

Space Surveillance Network

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The space surveillance network (SSN) is a combination of optical and radar sensors used to support the Joint Space Operations Center's (JSpOC) mission to detect, track, identify, and catalog all manmade objects orbiting the earth. This chapter looks at the various components of the SSN, its sites, and how they combine to support the space surveillance mission. This chapter also contains a description of the radar and optical sensors, which are the two primary technologies used by the SSN.

SSN Radar Sensor Systems

Radar sensors used by the SSN are divided into two categories: mechanical, the oldest type of radar used by the SSN, and the newer phased-array radars.

Mechanical Radars

Mechanical radars (fig. 19-1), or mechanical trackers, are employed to track a target throughout the radar's coverage. A single beam of radar energy is sent out toward the target. The energy is reflected off the target and returned to the radar receiver for measurement. The transmitter sends out another beam of radar energy, and the cycle repeats itself as the radar follows the target throughout its coverage. The mechanical tracker is a good system for tracking near-Earth objects because it can acquire a large number of data points. It directs the radar beam by reorienting the antenna and is very precise in predicting the trajectory of near-Earth objects. The main limitation of the mechanical tracker is that it can track only one object at a time. It cannot "search" for targets very efficiently because it sends out only a single beam of radar energy at a time. Some mechanical radars have the ability to move the radar beam in a pattern so that the radar can perform a search function.¹

Phased-Array Radar

Phased-array radar (PAR) is the newest radar technology used within the SSN. Rather than the antenna being moved mechanically, the radar energy is steered electronically. In a PAR there are many thousands of small transmit/receive (T/R) antennas placed on the side or face of a large wedge-shaped structure. If the signals from the separate T/R antennas are released at the same time and in phase, they form a radar beam whose direction of travel is perpendicular to the array face.



Figure 19-1. Kwajalein tracking radar. (US Army photo)

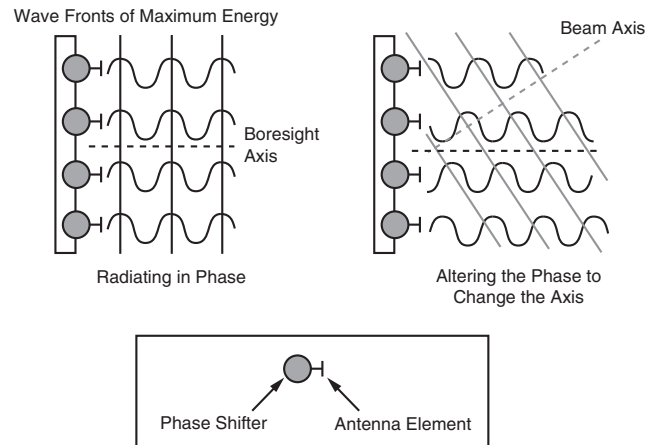


Figure 19-2. Changing direction of beam in phased-array radar. (Adapted from University of Wisconsin Naval ROTC, "Naval Weapons Systems Lesson 7: Electronic Scanning and Phased Array Radars," course files.)

To detect objects that do not lie directly in front of the array face, time-delay units, or phase shifters, are used. This phase-lag steering is a computer procedure in which the radiating elements are delayed sequentially across the array, causing the wave front to be at an angle to the perpendicular as shown in figure 19-2. This controls the direction of the beam. Since these radars have several thousand T/R antenna elements, multiple beams can be formed at the same time. A PAR is capable of simultaneously tracking numerous targets since a computer calculates the proper time delays of these beams.² The number of targets a PAR can track is most often limited by the amount of power available. However, there are two disadvantages of a PAR: the high cost of building it and complex maintenance.

Optical Sensor Systems

Optical sensors are very basic. They simply gather light waves reflected off of an object to form an image. This image can then be measured, reproduced, and analyzed. However, these sensors are limited due to their reliance on light; they cannot track during the day or under overcast sky conditions. The objects tracked must also be in sunlight and have some reflective qualities. Electro-optical sensors are the only optical sensors used operationally today to support the space surveillance mission.

Electro-optical refers to the way the sensor records the optical image. Instead of being imprinted on film, the image is changed into electrical impulses and recorded onto magnetic tape. This is similar to the process used by video recorders. The image can also be analyzed in real time. The primary electro-optical sensors used in the SSN are part of the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) System.

Space Object Identification

Space object identification (SOI) analyzes signature data to determine satellite characteristics such as size, shape, motion, and orientation. SOI information is used to

determine the operational status of various payloads and may forecast maneuvers or deorbits. The process of using SOI data, in conjunction with other intelligence resources, to determine the nature of unidentified payloads is called mission payload assessment.

There are four categories of sensor SOI: wideband, narrowband, photometric, and optical imaging. Wideband SOI provides a detailed radar picture of the satellite. Two sensors (Haystack and the Advanced Research Projects Agency [ARPA] Lincoln C-Band Observable Radar [ALCOR]) have the capability of providing wideband SOI.³ Narrowband SOI provides a two-dimensional depiction of the radar energy charted on a graph as amplitude versus time. Narrowband SOI sensors include Ascension, Beale, Cavalier, Clear, Cape Cod, Cobra Dane, Eglin, Fylingdales, and Millstone. Photometric SOI is the analysis of the intensity, luminance, and illuminance from systems like GEODSS and the Midcourse Space Experiment/Space-Based Vehicle (MSX/SBV). Finally, optical-imaging SOI refers to object identification obtained using optical telescopes that are augmented with Advanced Electro-Optical System (AEOS) long-wave infrared (LWIR) (AEOS-L) and AEOS adaptive optics sensors.⁴

Space Surveillance Network Sensor Missions

All sensors in the SSN are responsible for providing space surveillance and SOI to the JSpOC located at Vandenberg AFB, California, and to the Alternate Space Control Center (ASCC) at Dahlgren, Virginia. The sensors in the network are categorized primarily by their availability to support the JSpOC. This availability is based on the primary mission of each sensor. The SSN sensor missions are divided into three categories: dedicated, collateral, and contributing.

Dedicated Sensors

A dedicated sensor is a US Strategic Command (USSTRATCOM) operationally controlled sensor with a primary mission of space surveillance support. Dedicated sensors include GEODSS systems, the Air Force Space Surveillance System (AFSSS), and the Eglin AFB AN/FPS-85 phased-array radar.⁵

GEODSS. GEODSS has the mission to detect, track, and collect SOI on deep-space satellites in support of the JSpOC. Each GEODSS site (fig. 19-3) is controlled and operated by the 21st Space Operations Group, 21st Space Wing, Peterson AFB, Colorado.



Figure 19-3. GEODSS Diego Garcia. (USAF photo by SMSgt John Rohrer)

There are currently three detachments operating GEODSS sensors: Detachment 1, Socorro, New Mexico; Detachment 2, Diego Garcia, British Indian Ocean Territories; and Detachment 3, Maui, Hawaii.⁶ The GEODSS sites provide near-real-time deep-space surveillance capability.

To perform its mission, GEODSS depends on three main elements: powerful telescopes, low-light television, and high-speed computers. Each site has three telescopes: two main and one auxiliary (with the exception of Diego Garcia, which has three main telescopes). The

main telescopes have a 40-inch aperture and a two-degree field of view. The system operates only at night, when the telescopes are able to detect objects 10,000 times dimmer than the human eye can detect. Since it is an optical system, cloud cover and local weather conditions influence its effectiveness.⁷

The telescopes move across the sky at the same rate as the stars appear to move. This keeps the distant stars in the same positions in the field of view. As the telescopes slowly move, the GEODSS cameras take very rapid electronic snapshots of the field of view. Four computers then take these snapshots and overlay them on each other. Star images, which remain fixed, are electronically erased. However, manmade space objects do not remain fixed, and their movements show up as tiny streaks that can be viewed on a console screen. Computers measure these streaks and use the data to calculate the positions of objects, such as satellites in orbits from 3,000 to 22,000 miles. This information is used to update the list of orbiting objects and is sent nearly instantaneously from the sites to JSpOC.⁸ The GEODSS system can track objects as small as a basketball more than 20,000 miles in space.

Moron Optical Space Surveillance. The Moron Optical Space Surveillance (MOSS) System was fielded at Moron AB, Spain, during the first quarter of fiscal year 1998. MOSS operates in conjunction with the existing GEODSS network. The GEODSS network called for an additional site in the Mediterranean to provide contiguous geosynchronous coverage. Air Force Space Command (AFSPC) fielded MOSS to provide this critical geosynchronous belt metric and SOI coverage.⁹

MOSS consists of one high-resolution electro-optical telescope and the MOSS Space Operations Center (MOSC) van. The telescope has a nominal aperture of 22 inches and a focal length of 51 inches (f 2.3). The camera houses a 1024 x 1024 MIT/LL charge-coupled device focal-plane array. Commercial power is conditioned by an uninterruptible power supply and backed up by a diesel generator.¹⁰

Air Force Space Surveillance System. Naval Space Command built the oldest sensor system in the SSN—Naval Space Surveillance (NAVSPASUR), also known as the Fence—whose mission was to maintain a constant surveillance of space and provide satellite data to the SSN. It reached initial operational capability in 1961. NAVSPASUR operations were transferred to Air Force control on 1 October 2004, and it was renamed the Air Force Space Surveillance System.¹¹

AFSSS uses three transmit antennas and six receive antennas, all geographically located along the 33rd parallel of the United States. The transmitters send out a continuous wave of energy into space, forming a “detection fence” which covers 10 percent of the earth’s circumference and extends 15,000 miles into space. When a satellite passes through the fence, the energy from the transmitter sites “illuminates” it, and a portion of the energy is reflected back to a receive station. When the reflected energy is acquired by at least two receive sites, an accurate position of the satellite can be determined through triangulation.¹²

AN/FPS 85 PAR. Located at Eglin AFB, Florida, the AN/FPS-85 PAR (fig. 19-4) is operated by AFSPC, 21st Space Wing, 20th Space Surveillance Squadron (SPSS). The 20 SPSS operates and maintains the only phased-array space surveillance system dedicated to tracking space objects. Built in the mid-1960s, it is one of the earliest phased-array radars. The Air Force assumed operational control of the site on 24 January 1969. The previous primary mission at Eglin was submarine-launched ballistic missile (SLBM) warning. Once the southeast radar at Robins AFB, Georgia, known as the Perimeter Acquisition Vehicle Entry Phased-Array Weapons System (PAVE PAWS),

became operational, the SLBM warning coverage was redundant, and Eglin's mission changed in 1987 to dedicated space surveillance.¹³



Figure 19-4. AN/FPS-85 PAR at Eglin AFB. (USAF photo)

Collateral Sensors

A collateral sensor is a USSTRATCOM operationally controlled sensor with a primary mission other than space surveillance (usually, the site's secondary mission is to provide surveillance support). Collateral sensors include the Maui Optical Tracking and Identification Facility (MOTIF), Maui Space Surveillance System (MSSS), Ballistic Missile Early Warning System (BMEWS), PAVE PAWS, and Perimeter Acquisition Radar Attack Characterization System (PARCS), as well as the Antigua, Ascension, and Kaena Point radars.¹⁴ MSSS was once part of

the 18th SPSS Detachment 3, but AFSPC transitioned it to the Air Force Research Laboratory on 1 October 2000.¹⁵

Ballistic Missile Early Warning System. BMEWS is a key radar system developed to provide warning and attack assessment of an intercontinental ballistic missile (ICBM) attack on the continental United States (CONUS) and southern Canada from the Sino-Soviet land mass. BMEWS III also provides warning and attack assessment of an SLBM/ICBM attack against the United Kingdom and Europe. The tertiary mission of BMEWS is to conduct satellite tracking as collateral sensors in the space surveillance network. BMEWS consists of three sites: site 1 at Thule AFB, Greenland; site 2 at Clear AFS, Alaska; and site 3 at Royal Air Force Station Fylingdales, United Kingdom.



Figure 19-5. PAR at Thule AFB. (USAF photo)

Site 1, Thule (fig. 19-5), is operated by the 12th Space Warning Squadron (SWS), a unit of AFSPC's 21st Space Wing. Initial operations at site 1 began in October 1960. Its original equipment consisted of four detection radars (DR) and a single tracking radar (TR). After more than 26 years of continuous operation, the DRs and TR were replaced with a phased-array radar. The upgraded radar became operational in June 1988.¹⁶

The 13 SWS at Clear AFS, Alaska, began operations in 1961 with three DRs (AN/FPS-50s), each 400 feet long and 165 feet high, and a TR (AN/FPS-92) that was 84 feet in diameter and weighed 100 tons (fig. 19-6). Clear has been upgraded with a dual-faced phased-array radar similar to Thule and the PAVE PAWS sites. The radar system has two faces, which together form a coverage area 240 degrees wide and 4,828 kilometers into space. The coverage extends from the Arctic Ocean all the way to the west coast of the lower 48 states.

The Royal Air Force at Fylingdales operates a three-faced phased-array radar. The original configuration consisted of three mechanical tracking radars that have since



Figure 19-6. Tracking radar at Clear AFS. (USAF photo)



Figure 19-7. Solid state PAR at Fylingdales. (Royal Air Force photo)



Figure 19-8. PAVE PAWS site. (DOD photo)

been dismantled. The Fylingdales PAR searches the sky for possible missile threats with full 360-degree coverage. Fylingdales' primary mission is to provide warning of an IRBM, medium-range ballistic missile (MRBM), or SLBM attack against the United Kingdom and Western Europe. Its secondary mission is to provide warning of an ICBM/SLBM attack against the CONUS. Fylingdales' tertiary mission is to provide space surveillance data on orbiting objects to the JSpOC Space Situational Awareness Operations Cell and Alternate Space Control Center.¹⁷

PAVE PAWS. Advancing technology provided the former Soviet Union the capability to launch ballistic missiles from submarines. Studies indicated the need for early warning facilities to detect such an attack. The PAVE PAWS mission is to provide warning and attack assessment of an SLBM attack against the CONUS and southern Canada. PAVE PAWS also provides limited warning and attack assessment of an ICBM attack against North America from the Sino-Soviet land mass. The secondary mission, like BMEWS, is to provide satellite tracking data as collateral sensors in the space surveillance network.¹⁸

PAVE PAWS currently consists of the initial two sites. Site 1 (fig. 19-8) is located at Cape Cod AFS, Massachusetts, and is operated by the 6 SWS. Site 2 is at Beale AFB, California, and is operated by the 7 SWS. Both sites operate a dual-faced phased-array radar (AN/FPS-115). The computer hardware and software were upgraded in the mid-1980s, when the other two sites were built.

The PAVE PAWS phased-array antenna, as with any other directional antenna, receives signals from space only in the direction in which the beam is aimed. The maximum practical deflection on either side of the antenna

center of the phased-array beam is 60 degrees. This limits the coverage from a single antenna face to 120 degrees. To provide surveillance across the horizon, the building housing the entire system and supporting antenna arrays is constructed in the shape of a triangle. Two of the three sides have radar elements mounted on them. The two radiating faces, each with 1,792 active elements, are tilted back 20 degrees to allow for an elevation deflection from three to 85 degrees above the horizon. The lower limit provides receiver isolation from signals returned from ground clutter and for environmental microwave-radiation hazard protection of the local area. PAVE PAWS radar beams reach outward for nearly 5,556 kilometers in a 240-degree sweep. At its

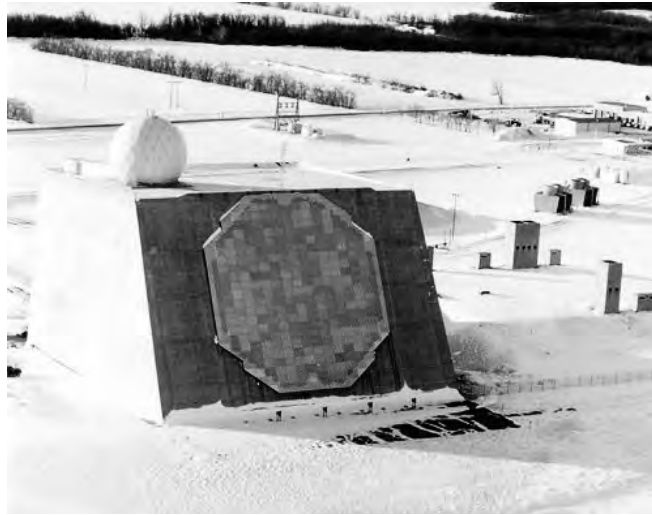


Figure 19-9. PARCS at Cavalier AFS. (USAF photo)

extreme range, it can detect an object the size of a small car. Smaller objects can be detected at closer range.¹⁹

The PAVE PAWS system is capable of detecting and monitoring a large number of targets that would be consistent with a massive SLBM attack. The system must rapidly discriminate between vehicle types, calculating their launch and impact points in addition to the scheduling, data processing, and communications requirements. The operation is entirely automatic, only requiring people for system monitoring and maintenance and as a final check on the validity of warnings. Three different computers communicating with each other form the heart of the system, which relays the information to JSpOC and Cheyenne Mountain AFS.

Perimeter Acquisition Radar Attack Characterization System. PARCS is operated by the 10 SWS, located just 15 miles south of the Canadian border at Cavalier AFS, North Dakota (fig. 19-9). The PARCS sensor was originally built as part of the Army's Safeguard antiballistic missile (ABM) system. It became operational on 1 October 1975 and was ordered deactivated the next day by Congress. It was modified by the Air Force in 1977 for use as a missile warning/space surveillance sensor.

The PARCS mission is to provide warning and attack characterization of an SLBM and ICBM attack against the CONUS and southern Canada. It is one of the workhorses of the SSN, along with Eglin, providing surveillance, tracking, reporting, and SOI data on highly inclined and polar-orbiting objects. Because of its unique origin, PARCS can track hundreds of objects simultaneously. PARCS uses a single-faced phased-array radar (AN/FPQ-16). The radar, computer, communications equipment, and operations rooms are housed in a reinforced concrete building, originally designed to ride out a missile attack as part of the Safeguard ABM system. The single-faced radar looks due north and slopes from the side of the building at a 35-degree angle.²⁰ This site is considered a "CONUS isolated" location due to its remote location.

Ascension Radar. The primary mission of the Ascension radar is to provide radar-tracking data to support test and evaluation of developmental and operational ICBMs, space launch vehicles, and aeronautical development programs for the Launch Test Range System (LTRS), formerly the Eastern Range (ER). When not supporting its

primary mission, the unit has the secondary mission of space surveillance in support of the USSTRATCOM space surveillance network.²¹

Kaena Point Radar. The Kaena Point radar became operational as a Western Range asset in 1978. It is located at the northwesternmost corner of the island of Oahu, Hawaii. In 1986 the site began supporting the SSN as a collateral SSN sensor. The Kaena Point radar ceased support to the space surveillance network on 31 December 2006.

Contributing Sensors

Contributing sensors are those owned and operated by other agencies that provide space surveillance support upon request from the JSpOC. They are Millstone/Haystack, the ARPA Long-Range Tracking and Identification Radar (ALTAIR), and Cobra Dane.

Millstone/Haystack. The Millstone/Haystack complex is owned and operated by Lincoln Laboratories of the Massachusetts Institute of Technology (MIT). Millstone/Haystack is part of the Lincoln Space Surveillance Complex (LSSC), which consists of four large-aperture high-power radars: the Millstone Hill Radar (MHR) L-Band, the MHR ultra-high frequency (UHF), Haystack Long-Range Imaging Radar (LRIR), and the Haystack Auxiliary (HAX) Radar. The LSSC sensors are contributing sensors. Millstone Hill Radar and Haystack LRIR are both located in Tyngsboro, Massachusetts.²²

Millstone is a deep-space radar that contributes 80 hours of space surveillance per week to the JSpOC. Haystack is a deep-space imaging radar that provides wideband SOI data to the JSpOC. Haystack supports the JSpOC one week out of every six. USSTRATCOM has limited recall of the Haystack sensor outside of scheduled times.

ALTAIR. ALTAIR is located on Kwajalein Atoll in the western Pacific Ocean and is operated by the Army. Its primary mission is to support test and evaluation of developmental and operational ICBMs, space launch vehicles, and aeronautical development programs. ALTAIR also serves as a contributing sensor in support of the space surveillance mission. ALTAIR is a near-Earth and deep-space tracking radar. Due to its proximity to the equator, ALTAIR alone can track one-third of the geosynchronous belt.²³

Space Surveillance

Because of the limited number of sensors and their geographical distribution (fig. 19-10), the SSN cannot track every satellite continuously. To maintain a database of all manmade objects in Earth orbit, the JSpOC uses a tracking cycle that starts with a prediction. The JSpOC makes an assumption as to where a newly launched object will be and then sends out this prediction in the form of a “nominal” element set (ELSET) to the space surveillance sensors. These sensors use this nominal ELSET to search for the object. If the assumption is close, the sensor will detect and track the object. The sensor then collects observations from the space track and transmits the observation data back to JSpOC for processing and analysis.

The JSpOC uses this information to compute an initial ELSET, or prediction, which is then sent to the other sensors in the SSN. Once an object’s ELSET is established, the JSpOC will periodically update it to correct for maneuvers and orbital perturbations.²⁴ This cycle continuously repeats itself for new launches as well as for existing Earth-orbiting space objects. Refer to chapter 6 for more detailed information on ELSETs.

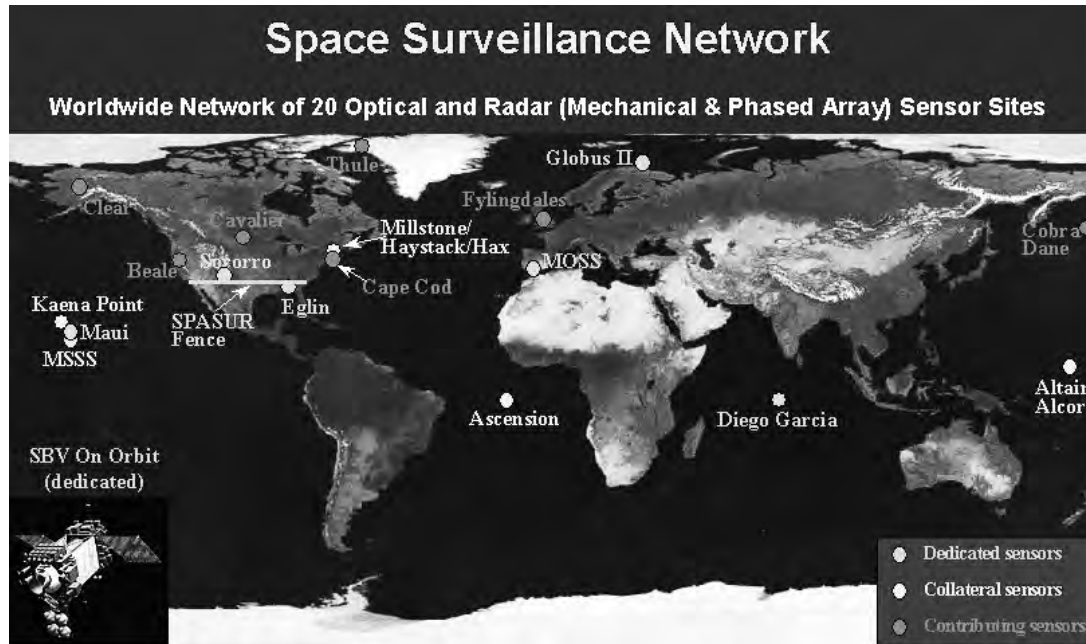


Figure 19-10. Space surveillance network. (DOD graphic)

Another tool used by JSpOC to efficiently distribute the limited tracking capabilities of the SSN is prioritized sensor tracking. A North American Aerospace Defense Command (NORAD)/USSTRATCOM regulation defines categories of priority and specific data-collection instructions, assigned according to each satellite's type and orbit. Generally, satellites with high-interest missions or unstable orbits (objects about to decay) will have higher priority and data-collection requirements than other satellites.

Summary

The space surveillance network is absolutely essential to the United States and its goal of maintaining space superiority and space situational awareness. The information provided by the SSN is used by the Joint Space Operations Center in operational and tactical planning for all Department of Defense space capabilities. The synergistic effects of the various sensor sites described above have allowed the Joint Space Operations Center to maintain a robust satellite catalog of over 11,000 objects that are currently orbiting the earth. This chapter discussed the different sensor technologies used to track satellites orbiting the earth. It also highlighted features of the various sensor sites that constitute the space surveillance network and provided a brief description of the JSpOC process of tasking sensor sites and analyzing space track data. It is important to understand that as the technology and capabilities of spaceborne platforms improve and the population of objects orbiting Earth increases, the sensor sites of the space surveillance network need to be modified and enhanced to keep pace with the evolving space environment.

Notes

1. AFSPC, *Space Surveillance Network (SSN) Site Information Handbook*, 24 October 2007, 96.
2. *Ibid.*, 70.
3. William W. Camp, Joseph T. Mayhan, and Robert M. O'Donnell, "Wideband Radar for Ballistic Missile Defense and Range-Doppler Imaging of Satellites," *Lincoln Laboratory Journal* 12, no. 2 (2000): 267–80.
4. AFSPC, *SSN Site Information Handbook*, 57.
5. Jeffrey T. Richelson, *The U.S. Intelligence Community* (Boulder, CO: Westview Press, 1999), 243–46.
6. AFSPC, *SSN Site Information Handbook*, 121.
7. *Ibid.*
8. *Ibid.*, 123.
9. *Ibid.*, 139.
10. *Ibid.*
11. Air Force, "20th Space Control Squadron, Detachment 1," Fact Sheet, <http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4729> (accessed 16 January 2008).
12. AFSPC, *SSN Site Information Handbook*, 143.
13. *Ibid.*, 78.
14. Richelson, *U.S. Intelligence Community*, 246–47.
15. Air Force, "Det 3, 21st Operations Group," Fact Sheet, <http://www.peterson.af.mil/library/factsheets/factsheet.asp?id=4741> (accessed 24 February 2008).
16. AFSPC, *SSN Site Information Handbook*, 73.
17. *Ibid.*
18. *Ibid.*, 86.
19. *Ibid.*
20. *Ibid.*, 82.
21. *Ibid.*, 96.
22. *Ibid.*, 103.
23. *Ibid.*, 110.
24. *Ibid.*, 40–41.