Chapter 3.

SENTINEL SYSTEM

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The SENTINEL System was formulated to defend against the potential ICBM threat from both the Chinese People's Republic (CPR) and the USSR during the 1970s. The deployment decision limited its initial role to a complete area defense against a CPR industrial/urban attack on the Continental United States (CONUS), and contained a growth option for defending certain U.S. ICBM bases against USSR attack. Damage prevention was the defense objective against a credible CPR attack while damage limitation was the defense objective against a future expanded CPR threat and against a USSR counterforce attack on major Minuteman installations.

The SENTINEL System evolved from the NIKE-X program, specifically the I-67 System Study.[1-3] The objectives of this study were to:

- Devise a defense against a countervalue attack with ICBMs from the CPR
- Provide for defense against a counterforce attack with ICBMs and SLBMs from the USSR
- Hold total system investment costs to $5 billion
- Meet an Initial Operational Capability (IOC) date within 54 months of a deployment decision. (This requirement limiting the choice of system elements to NIKE-X equipment.)

The study concluded that a system consisting of modified NIKE-X subsystems deployed at installations within CONUS and on Hawaii would meet these objectives.

In September 1967, the decision was made to proceed with the development, production, and installation of this system — given the project name SENTINEL. Further studies led to relatively minor modifications of the components and deployment called for in the I-67 System Study. It was also decided to give first priorities to the installations necessary for an area defense against a CPR attack. This deployment would then be augmented later to defend Minuteman sites against a USSR attack.

SYSTEM DESCRIPTION

The SENTINEL System consisted of the following major subsystems:

- Perimeter Acquisition Radar (PAR) and associated PAR Data Processor (PARDP) for long-range surveillance and tracking of attacking ICBMs
- Missile Site Radar (MSR) and associated Missile Site Data Processor (MSDP) for close-in target surveillance and tracking, and for command guidance of defensive missiles
- SPARTAN missiles with high-yield nuclear warheads for long-range intercepts
- SPRINT missiles with low-yield nuclear warheads for close-in, fast response intercepts

- A Command and Control structure linking these elements.

Deployment

The initial SENTINEL deployment, to provide an area countervalue defense of CONUS and Alaska, was to consist of 6 PARs, 16 MSRs, 480 SPARTANs, and 192 SPRINTs. An additional MSR and 28 SPRINTs were to be provided for Hawaiian defense. The PARs would have their single arrays generally faced to the north. The MSRs would have one, two, or four array faces depending on their location and role in the defense. This initial deployment could grow to include defense of strategic missile bases by the addition of 208 SPRINTs and modification of the data processing hardware and software at the sites located near Minuteman bases.

This system was to be closely netted and would have the ability to modify its response to specific attacks. Overall command and control, administration, and status of the system was to be effected through netting of local and area defense centers and, these in turn, with the Continental Air Defense Command (CONAD). This deployment is depicted in Figure 3-1.

Area Coverage

The area defense provided by the SENTINEL deployment involved nearly complete coverage of the contiguous United States, as well as parts of Alaska and Hawaii, against the defined CPR threat.[4]

The defensive coverage planned for each SPARTAN firing site is depicted in Figure 3-2.

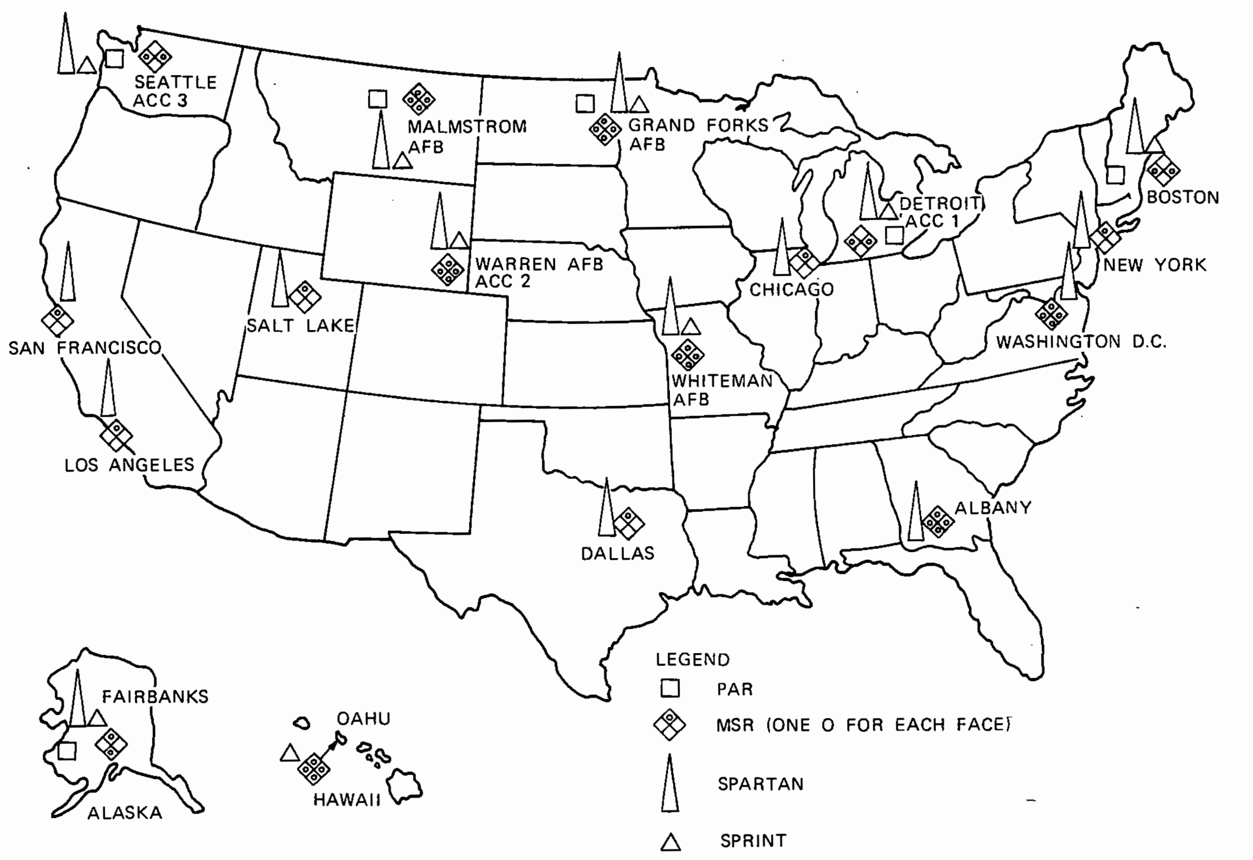

Figure 3-1. Locations of Sites for SENTINEL Deployment

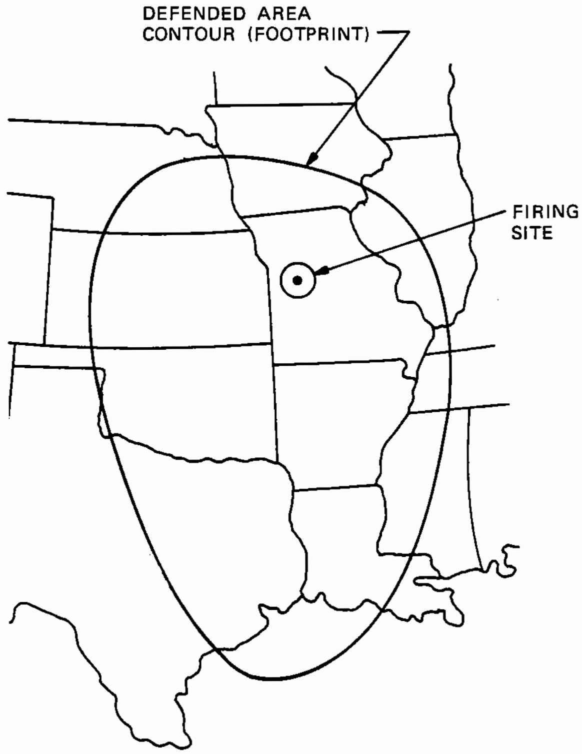

Figure 3-2. Ground Impact Area Coverage

The contour shown encloses the impact points of attacking ICBMs which could be intercepted above the atmosphere by a SPARTAN launched from that site. In general, the coverage (sometimes called a "footprint") was limited in the forward direction by the PAR detection range, and to the side and rear by a combination of missile capability and MSR scan limits.[5]

Achieving an effective area defense depends on the ability to search and detect objects at ranges that provide sufficient time to launch an interceptor at the attacking ICBM. This function of long-range search and detection would be performed by the Perimeter Acquisition Radar. Five PAR installations were to be located along the northern periphery of the United States, with one additional installation in Alaska.[6,7] The PARs would also have a verification and tracking capability to provide trajectory information to the missile firing sites and to command and control centers.

The SPARTAN missile firing sites, each with an MSR, were located in such a manner that their defended area footprints encompassed the entire CONUS. The SPARTAN firing site in Alaska provided a defense for most of the population there, while a SPRINT firing site on Hawaii provided almost complete area coverage of Oahu.

Collocated with each of the six PARs was a missile firing site using SPRINT to provide a high-confidence, terminal-intercept capability for the defense of these forward radars.

Minuteman Defense Coverage

The SENTINEL deployment called for growth to provide a terminal (SPRINT) defense of Minuteman squadrons at five bases.[8,9] The deployment objective was the maximization of silo coverage and survival against a large USSR attack.

The defense coverage to be provided, as contrasted with area defense, was strongly dependent on the characteristics of the threat, the actual site locations, and the level of deployment. Of particular importance was the target commit altitude, i.e., the altitude of the target at the time of launching a defensive missile. The commit altitude was determined by radar coverage, system response against a specified threat, and defensive missile fly-out time.

Remote launch of SPRINT was specified for the Minuteman defense sites to minimize fly-out time. These remote missile farms were located near the Minuteman silos at distances of about 25 miles from the MSR.

The SPARTAN missile, in addition to its area defense role, provided additional protection of Minuteman bases.

Command and Control

Of importance to the system operation and response was the concept that Command and Control should be designed to allow appropriate authority to reside at the lowest level in the command hierarchy, consistent with the level at which available data would support system functions and decisions.[10]

The SENTINEL Command and Control is illustrated in Figure 3-3. The system was to operate under a three-level hierarchy of Command and Control headed by the Ballistic Missile Defense Center (BMDC) which was the interface point between SENTINEL and CONAD. The BMDC was to be the command point through which the Commanding General of the Army Air Defense Command (ARADCOM) would exercise command and technical supervision over the SENTINEL System.[11] The BMDC was charged with defense of the entire United States through coordination with three Area Control Centers (ACCs) under its command.[12] The ACC responsibilities included PAR command and control,[13] MSR command,[14] and SPARTAN command. Missile Direction Centers (MDCs) were grouped on an area basis with five or six MDCs under the control of an ACC. The MDC was responsible for MSR control, SPRINT command and control, and/or SPARTAN control.[10]

The three ACCs were collectively responsible for three areas of CONUS. The boundaries between areas were drawn to minimize SPARTAN coverage overlays and to provide necessary coordination. Each primary ACC had an alternate as shown in Figure 3-4 which illustrates the MDCs and PARs included in the command and control structure of ACC No. 2. Here, the primary ACC was located at Warren AFB and the alternate was located at Whiteman. A failure at Warren resulted in a preplanned, progressive sequencing of control to Whiteman.

Communication circuits were to be provided, for both voice and data, with two geographically

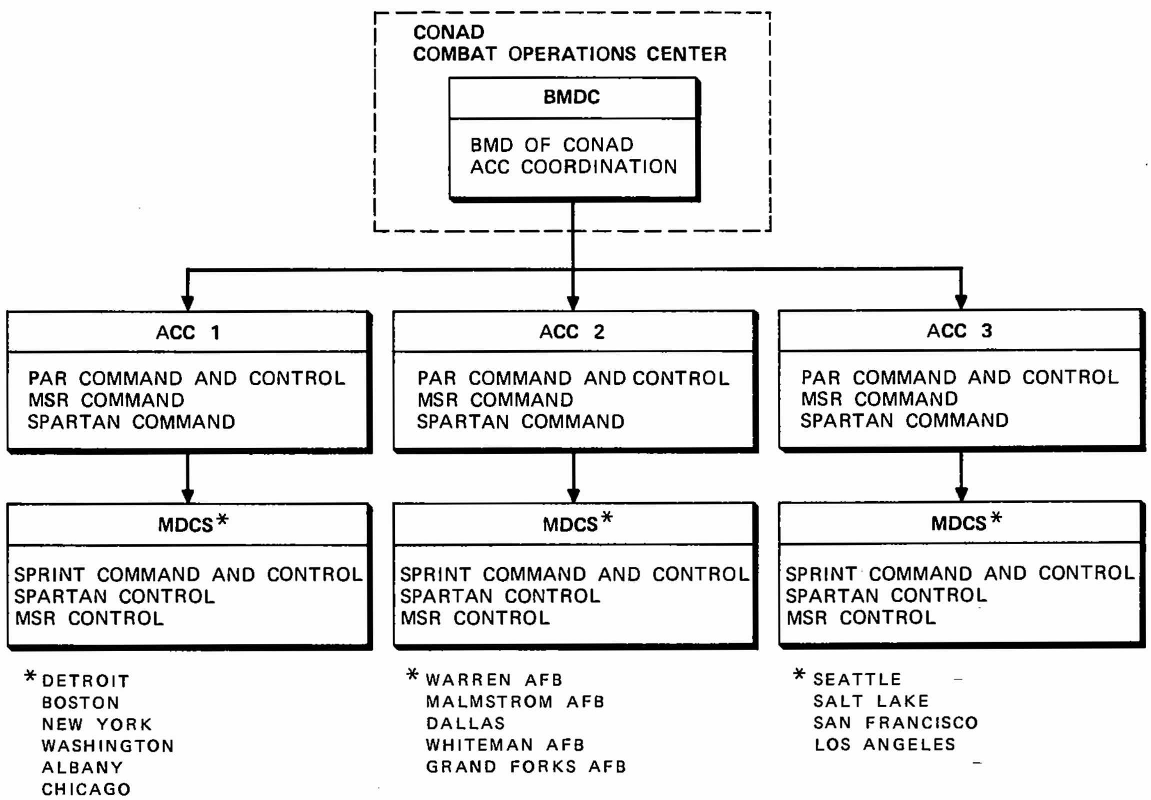

Figure 3-3. SENTINEL Command and Control Structure

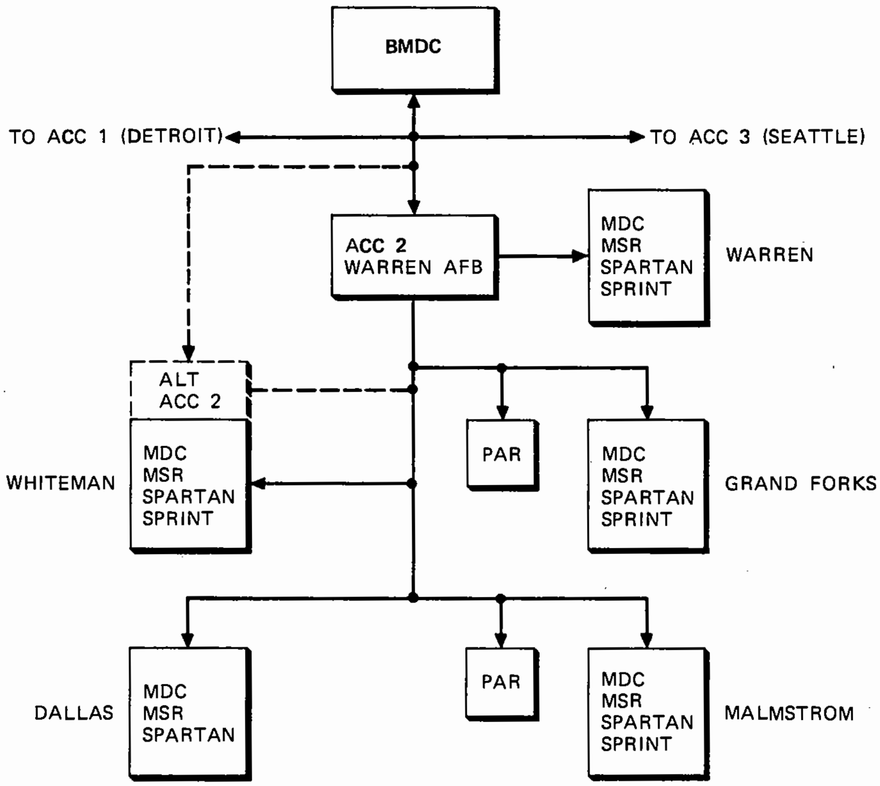

Figure 3-4. Area Control Center Number 2

separate paths required for all links. Inter-area communications were to be provided only between ACCs, with PAR data being sent to the BMDC via the ACC; MSR data were to be sent to the controlling ACC for inter-area MSR coordination and threat evaluation.

System Operation and Response

Long-range surveillance and target tracking in the SENTINEL System were to be provided by the PAR. For urban defense, the SPARTAN was the primary interceptor and was tracked and guided by MSRs. Minuteman defense would be accomplished largely as a terminal defense with SPRINT, supplemented by SPARTANs, contributing where they could be effectively brought to bear.

Generally, targets would be detected first by the PARs and, after a few seconds of tracking, trajectories and impact points would be determined and an MDC designated. For SPARTAN intercepts, target information relative to interception would be continually refined and passed to the appropriate point. The MSR, in some instances, would acquire and track the target prior to SPARTAN burst and thus reduce the intercept error.

For SPRINT engagements, the PAR data would be passed to the assigned MDC for subsequent action once the local MSR had established track. For terminal defense, the MDC could act autonomously with the MSR providing target surveillance and acquisition, as well as target and missile track.

For area defense, the SPARTAN engagement would be planned at the ACC and take into account blackout and fratricide constraints, defensive missile stockpile balance, and other restrictions.

The ACC would determine effectiveness against possible follow-on attackers. Allocation thresholds would be set and the stockpile balance among SPARTAN firing sites adjusted accordingly. The intercept would be planned specifying the place, the time, and how many SPARTANs were to be used in meeting effectiveness criteria. Continuous evaluation of the engagement plan would be provided to ensure its adequacy. The BMDC would coordinate the roles of the ACCs and provide information on estimated future attack size and defense objectives. Implementation of the SPARTAN engagement plan would be performed by the MDC, including post-intercept evaluation for use at the ACC.

For Minuteman defense, the BMDC would provide information to the ACC as in area defense, together with any Minuteman silo coverage constraints on the defense. The ACC would determine the division of the total attack for SPARTAN and/or SPRINT engagement assignments. These assignments would be sent to the designated MDCs where engagement plans would be completed. Any conflicts involving fratricide or blackout between SPARTAN and SPRINT would be resolved by the MDC. The MDC would also select the SPRINT farm to be used and plan the engagement to achieve the effectiveness level specified by system objectives, including preferential defense of Minuteman and the SENTINEL complex.

System Readiness Verification

The SENTINEL System design was strongly influenced by stringent availability/reliability objectives, that is, requirements for high probability that the system would be available if an attack should occur, coupled with requirements for high reliability during an attack.[15-19] The design intent was to provide a built-in capability for comprehensive testing of all system elements to provide continuous confidence in the system's readiness to perform its mission. This led to requirements for developing a large array of subsystem, functional, and hardware tests. In addition, a system exerciser would test the fully-integrated system, partially by simulation. The collection of hardware and software required to provide this built-in test capability was referred to as System Readiness Verification (SRV).[20]

The SRV tests were oriented toward providing:

- Verification that critical system performance parameters were within specified limits
- Detection, isolation, and indication of hardware faults
- Verification that the dynamic response of individual and collective sites (including hardware, software, and personnel) to design-level attacks was correct and that predetermined results were obtained.

In the PAR and MSR, fault detection tests were designed to run cyclically during the radar pulse-cycle dead-time while the system was performing its major role. If test results did not meet specified limits, spare groups of equipment would be automatically switched in while monitors indicated the faulty equipment. Additional fault detection and isolation tests were provided for the off-line equipment.

Data Processing System (DPS) hardware was checked by periodically scheduling units (processors, memories, etc.) off-line for testing by the Maintenance and Diagnostic Subsystem. A fixed set of tests was applied to each unit, results analyzed, and, in most cases, the fault identified.

For SPRINT and SPARTAN, special test programs were periodically run in the DPS to exercise missile subsystem hardware via normal interface channels. Monitors would indicate if the tests were unsuccessful and additional tests would be run to isolate the fault.

A System Exerciser provided the means for additional testing of system hardware as well as for exercising the tactical software (known as the weapons system process). This was accomplished by partitioning the DPS equipment at each site into two separate data processors — one to simulate a specified threat and the other to respond as during a real engagement. During an exercise, the simulator would generate radar returns representing the preselected attack for injection into the radar receivers. The system would respond in a normal manner except that simulated defensive missiles would be launched and guided under control of the weapons system process. The results of the exercise would be checked to make certain that the engagement proceeded as expected.

The System Exerciser concept also provided the means for developing and testing software in the SENTINEL Data Processing Laboratory (SDPL) at Whippany, where site equipment was either duplicated or simulated. Similarly, the System Exerciser would provide the major tool for integrating and testing software at tactical sites.

SYSTEM REQUIREMENTS AND DEVELOPMENT

Documentation

The basic requirements for the SENTINEL System and its major components were developed during the initial system studies (e.g., I-67 System Study) and refined during the first phase of system development following the deployment decision. These requirements evolved into a hierarchy of performance/design specifications which were to be prepared by Bell Laboratories and approved and placed under configuration-management control by the Army.[21] The functional organization and objective of these specifications were:

- SENTINEL System Specification — included threat parameters, overall performance requirements, deployment plan, radar and missile types and locations, and a list of sub-specifications.
- Hardware Oriented Specifications — one each for the PAR, MSR, BMDC, Data Processor, and SPARTAN and SPRINT with their associated equipment; performance requirements and design characteristics were included in each document.
- Specifications for Maintenance Facilities — stipulated requirements for Test Equipment, Maintenance Data System, and System Readiness Verification.
- Software Oriented Specifications — one each for the programs in the MSDP, PARDP, BMDC, and System Readiness Verification; requirements for inputs, outputs, operations, and major functions were included in each document.

These specifications were also used in the contractual requirements placed on the major subcontractors for the radars and missiles.

System Engineering

System engineering activities were primarily concerned with definition, documentation, and specification of the SENTINEL System operational requirements. Simulations were developed for evaluating tactical concepts and system effectiveness.[22] A mathematical model was prepared to simulate, in a computer, the proposed SENTINEL deployment to evaluate the complete system design and interaction among its various parts.[23-27] As data from MSR and MSDP tests at Meck Island and from SPRINT and SPARTAN firings became available, they were introduced into the simulation to increase the accuracy of results.

Missile Site Radar

The Missile Site Radar (MSR), an S-band single-beam, phased-array radar, was used with the Missile Site Data Processor (MSDP) to perform surveillance and limited discrimination, track of reentry targets, and track and command guidance of SPRINT and SPARTAN missiles.[28] The Raytheon Company, Bedford, Mass., was the MSR subcontractor with Bell Laboratories providing overall direction, design control, and assistance in critical areas.

The MSR was structurally a part of the Missile Site Control Building which also housed the MSDP. It was designed to have one, two, or four antenna faces inclined 51.5 degrees from the horizontal. Each face was used for both transmitting and receiving, with a single transmitter and a single receiver time-shared among faces. The transmitter (up to the final klystron amplifiers) and the receiver had duplicate equipment and automatic switching for redundancy. The two final klystron amplifiers were operated in parallel but also could operate alone at reduced power. Face switching and beam forming and steering were computer controlled.

With the change to SENTINEL, the autonomous role of the MSR was expanded, thus necessitating major changes to upgrade its tracking capability. An example of this change was the required five-fold increase in its output average power level. A prototype MSR with two array faces was constructed on Meck Island and tested extensively. This test program provided significant data useful in the design of the follow-on SAFEGUARD System.

Perimeter Acquisition Radar

The Perimeter Acquisition Radar (PAR), a single-beam, phased-array radar, was used with the PAR Data Processor (PARDP) to perform long-range surveillance, target verification, and tracking of attacking ICBMs.[29] The requirements specified a maximum detection range sufficient to allow time for SPARTAN missiles to intercept warheads outside the atmosphere. The PAR initially was planned as an "off the shelf" VHF-band radar, but following a study on the effects of nuclear blackout,[30] the frequency was changed to the UHF band, necessitating an extensive redesign program.

PAR was designed to operate in a hostile environment consisting of false targets (aircraft, satellites, meteors, or aurora), clutter signals (from the ground, chaff, or aurora), and nuclear disturbances (electromagnetic pulses, blast waves, ground shock, thermal radiation, and other radiation from nuclear weapons).

Development of the PAR was divided into three phases as follows:

- Phase I — Performance definition and equipment specification
- Phase II — Design and manufacture of a prototype at a site near Boston
- Phase III — Production and deployment of the remaining five radars.

The General Electric Company, Syracuse, New York, was responsible for PAR development under subcontract to Bell Laboratories. At the time the decision was made to reorient SENTINEL System development to SAFEGUARD objectives, the prototype site near Boston was underway and had to be moved to Cavalier, North Dakota.

SPRINT Missile Subsystem

SPRINT, a two-stage, solid-propellant missile, was the interceptor for terminal defense in the SENTINEL System. It was designed to be extremely fast reacting and capable of delivering a nuclear warhead to an intercept point, at short ranges, within seconds after launch.[31]

Development test firings of SPRINT were first conducted at White Sands Missile Range as part of the NIKE-X program. Later SPRINT launches at Meck and Illeginni Islands were conducted using SENTINEL MSR/MSDP guidance in SAFEGUARD System missions.

The Martin Marietta Corporation, Orlando, Florida, was the subcontractor to Bell Laboratories for development of SPRINT. Missile-borne guidance equipment was developed by Bell Laboratories and manufactured by Western Electric.

SPARTAN Missile Subsystem

The SPARTAN missile, in its primary role, provided long-range, large-payload, intercept capability against exoatmospheric targets.[32] The three-stage missile employed booster and sustainer motors to achieve peak velocity and a third-stage controllable jet motor for final intercept control.

Design and development of SPARTAN was the responsibility of the McDonnell Douglas Corporation, Santa Monica, California, under subcontract to Bell Laboratories. Guidance equipment for SPARTAN was developed by Bell Laboratories and manufactured by Western Electric.

Many of the basic design features of the NIKE-ZEUS DM-15C missile were used in SPARTAN. Design emphasis for use in SENTINEL was concentrated on those areas in which changes had to be made to carry a heavier warhead for the longer range, barrage-type function of SPARTAN.

The SPARTAN missile development flight-test program began at Kwajalein in March 1968 and continued into 1969. Use of SPARTAN in SAFEGUARD system missions began in April 1970.

Data Processing

Each SENTINEL installation included a Data Processing Subsystem which controlled the functioning of its radar (PAR or MSR), analyzed attacks, allocated system resources, and commanded the launch and guidance of interceptor missiles.[33]

Two R&D versions of partial data processing subsystems were installed: the SENTINEL Data Processing Laboratory (SDPL) at Whippany, and a minimum Missile Site Data Processing Subsystem (MSDPS) at Meck. The SDPL was used for equipment evaluation and software program development; the MSDPS was integrated with the MSR and used for MSR testing and performance verification.

The DPS hardware was of modular design to permit sizing to meet requirements of the processing tasks associated with each deployed site. The design was standardized so that any number of processors could be combined with any number of storage units to meet the requirements of a given site.

Most equipment was designed, developed, and manufactured by Bell Laboratories and Western Electric. Lockheed Electronics produced core memory systems for program and variable stores.

Software

The basic tactical functions of the SENTINEL System were embodied in the software programs which would drive the data processors at each site. These tactical functions were to be implemented in three generic weapons processes — one each for the PAR, MSR, and BMDC. Versions of these processes would be used at the various sites, with each version site-unique and capable of operating only in the DPS at the site for which it was designed.[34]

The Weapons Process requirements were specified in Data Processing System Performance Requirements (DPSPRs), prepared as a result of system engineering and analysis of overall system objectives. These documents specified the fundamental concepts, functional requirements, and constraints for SENTINEL System deployment. In addition, requirements for software-driven equipment tests and readiness verification were included.

The plan for development of SENTINEL weapons processes as well as other software required at the tactical sites included development of tactical support software.[35,36] In this category were:

- Program Preparation Facilities — including all tools necessary to assemble, maintain, and construct a process
- Program Execution Facilities — including the basic DPS management facility and the Tactical Operating System
- DPS Test and Maintenance Facilities — including provisions for maintenance of DPS hardware and diagnosis of faults.

Software development also included special installation software packages for use during installation and testing of SENTINEL site hardware. Three types of installation software were to be developed: (1) the DPS Installation Test Facility, (2) the PAR Installation Process, and (3) the MSR Installation Process.

In addition, software processes were developed for the Meck Test System. The initial software provided for Meck was much like the DPS and MSR Installation Processes. A software process, referred to as M-1, was an early prototype for the tactical MSR Weapons Process and provided the method for exercising the MSR, MSDP, and missile subsystems.

Testing

Major testing for the SENTINEL System was conducted with the Meck Test System which consisted of the MSR, MSDP, SPARTAN, and SPRINT subsystems.[37] The purpose of the Meck test program was to:

- Exercise and evaluate all elements of the subsystems installed
- Achieve SPRINT and SPARTAN intercepts against high-performance targets of known and controlled characteristics
- Permit study and evaluation of man's role in augmenting system responses
- Gather data applicable to the continuing design effort.

The test plan was directed toward evaluating those functions related specifically to SENTINEL deployment. This plan involved several phases of system testing at Meck Island. The M-0 phase used sets of comparatively small software packages to facilitate checkout of the radar, data processor, missile subsystems, and the interfaces between subsystems. The M-1 phase provided initial tactical functional capabilities required in the area defense role, including the first MSR-guided SPARTAN and SPRINT intercepts. Subsequent phases were to be designed with the functional capability required to test against the growth threat and to evaluate hardsite defense.

SUMMARY AND CONCLUSIONS

In the total story of ABM development, the SENTINEL System is but one brief chapter. Although not actually deployed, SENTINEL was significant in that it was the first ABM system on which an affirmative decision to deploy was made. This decision initiated development and other related activities not addressed as specifically, or in as much depth, for earlier systems. Not surprisingly, some of these activities turned up important problems that required significant attention and therefore became important conclusions in the planning for SAFEGUARD.

Because the SENTINEL System evolved into the SAFEGUARD System, rather arbitrary judgments were required to identify the conclusions, or lessons learned, from SENTINEL. The following list emphasizes those items which relate only to SENTINEL, or which were clearly highlighted before the transformation to SAFEGUARD.

- It became very clear that development, testing, and integration of the large and complex software programs required for the system seriously affected successful, on-schedule completion of the project. This led to an intensive effort to expedite the software development for SAFEGUARD. The technical and management procedures which resulted are described in Chapter 4, SAFEGUARD System, and Part III, Management and Overall Approach.
- Providing adequate confidence that the system was operational emerged as a difficult task. The design of an extensive built-in System Readiness Verification subsystem therefore became an important part of the system design.
- Specification of requirements for positive nuclear control having a very short reaction time necessitated a complex interface with the various organizations involved.
- A complex Command and Control System was required to internet the elements of the SENTINEL deployment. The unique requirements of SENTINEL made the design of such a system difficult.
- An organization of Configuration Control Boards was established to provide a Configuration Management System to control the requirements for the many elements of the SENTINEL System.