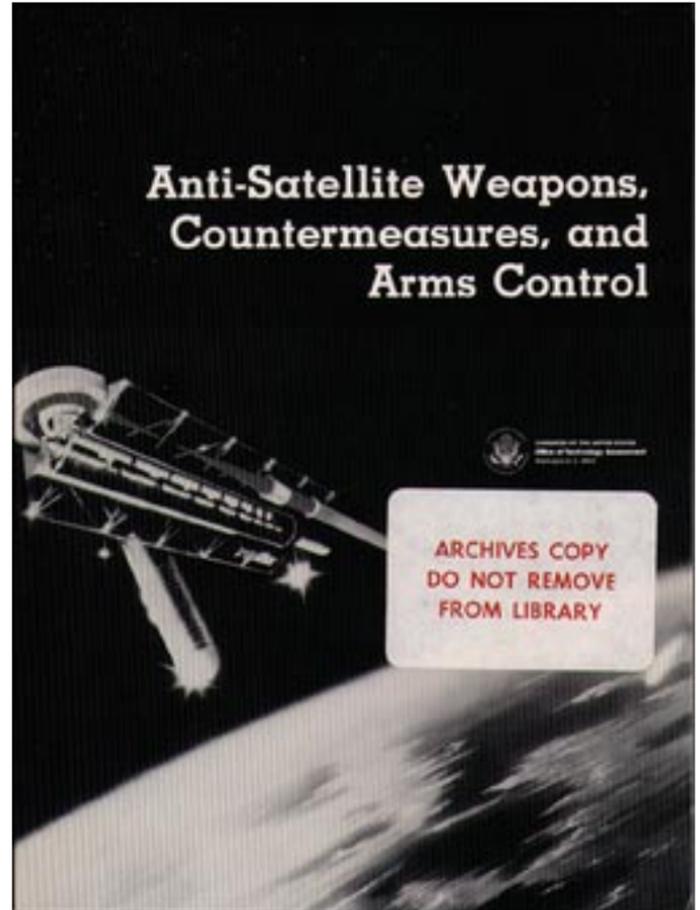


*Anti-Satellite Weapons, Countermeasures,
and Arms Control*

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Foreword

At the requests of the House Armed Services Committee and the Senate Foreign Relations Committee, OTA undertook an assessment of the opportunities and risks involved in an accelerated program of research on new ballistic missile defense technologies, including those that might lead to deployment of weapons in space. The resulting report, *Ballistic Missile Defense Technologies*, is being published concurrently with this volume. This report on *Anti-Satellite Weapons, Countermeasures, and Arms Control* discusses additional implications of the same or similar technologies.

Closely related to BMD technology, system survivability, and arms control issues are questions about the development and deployment of anti-satellite weapons. Whether or not the United States decides to deploy BMD systems in space, other military uses of space will continue to grow in importance. How can the United States respond to the potential threat to its military capabilities posed now and in the future both by Soviet military satellites and by Soviet anti-satellite weapons (ASAT)? This report examines U.S. options for countering Soviet military satellite capabilities and explores both unilateral and cooperative measures for limiting the ASAT threat. Possible unilateral steps include active and passive countermeasures as well as deterrence; possible cooperative steps include a variety of arms control agreements. The report examines the pros and cons of several illustrative "arms control regimes" for space weapons, ranging from lesser to greater limitations than now exist. It suggests that some combinations of unilateral and cooperative measures might provide more military security than either type alone.

It should be recognized that the relative roles of anti-satellite weapons, countermeasures, and arms control will be strongly affected by the course followed in the development and deployment of space-based BMD systems

OTA gratefully acknowledges the contributions of the many individuals, firms, laboratories, and government agencies who assisted its research and writing for this report.



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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The views expressed in this OTA report, however, are the sole responsibility of the Office of Technology Assessment. Participation on the advisory panel does not imply endorsement of the report.

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Glossary of Acronyms and Terms

Glossary of Acronyms

ABM	—anti-ballistic missile	LEO	—low-Earth orbit
ASAT	—anti-satellite	LIDAR	—light detection and ranging
ASATCC	—ASAT Control Center	LTBT	—Limited Test Ban Treaty
BMD	—ballistic missile defense	MW	—megawatt
CMC	—Cheyenne Mountain Complex	MeV	—million electron-volts
DSAT	—defensive satellite	MHV	—miniature homing vehicle
DEW	—directed-energy weapon	MILSAT	—military satellite
FEL	—free-electron laser	MV	—miniature vehicle
FOBS	—Fractional-Orbit Bombardment System	NSSC	—National Space Surveillance Center
GEO	—geosynchronous Earth orbit	PMOC	—Prototype Mission Operations Center
GRASER	—gamma-ray amplification by stimulated emission of radiation	RADAR	—radio detection and ranging; the acronym "radar" is no longer capitalized in current usage
GSO	—geostationary Earth orbit	ROCC	—Regional Operations Control Center
HEO	—high-Earth orbit	SAR	—synthetic aperture radar
INW	—isotropic nuclear weapon	SPADATS	—Space Detection and Tracking System
K	—degrees Kelvin	SPADOC	—Space Defense Operations Center
KEW	—kinetic-energy weapon	WWMCCS	—World-Wide Military Command and Control System
LASER	—Light amplification by stimulated emission of radiation; the acronym "laser" is no longer capitalized in current usage		

Glossary of Terms

Ablative Shield: A shield that evaporates when heated, absorbing laser energy and protecting the object which is behind it from heat damage.

Ablative Shock: Generation of a mechanical shock wave at the surface of an object exposed to intense pulsed electromagnetic radiation. A thin layer of the objects surface violently and rapidly boils off; the resulting vapor suddenly exerts pressure against the surface, generating a mechanical shock wave at the surface. This shock wave then propagates deeper into the object and can cause melting, vaporization, and spallation of surface material and structural failure of the object.

ABM Treaty: A Treaty of 1972, signed and ratified by the Soviet Union and the United States, prohibiting development of many types of anti-ballistic missile systems and limiting deployments on each side to a specified number of land-based units, which use only rocket interceptors and ground-based radar.

Acquisition: Detection of a potential target by the sensors of a weapons system.

Active Sensor: One that illuminates a target, producing return secondary radiation, which is

then detected in order to track and or identify the target. An example is *LIDAR*.

Adaptive Optics: Optical systems which can be modified (e.g., by controlling the shape of a mirror) to compensate for distortions. An example is the use of information from a beam of light, passing through the atmosphere to compensate for the distortion suffered by another beam of light on its passage through the atmosphere. Used to eliminate the "twinkling" of stars in observational astronomy and to reduce the dispersive effect of the atmosphere on laser beam weapons.

Amplified Spontaneous Emission: See *Superradiance*.

Anti-satellite Weapon (ASAT): A weapon to destroy satellites in space.

Anti-simulation: Deceiving adversary sensors by making a strategic target look like a decoy.

Apogee: The maximum altitude attained by an Earth satellite.

Ballistic Missile Defense (BMD): A defense system that is designed to protect a territory from attacking ballistic missiles.

Birth-to-death Tracking: The tracking of space objects—e.g., satellites, reentry vehicles, or decoys which simulate these—from the time that

- they are deployed from a booster or post-boost vehicle until they are destroyed.
- Bistatic Radar:** A radar system which has transmitters and receivers stationed at two locations; a special case of multistatic radar.
- Boost Phase:** The phase of a missile trajectory from launch to burnout of the final stage. For ICBMS, this phase typically lasts from 3 to 5 minutes, but studies indicate that reductions to the order of 1 minute are possible.
- Brightness:** In this report, the amount of power that can be delivered per unit solid angle by a directed-energy weapon.
- Capital Satellite:** A highly valued or costly satellite, as distinct from an inexpensive decoy satellite. Some decoys might be so expensive as to be considered capital satellites.
- Chaff:** Confetti-like metal foil ribbons which can be ejected from spacecraft (or terrestrial vehicles) to reflect enemy radar signals, thereby creating false targets or screening actual targets from the "view" of radar.
- Coherence:** The matching, in space (transverse) or time (temporal coherence), of the wave structure of different parallel rays of a single frequency of electromagnetic radiation. This results in the mutual reinforcing of the energy of these different components of a larger beam. Lasers and radar systems produce partially coherent radiation.
- Command Guidance:** The steering and control of a missile by transmitting commands to it.
- Counter-countermeasures:** Measures taken to defeat countermeasures.
- Countermeasures:** In this report, measures taken by the offense to overcome aspects of a BMD system.
- Dazzling:** In this report, the temporary blinding of a sensor by overloading it with an intense signal of electromagnetic radiation, e.g., from a laser or a nuclear explosion.
- Decoy:** An object that is designed to make an observer believe that the object is more valuable than is actually the case. Usually, in this report, a decoy refers to a light object designed to look like a satellite.
- Deep Space:** The region of outer space at altitudes greater than 3,000 nautical miles (about 5,600 kilometers) above the Earth's surface.
- Defensive Satellite (DSAT) Weapon:** A space-based ASAT weapon that is intended to defend satellites by destroying attacking ASAT weapons.
- Defensive Technologies Study Team (DTST):** A committee, generally known as the "Fletcher Panel," after its Chair, appointed by President Reagan to investigate the technologies of potential BMD systems.
- Delta-V:** A numerical index of the maneuverability of a satellite or rocket. It is the maximum change in velocity which a spacecraft could achieve in the absence of a gravitational field.
- Diffraction:** The spreading out of electromagnetic radiation as it leaves an aperture, such as a mirror. The degree of spread, which cannot be eliminated by focusing, is proportional to the ratio of the wavelength of radiation to the diameter of the aperture.
- Digital Processing:** The most familiar type of computing, in which problems are solved through the mathematical manipulation of streams of numbers.
- Directed-Energy Weapon:** A weapon that kills its target by delivering energy to it at or near the speed of light. Includes lasers and particle beam weapons.
- Discrimination:** The ability of a surveillance system to distinguish decoys from intended targets, e.g., certain types of satellites.
- Early Warning:** In this report, early detection of an enemy ballistic missile launch, usually by means of surveillance satellites and long-range radar.
- Electromagnetic Radiation:** A form of propagated energy, arising from electric charges in motion, that produces a simultaneous wavelike variation in electric and magnetic fields in space. The highest frequencies (or shortest wavelengths) of such radiation are possessed by gamma rays, which originate from processes within *atomic* nuclei. As one goes to lower frequencies, the electromagnetic spectrum includes X-rays, ultraviolet light, visible light, infrared light, microwave, and radio waves.
- Electron-volt:** The energy gained by an electron in passing through a potential difference of 1 volt. 6.25 quintillion electron-volts equals 1 joule; 22.5 billion trillion electron-volts equals 1 kilowatt-hour.
- Elliptical Orbit:** A noncircular *Keplerian orbit*.
- Endoatmospheric:** Within the atmosphere; an endoatmospheric interceptor intercepts its target within the atmosphere.
- Ephemeris:** A collection of data about the predicted positions (or apparent positions) of celestial objects, including artificial satellites, at various times in the future. A satellite ephemeris might contain the orbital elements of satellites and predicted changes in these.
- Equatorial Orbit:** An orbit above the Earth's Equator.
- Excimer:** A contraction for "excited dimer"; a type of lasant. A dimer is a molecule consisting of two atoms. Some dimers—e.g., xenon chloride and krypton fluoride—are molecules which cannot exist under ordinary conditions of approxi-

- mate thermal equilibrium but must be created in an "excited" -i.e., energized-condition by special "pumping" processes in a laser.
- Exoatmospheric:** Outside the atmosphere; an exo-atmospheric interceptor intercepts its target in space.
- Fission:** The breaking apart of the nucleus of an atom, usually by means of a neutron. For very heavy elements, such as uranium, a significant amount of energy is produced by this process. When controlled, this process yields energy which may be extracted for civilian uses, such as commercial electric generation. When uncontrolled energy is liberated very rapidly: such fission is the energy source of uranium- and plutonium-based nuclear weapons; it also provides the trigger for fusion weapons.
- Fratricide:** In this report, the unintended destruction of some of a nation's weapons or other military systems (e. g., satellites) by others.
- Free-electron Laser:** A type of laser which does not use ordinary matter as a lasant but instead generates radiation by the interaction of an electron beam with a static magnetic or electric field. Loosely speaking, free-electron laser technology resembles and evolved from that used by particle accelerators ("atom smashers"). Lasers which are not freeelectron lasers are bound-electron lasers.
- Functional Kill:** The destruction of a target by disabling vital components in a way not immediately detectable, but nevertheless able to prevent the target from functioning properly. An example is the destruction of electronics in a guidance system by a neutral particle beam.
- Fusion:** More specifically, nuclear fusion: The fusing of two atomic nuclei, usually of light elements, such as hydrogen. For light elements, energy is liberated by this process. Hydrogen bombs produce most of their energy through the fusion of hydrogen into helium.
- Graser:** See *Gamma-ray Laser*.
- Gamma-ray Laser:** A laser which generates a beam of *gamma rays*; also called a *graser*. A gamma-ray laser, if developed, would be a type of X-ray laser; although it would employ nuclear reactions, it need not (but might) employ nuclear fission or fusion reactions or explosions.
- Gamma Rays:** X-rays emitted by the nuclei of atoms.
- Geostationary Orbit:** An orbit at an altitude of 35,800 kilometers above the Earth's Equator. A satellite placed in such an orbit revolves around the Earth once per day, maintaining the same position relative to the surface of the Earth. It then appears to be stationary, and can be used as a communications relay or as a surveillance post.
- Geosynchronous Orbit:** An orbit about 35,800 km
- above the Equator. A satellite placed in such an orbit revolves around the Earth once per day. See *Geostationary Orbit*.
- Gray:** The Systeme International unit of absorbed dose of ionizing radiation. One gray (abbreviated 1 Gy) is 1 joule of absorbed energy per kilogram of matter.
- Hard Kill:** Destruction of a target in such a way as to produce unambiguous visible evidence of its neutralization.
- Hardness:** A property of a target; measured by the power needed per unit area to destroy the target by means of a directed-energy weapon. A hard target is more difficult to kill than a soft target.
- High-Earth Orbit:** An orbit about the Earth at an altitude greater than 3,000 nautical miles (about 5,600 kilometers).
- Homing Device:** A device, mounted on a missile, that uses sensors to detect the position or to help predict the future position of a target, and then directs the missile to intercept the target. It usually updates frequently during the flight of the missile.
- Impulse:** A mechanical jolt delivered to an object. Physically, impulse is a force applied for a period of time, and the Systeme Internationale unit of impulse is the newton-second (abbreviated N-s). See *Impulse Intensity*.
- Impulse Intensity:** Mechanical impulse per unit area. The Systeme International unit of impulse intensity is the pascal-second (abbreviated Pa-s) A conventionally used unit of impulse intensity is the "tap," which is one dyne-second per square centimeter; hence 1 tap = 0.1 Pa-s.
- Impulse Kill:** The destruction of a target, using directed energy, by ablative shock. The intensity of directed energy maybe so great that that the surface of the target violently and rapidly boils off delivering a mechanical shock wave to the rest of the target and causing structural failure.
- Inclination:** The inclination of an orbit is the (dihedral) angle between the plane containing the orbit and the plane containing the Earth's Equator. An equatorial orbit has an inclination of 00 for a satellite traveling eastward or 1800 for a satellite traveling westward. An orbit having an inclination between 00 and 900 and in which a satellite is traveling generally eastward is called a prograde orbit. An orbit having an inclination of 900 passes above the north and south poles and is called a polar orbit. An orbit having an inclination of more than 900 is called a retrograde orbit.
- Ionization:** The removal or addition of one or more electrons to a neutral atom, forming a charged ion.
- Isotropic:** Independent of direction; referring to

the radiation of energy, it means "with equal intensity in all directions," i.e., omnidirectional.

Isotropic Nuclear Weapon (INW): A nuclear explosive which radiates X-rays and other forms of radiation with approximately equal intensity in all directions. The term "isotropic" is used to distinguish them from nuclear directed-energy weapons.

Joule: The Systeme International unit of energy. One kilowatt-hour is 3.6 million joules.

Keep-out Zone: A volume around a space asset, off limits to parties not owners of the asset. Keep-out zones could be negotiated or unilaterally declared. The right to defend such a zone by force and the legality of unilaterally declared zones under the Outer Space Treaty remain to be determined.

Kelvin Temperature: A scale of temperature on which zero degrees Kelvin (abbreviated 00 K) corresponds to "absolute zero. Temperature in degrees Kelvin equals temperature in degrees Celsius plus 273.16, thus ice melts at 273.16 °C K, and water boils at 373.16° K.

Keplerian Orbit: The orbit which a satellite would follow if the Earth were a uniform sphere with no atmosphere, and if other simplifying assumptions were valid. Such an orbit would be an ellipse having the center of the Earth as one focus. A special case of such an orbit is a circular orbit about the center of the Earth.

Kill Assessment: The detection and assimilation of information indicating the destruction of an object under attack. Kill assessment is one of the many functions to be performed by a battle management system.

Kinetic-Energy Weapon: A weapon that uses kinetic energy, or energy of motion, to kill an object. Weapons that use kinetic energy are a rock, a bullet, a nonexplosively armed rocket, and an electromagnetic radgun.

Lasant: A material that can be stimulated to produce laser light. Many materials can be used as lasants; these can be in solid, liquid, or gaseous form (consisting of molecules—including excimers— or atoms) or in the form of a plasma (consisting of ions and electrons). Lasant materials useful in high-energy lasers include carbon dioxide, carbon monoxide, deuterium fluoride, hydrogen fluoride, iodine, xenon chloride, krypton fluoride, and selenium, to mention but a few.

Laser: A device that produces a narrow beam of coherent radiation through a physical process known as stimulated emission. Lasers are able to focus large quantities of energy at great distances, and are among the leading candidates for BMD weapons.

LIDAR: A technique analogous to radar, but which uses laser light rather than radio or mi-

crowaves. The light is bounced off a target and then detected, with the return beam providing information on the distance and velocity of the target.

Limited Test Ban Treaty: The multilateral Treaty signed and ratified by the United States and the U.S.S.R. in 1963 which prohibits nuclear tests in all locations except underground.

Megawatt: One million watts; a unit of power. A typical commercial electric plant generates about 500 to 1,000 megawatts.

MeV: One million electron-volts. A unit of energy usually used in reference to nuclear processes. It is equivalent to the energy that an electron gains in crossing a potential of 1 million volts.

Micron: One-millionth of a meter (equivalently, one-thousandth of a millimeter). Roughly twice the wavelength of visible light.

Midcourse Phase: The phase of a ballistic missile trajectory in which the RVS travel through space on a ballistic course towards their targets. This phase lasts up to 20 minutes.

Military Satellite (MILSAT): A satellite used for military purposes, such as navigation or intelligence gathering.

Miniature Homing Vehicle (MHV)/Miniature Vehicle (MV): An air-launched direct-ascent ("pop-up") kinetic-energy ASAT weapon currently being developed and tested by the U.S. Air Force.

Monostatic Radar: A radar system in which the receiver and transmitter are colocated.

Multistatic Radar: A radar system that has transmitters and receivers stationed at multiple locations; typically, a radar system with a transmitter and several receivers, all of which are geographically separated. A special case is bistatic radar. An advantage of multistatic radar over monostatic radar is that even if transmitters—which might be detected by the enemy when operating—are attacked, receivers in other locations might not be noticed and might thereby escape attack.

Obscur&.nt: A material-e. g., smoke or chaff-used to conceal an object from observation by a radio or optical sensor. Smoke maybe used to conceal an object from observation by an optical sensor, and chaff may be used to conceal an object from observation by a radio sensor (e.g., radar).

On-line: Operating, as distinct from dormant.

Orbital Elements: Any set of several parameters (e.g., apogee, perigee, inclination, etc.) used to specify a Keplerian orbit and the position of a satellite in such an orbit at a particular time. Seven independent orbital elemets are required to unambiuously specify the position of a satellite in a Keplerian orbit at a particular time.

Outer Space Treaty of 1967: A multilateral treaty

- signed and ratified by both the United States and the Soviet Union. Article IV of the Outer Space treaty forbids basing nuclear weapons or other weapons of mass destruction in space.
- Passive Sensor:** One that detects naturally occurring emissions from a target for tracking and/or identification purposes.
- Perigee:** The minimum altitude attained by an Earth satellite.
- Phased-Array Radar (PAR):** A radar with elements that are physically stationary, but with a beam that is electronically steerable and can switch rapidly from one target to another. Used for tracking many objects, often at great distances.
- Pointing:** The aiming of sensors or defense weapons at a target with sufficient accuracy either to track the target or to aim with sufficient accuracy to destroy it.
- Polar Orbit:** An orbit having an inclination of 90°.
- Prograde Orbit:** An orbit having an inclination of between 0° and 90°. See *Retrograde Orbit*.
- Pumping:** In this report, the raising of the molecules or atoms of a lasant to an energy state above the normal lowest state, in order to produce laser light. This results when they fall back to a lower state. Pumping may be done using electrical, chemical, or nuclear energy.
- Rad:** A unit of absorbed dose of ionizing radiation. One rad is 0.001 gray.
- Radar:** A technique for detecting targets in the atmosphere or in space by transmitting radio waves (e.g., microwaves) and sensing the waves reflected by objects. The reflected waves (called "returns" or "echos") provide information on the distance to the target and the velocity of the target and may also provide information about the shape of the target. (Originally an acronym for "RAdio Detection And Ranging.")
- Radian:** A unit of angular measure. One radian is about 57.30. One microradian (0.000001 radian) is the angle subtended by an object 1 meter across at a distance of 1,000 kilometers.
- Reaction Decoy:** A decoy deployed only upon warning or suspicion of imminent attack.
- Reentry:** The return of objects, originally launched from Earth, into the atmosphere.
- Retrograde Orbit:** An orbit having an inclination of more than 90°. See *Prograde Orbit*.
- Robust:** In this report, describing a system, indicating its ability to endure and perform its mission against a reactive adversary. Also used to indicate ability to survive under direct attack.
- Salvage-fused:** Describing a warhead, that is set to detonate when it is attacked. Usually refers to a nuclear warhead.
- Sensors:** Electronic instruments that can detect radiation from objects at great distances. The information can be used for tracking, aiming, discrimination, attacking, kill assessment, or all of the above. Sensors may detect any type of electromagnetic radiation or several types of nuclear particles.
- Shoot-back** In this report, the technique of defending a space asset by shooting at an attacker.
- Signature:** Distinctive type of radiation emitted or reflected by a target, which can be used to identify that target.
- Simulation:** The art of making a decoy look like a more valuable strategic target See *Anti-simulation*.
- Slew Time:** The time needed for a weapon to reaim at a new target after having just fired at a previous one.
- Smoke:** An obscurant which may be used in the atmosphere or in space to conceal an object from observation by an optical sensor.
- Soft Kill:** Same as *functional kill*.
- Space Detection And Tracking System (SPADATS):** A network of space surveillance sensors operated by the U.S. Air Force.
- Space Mines:** Hypothetical devices that can track and follow a target in orbit, with the capability of exploding on command or by pre-program, in order to destroy the target.
- Stimulated Emission:** Physical process by which an excited molecule is induced by incident radiation to emit radiation at an identical frequency and in phase with the incident radiation. Lasers operate by stimulated emission.
- Superfluorescence:** See *Superradiance*.
- Superradiance:** The process used by a superradiant laser to generate or amplify a laser beam in a single pass through a lasant material, or—in the case of a free-electron laser—through an electric or magnetic field in the presence of an electron beam. Superradiance is actually a form of stimulated emission. Also known as superfluorescence, or amplified spontaneous emission.
- Superradiant Laser:** A laser in which the beam passes through the lasant only once; mirrors are not required for the operation of such a laser, as they are with more conventional lasers which are sometimes called "cavity lasers" to distinguish them from superradiant lasers. Free-electron lasers may also be superradiant; the laser beam of a superradiant free-electron laser would pass once through an electric or magnetic field (instead of a lasant) in the presence of an electron beam.
- Synthetic Aperture Radar (SAR):** A radar system which correlates the echoes of signals emitted at different points along a satellite's orbit or an airplane's flight path. The highest resolution achievable by such a system is theoretically equivalent to that of a single large antenna as

wide as the distance between the most widely spaced points along the orbit that are used for transmitting positions. In practice, resolution will be limited and by the radar receiver's signal-processing capability or by the limited coherence of the radio signal emitted by the radar transmitter.

Thermal Kill: The destruction of a target by heating it, using directed energy, to the degree that structural components fail.

Threat: The anticipated inventory of enemy weapons and method of using them.

Tracking: The monitoring of the course of a moving target. Ballistic objects may have their

tracks predicted by the defensive system, using several observations and physical laws.

Warhead: A weapon, usually a nuclear weapon, contained in the payload of a missile.

World-Wide Military Command and Control System (WWMCCS): A communications network linking U.S. forces.

X-ray Laser: A laser which generates a beam or beams of *X-rays*. Also called an "x-raser" or "XRL."

X-rays: Electromagnetic radiation having wavelengths shorter than 10 nanometers (10 billionths of a meter).