Chapter 2.

NIKE-X SYSTEM

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Unlike its predecessor, NIKE-ZEUS, and its successors, SENTINEL and SAFEGUARD, NIKE-X was not a single ABM system concept. Rather, it should be thought of as a collective term to cover a number of studies and exploratory developments aimed at leading from the then outmoded NIKE-ZEUS to the next generation ABM system. Figure 2-1 maps the more significant NIKE-X System Studies and supporting R&D activities discussed in this chapter.

NIKE-X began about 1960, when it became apparent that by the early 1970s the USSR might be able to mount a high-traffic attack against the U.S. By 1963 it was accepted that the USSR had the technological ability and the expressed intention to develop at least a parity in warhead yield with the U.S. The sophistication of USSR mid-70s ICBM offensive systems was not readily predictable; conservative assumptions included chaff, decoys, and Electromagnetic Countermeasures (ECM) as penetration aids.

This escalation of the assumed USSR threat was a breakpoint in the general approach to the NIKE-ZEUS development. Until then the ZEUS system had been based on earlier assumptions of much lower USSR capabilities. The NIKE-ZEUS system had been designed to defend population and industrial centers from a relatively light attack. For example, in tracking targets and missiles, only one target and missile could be tracked at one time by the ZEUS Target Track Radar (TTR) and Missile Track Radar (MTR), respectively. Multiple targets and missiles were handled by multiple pairs of TTRs and MTRs. Adding single target-interceptor tracking subsystems was not a cost-effective response to escalation of the predicted threats; fundamental changes in radar data-gathering techniques were required. Furthermore, the best large-scale computers of the time were not capable of handling the data processing loads associated with the newly expanded threat concepts.

Fortunately, as the threat expanded, solid-state technology evolved enough to make possible two important improvements in ABM system capability. One of these was the development of large electronically steered, phased-array radars capable of tracking many targets simultaneously. The other was the development of high-reliability, very-large-throughput data processors for ABM needs. The combination of escalating threat and expanding technology gave impetus to the NIKE-X high-traffic ABM concepts.

The initial thrust of NIKE-X was to develop a base of knowledge from which the development effort could be started. For example, the

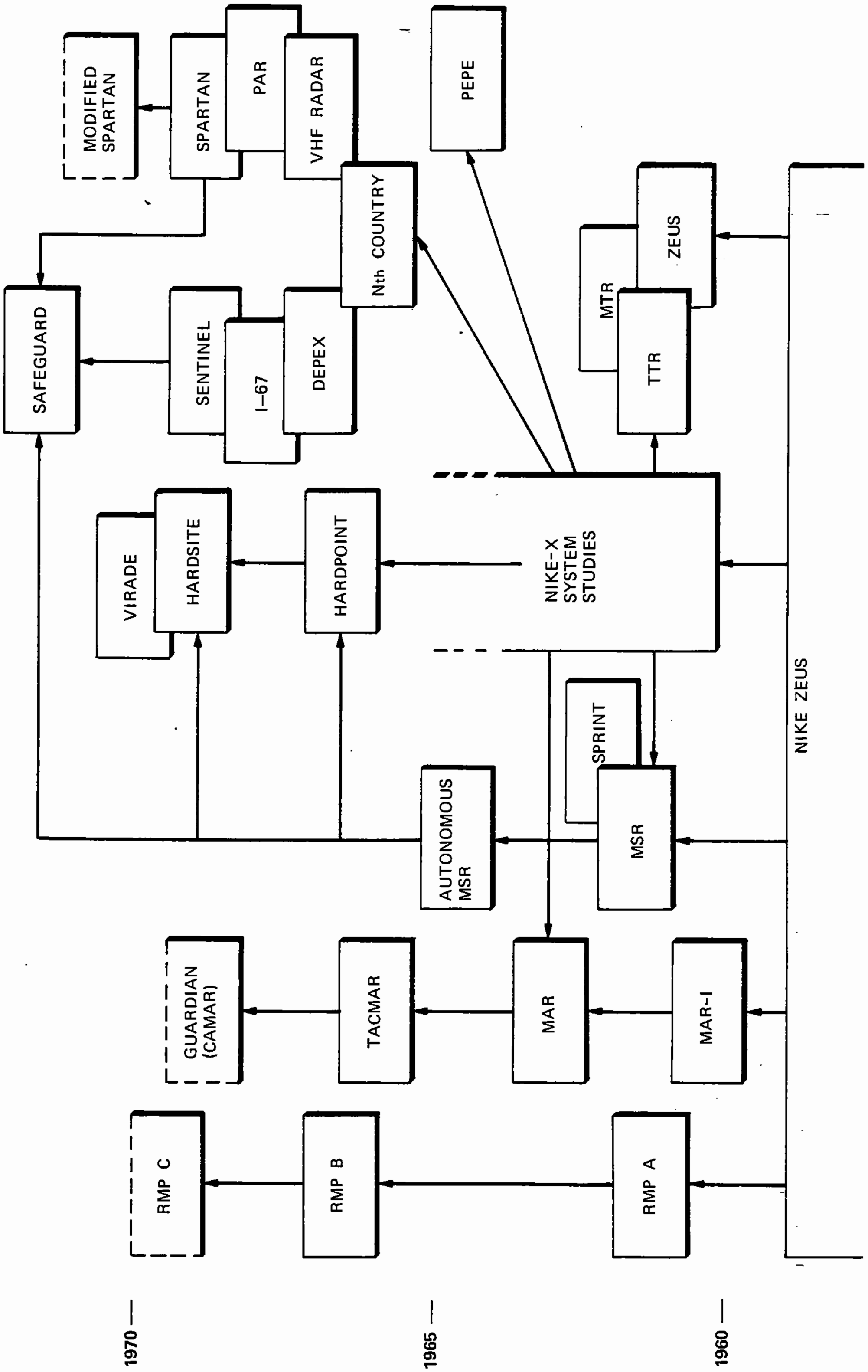

Figure 2-1. Map of the NIKE-X Era

MAR-I at White Sands Missile Range (WSMR) explored array radar designs to develop a firm technical base for NIKE-X. The Reentry Measurements Program (RMP A and B), in which NIKE-X radars observed reentries of IRBMs and ICBMs, was another very large, technically challenging effort that helped to establish the NIKE-X data base. RMP is discussed in detail later in this chapter.

NIKE-X CONCEPT

The first NIKE-X System Study, in 1963, considered a terminal defense for the larger U.S. cities against the sophisticated USSR attack postulated for the mid-1970s. It was unreasonable to make the defense impenetrable; the objective was to mitigate damage and thus deprive the offense of attractive attack opportunities.

In developing concepts to meet these city defense objectives, several major subsystems were defined. The Multifunction Array Radar (MAR), which performed search, track, and discrimination, was the centerpiece of city defense. The Missile Site Radar (MSR) and a high-acceleration, atmospheric interceptor, the SPRINT, formed a team for fast reaction, high-traffic, terminal interception of attacking ICBMs. The MAR, MSR, and SPRINT were also responsible for self-defense of the ABM facilities.

At the beginning of NIKE-X, a number of major elements were carried over from ZEUS: the Target Track Radar (TTR), the Missile Track Radar (MTR), and the ZEUS missile.

After the studies of deployment and system effectiveness, the defense of cities smaller than our 50 largest was studied next. This led to an enhanced role for the MSR — the defense of smaller cities. For cost reasons, the MSR, in addition to interceptor track and guidance, was assigned many roles similar to those of the MAR, such as search, track, and target designation. Where coverage with the reduced resources of the MSR was consistent with the small city requirements, the autonomous MSR served as a cost-effective duplication, on a lesser scale, of the MAR.

By the mid-1960s, system studies concentrated on reducing the cost of defense and improving its cost effectiveness. One approach, designated TACMAR, was a reduced-power variation of the MAR that could, if the need arose, grow to full MAR capability. By 1968, the city defense concepts were reassessed, and the decision was made to shift the defense objective to an area defense against relatively light attacks. The I-67 Study addressed this less costly area defense objective. With this shift in emphasis, ABM moved away from the city defense concept, thus removing the requirement for MAR/TACMAR. As a result, a much different kind of sensor was required; one that could detect, track, and designate targets above the atmosphere at very long ranges. This role was first assigned to a new VHF radar, which, late in the NIKE-X period, became the UHF Perimeter Acquisition Radar (PAR). The interceptor chosen for area defense was an extension of the ZEUS missile, called SPARTAN.

In summary, the light area defense concept was developed through various deployment studies, beginning with NIKE-ZEUS, which was a pure area defense system. The ZEUS area defense concept was partially incorporated into NIKE-X and became a separate concept in the Nth Country and I-67 Studies. The chronological sequence of area defense studies and postulated deployments included NIKE-ZEUS, Nth Country, DEPEX, I-67, SENTINEL, and finally SAFEGUARD. The other variant, point defense, is discussed next.

DEFENSE OF STRATEGIC FORCES— TERMINAL/POINT DEFENSE

By the mid-1960s, the NIKE-X program had two distinct defense objectives:

1. As discussed above, area defense against relatively light threats

2. Defense of strategic offensive forces against high-density, sophisticated threats.

Defense of strategic forces moved toward hardened defensive and offensive sites. The objective was to present significant, obvious uncertainties to the offense planner and hence produce influential deterrence. These terminal defense efforts led to a series of system studies: Hardpoint, Hardsite, and VIRADE. An early study[1] of the defense of U.S. strategic forces took place in 1963-64. For this study, two configurations were considered: one for defending hardened sites near defended urban areas (called HSD-I) and the other for autonomous defense of isolated sites (called HSD-II). The study sought to protect command and communication facilities and the U.S. strategic offensive force, including clusters of ICBMs and SAC bases.

Under joint directorship of the Army and the Air Force, a later study[2] emphasized an active defense dedicated to hardened ICBM silos which hold the Minuteman strike force. The study concentrated on technical tradeoffs between parameters in designing the various subsystems and drew conclusions about the relative effectiveness of tactics, deployments, and required technology.

The VIRADE (Virtual Radar Defense) mobile system was proposed as a way to increase radar attack price by presenting to the attacker a large number of possible locations for each available system. The proposed system is discussed later in this chapter.

BASIC NIKE-X SYSTEM

Threat Description

NIKE-X was designed to counter a high traffic, decoyed attack that included active jammers and low-visibility Reentry Vehicles (RVs).[3] Various threats were postulated to guide the design work and to serve as models for projecting effectiveness. These threat models used USSR ballistic missile characteristics, estimated on the basis of known technology and intelligence information, and were defense conservative.

The RV was assumed to have low radar cross section and high ballistic coefficient.[4] The USSR would use low cross section, in combination with chaff or jammers, to mask the exact RV position. Multiple warheads were considered likely, and an RV that maneuvered evasively in the terminal trajectory phase was considered possible. Assumed yields ranged from several kilotons to many megatons, depending on the mission of the particular RV. Chaff was considered a standard countermeasure to obscure the attack outside the atmosphere. In addition, "fast chaff" was postulated as a number of simple dipoles, with a moderately high ballistic coefficient, serving as traffic decoys at high altitudes. More sophisticated decoys would simulate RVs down to relatively low altitudes. They would match the radar cross section and ballistic coefficient of the RV down to an altitude which could force the defense to engage them as potentially dangerous. Active jammers were also assumed as penetration aids.

System Architecture and Operational Concept

System Elements

During its development, which extended through 1966, NIKE-X and its defense objectives changed several times, which in turn produced major changes in configuration. In its original form, NIKE-X used two types of phased-array radars (MAR and MSR), two defensive missiles (SPRINT and ZEUS), and a modular, multiprocessor data processing system. In addition, the NIKE-ZEUS Target Tracking Radar and Missile Tracking Radar remained parts of NIKE-X until it was verified that the phased-array MAR had the accuracy needed for long-range intercepts.

The L-band MAR was to be installed in densely populated urban/industrial areas (see artist's view of city defense in Figure 2-2) for (1) the long-range search needed for attack recognition and (2) the quick reaction, high-traffic capability needed for terminal defense. Associated with each MAR was a Defense Center Data Processing System (DCDPS) which controlled the MAR and any MSRs in the same area. With the MAR as its principal sensor, the DCDPS performed all urban defense functions: detecting, tracking, and evaluating threats, planning the battle, and guiding defensive missiles.

For terminal defense, NIKE-X relied on SPRINT, a relatively small, high-acceleration missile, which is described more fully in Chapter 9. SPRINT is aerodynamically guided (except for first-stage boost) and designed for intercepts within the atmosphere. Its warhead

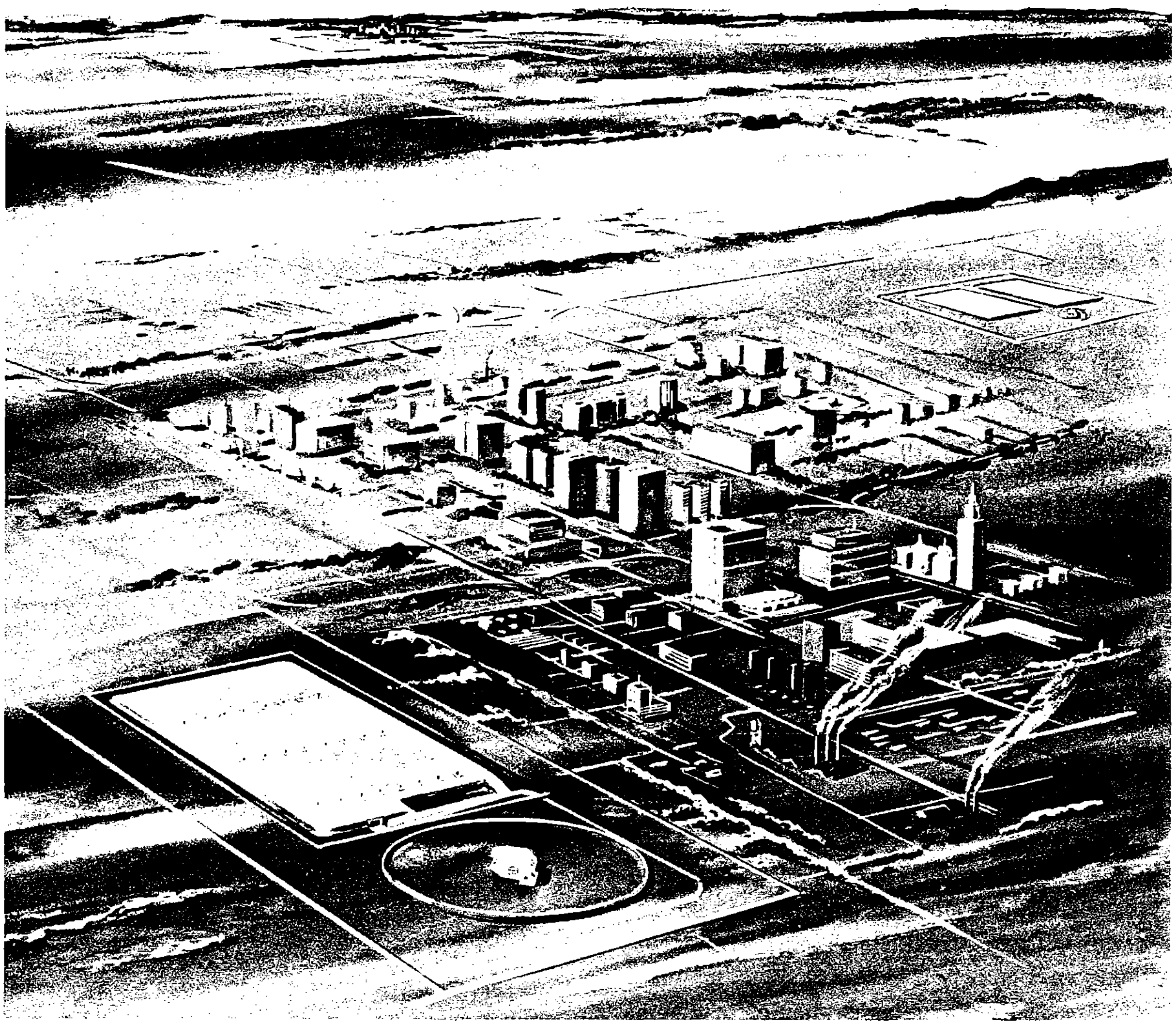

Figure 2-2. City Defense

has maximum lethality at its operational altitudes. For terminal defense of a large area, SPRINT missile farms were emplaced at various points about the defended urban center, particularly forward of the MAR.

The S-band MSR originally had two functions: missile tracking and target tracking at relatively short ranges. A missile tracker was needed at the forward SPRINT farms because the MAR would generally not have a line-of-sight to the SPRINTs at launch. The MSR could launch and guide the SPRINT to intercept, or launch and then transfer control to the MAR when the SPRINT came into the MAR's view. The MSR could track targets at relatively short range and look behind nuclear fireballs that obscured MAR coverage. Also, it could either look behind or permit triangulation on jammers, and generate additional tracks when required by traffic levels.

By mid-1964, a Small City Defense (SCD) concept was firmly established as part of NIKE-X. In this concept, the MSR role was expanded so that it was deployed either singly or in groups to provide a somewhat autonomous defense of small urban areas. The SCD also had a smaller version of the DCDPS, called a Local Data Processor (LDP). In addition to the target and missile tracking functions originally assigned to the MSR, the MSR-LDP combination carried on search, verification, and limited threat evaluation.

The ZEUS missile was included in NIKE-X whenever intercepts were required at extended ranges and high altitude. It was a somewhat modified version of the standard missile developed for NIKE-ZEUS. Although it was conceived that NIKE-X would defend concentrated urban areas and rely on close-in use of the SPRINT missile, several uses were envisioned for the ZEUS missile. Its exoatmospheric capability could "break up" a heavily cluttered attack, particularly if salvos of ZEUS missiles were launched. For attacks simpler than those expected against urban centers, such as submarine-launched missiles aimed at suburban or peripheral targets, the ZEUS missile could extend the effective coverage of a NIKE-X installation. Other potential uses for the ZEUS missile included intercept of a three-quadrant ballistic missile approaching from the south and intercept of low altitude satellites.

Operational Concept

NIKE-X was designed as a defense against a massive, sophisticated ballistic missile attack. All phases of the defense, from surveillance to missile guidance, were controlled by stored programs in the DCDPSs and LDPs. Man's role in the defense was regarded as one of augmenting and modifying system responses, once he had released the defending missiles. Although advantage would be taken of any attack that was simpler than expected (e.g., without decoys or chaff), the operational concept envisioned the decoyed, chaff-obscured attack, possibly also masked by active jammers.

The system's radars — the MAR supplemented by the MSR — would perform constant surveillance against attack from any direction, with emphasis on expected attack corridors. MAR would detect the large, chaff-obscured threat complexes, or "clouds," as they appeared above the radar horizon and start to track them. Depending on attack geometry, a track could be an individual object or a whole threat cloud.

Engagement planning would begin as soon as a threatening target was detected. The first action would be to determine the feasibility of launching ZEUS missiles. They would be launched to disperse chaff, disable jammers, disorganize or destroy decoys, and kill warheads. Any information from adjacent MARs with a side look at the threat cloud would facilitate ZEUS engagement planning. The next step would be to plan the SPRINT response. As the threat cloud entered the atmosphere, a "threat tube" would be defined. This tube would have a circular or elliptical cross section and define the envelope formed by the reentry trajectories of threatening objects in the cloud.

MAR used a "monosweep" technique to scan threat tubes and track each object separated from the chaff background by atmospheric interactions. In monosweep, a cluster of MAR receiver beams was simultaneously steered in angle and controlled in beamwidth so that the threat tube was "swept" for signal returns after each radar transmission. This technique, which used the flexibility of the Modulation Scan Array Radar (MOSAR) beamforming and steering method, produced receiver beam clusters whose width just matched the threat tube width at each range that yielded a radar return. The signal strength of objects in the threat tube was thus maximized at any given range.

As the reentering objects in the threat tube were resolved, their radar signals would be processed to estimate their weights and ballistic coefficients. SPRINT missiles would be launched to intercept threatening objects as they were identified.

Deployment

The NIKE-X system was modular, and the primary purpose of each module was to defend a single urban area. Defense components would be allocated to limit fatalities during those attacks designed to inflict maximum fatalities. Secondary deployments included locating the MARs to defend small cities and adjacent MAR modules.

Specific deployments analyzed during the NIKE-X development ranged from covering a relatively small number of cities, including no Small City Defense (SCD) modules, to furnishing essentially total city coverage, including a large number of SCD modules of various types. Each deployment could be implemented in phases to achieve the highest level of overall defense at any point in time.

Functional Capabilities of Major Subsystems

This paragraph briefly describes each major subsystem, emphasizing its role and relationship with the whole.[5]

Multifunction Array Radar (MAR)

MAR was an L-band, high-power, phased-array radar that was NIKE-X's principal sensor. It had four functions: (1) search and verification, (2) threat evaluation, (3) target track, and (4) missile track. Its multifunction capability was achieved through electronic beamforming and steering controlled by programmed data processing equipment.

The MAR had separate transmitting and receiving subsystems, with two transmitting and two receiving arrays per radar. Each set of one transmitting and one receiving array was effective over one quadrant of the radar's combined 180-degree azimuthal coverage. Each array consisted of a large number of cylindrical elements whose radiating ends formed a planar face approximately circular in shape.

The MAR could transmit signals of any of 14 different waveforms for its several functions. These waveforms varied from single CW pulses of 1 to 440 microseconds length to chirped pulses and pulse trains. The pulse trains were used for discrimination, with the most sophisticated being a sequence of 32 coherent 6.2-microsecond pulses, 12.4-microseconds apart with a 30-megahertz bandwidth. With its long search pulse, the MAR could detect small objects in a reentry complex as they crossed the radar horizon.

The MAR receiver used a technique of electronic beamforming and steering known as "modulation-scan" or MOSAR, which was described under Operational Concept above.

Missile Site Radar (MSR)

The MSR was an S-band, single beam, phased-array radar that, depending upon its defensive role, could be built with one to four phased-array

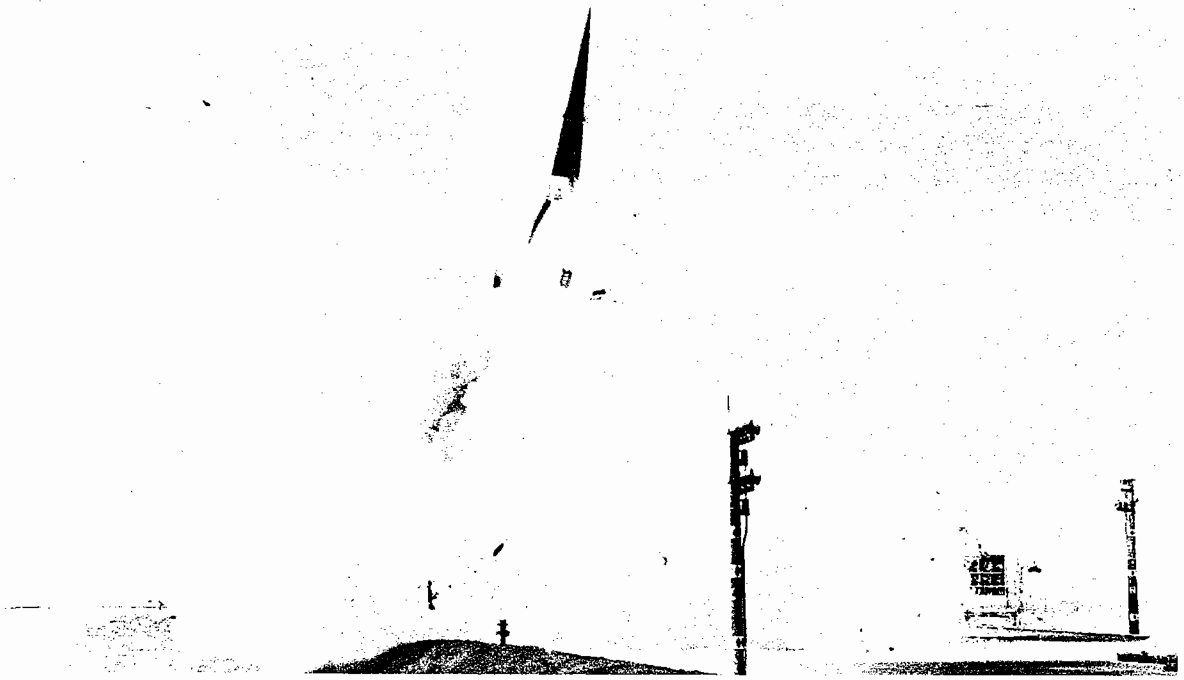

Figure 2-3. SPRINT Missile Firing

lens-type antenna faces. In all configurations, a single transmitter and receiver time-shared the face(s). The MSR could transmit or receive in one direction at a time as opposed to MAR's multifunction operation. The four-faced MSR provided 360-degree azimuthal coverage.

The MSR had four system functions: (1) search and verification, (2) target track, (3) limited threat evaluation, and (4) missile track. In the plan for Small City Defense, the MSR, along with its associated data processor, performed all four of these functions. When it was deployed as part of the MAR defense module, its role would be primarily that of target and missile tracking. The MSR could transmit any of six different waveforms, including short and long CW pulses, a chirped pulse, and a pair of pulses for threat evaluation.

SPRINT Missile

SPRINT was a two-stage, solid propellant missile designed for short-range intercepts inside the atmosphere. (See Figure 2-3.) It was intended to be guided by radio command guidance from either the MAR or MSR, but only the MSR guidance transponder was developed. Its first-stage flight was controlled in pitch and yaw by a thrust vectoring system in which liquid Freon* was injected into the booster exhaust. During second-stage flight the missile was steered by aerodynamic forces acting on air vanes. A pulsed transmitter in the missile served as an S-band or L-band beacon, depending on the ground radar.

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*Trademark of E. I. DuPont de Nemours.

The SPRINT missile was ejected vertically from an underground launch station by a gas-powered piston. After it cleared the launch cell, its first-stage motor was ignited; the second-stage motor was ignited after the first stage burned out. SPRINT was a high-acceleration, highly maneuverable missile that could intercept targets between 5 and 100 kilofeet high. A typical intercept would occur at an altitude of 40,000 feet, at a ground range of 10 nautical miles, after about 10 seconds of flight time. See Chapter 9 for a more complete description of this missile.

ZEUS Missile

ZEUS was a three-stage, solid propellant missile designed for long-range intercepts with radio command guidance from either the MAR or MSR. (See Figure 2-4.) In the atmosphere, aerodynamic forces acting on the third-stage control fins controlled steering. Outside the atmosphere, gases expelled through the same fins controlled motion. A pulsed transmitter in the missile was beacon tracked by the ground radar.

Figure 2-4. ZEUS Missile Firing

The ZEUS missile, launched from an underground station at an angle of 85 degrees from horizontal, was unguided until second-stage ignition. The first and second stages had similar characteristics and accelerated the third stage to peak velocity. The third stage carried the warhead, missile guidance set, autopilot, fin servo system, hydraulic system, and the thrust vector motor. See Chapter 1 for a more complete description of ZEUS, and Chapter 10 for a description of SPARTAN, the successor to the ZEUS missile.

A typical ZEUS missile intercept, which would take place 100 nautical miles above the tangent plane at a tangent range of about 300 nautical miles, would require a flight time of about 300 seconds. For such an intercept, aerodynamic steering would remove trajectory errors before the missile left the atmosphere. The missile would then "coast" without guidance or thrust until third-stage ignition. Controlling the third stage by thrust vector reaction would remove residual trajectory errors just before intercept. For longer range intercepts, the third-stage motor could be ignited earlier and used to increase missile range at the expense of accuracy.

Data Processor

There were two general forms of data processor in NIKE-X: the Defense Center Data Processor (DCDP) and the Local Data Processor (LDP). The difference between them was in the number of modules (processors, stores, display consoles, etc.) each contained. Because of its modular design, the data processor could be sized for its particular application at each site. Within each DCDP and LDP, the general purpose Central Logic and Control (CLC) performed the computation and central processing. Manual command and control was implemented by the Display Subsystem (DSS).

Automatic control was centered in the CLC. Computer programs, stored in program stores, controlled NIKE-X system operations as interpreted and executed by processor units. The processor units obtained input data from variable stores and stored computation results there. Processor units operated in parallel, forming a multiprocessor system in which each processor, as it became idle, was assigned a computational task, or program segment, to execute.

The DCDP used separate report processors for routine initial data processing of MAR radar returns. This wired logic preprocessing relieved the CLC of many repetitive computations on a large amount of data.

Nth COUNTRY DEFENSE STUDIES

Basic to the NIKE-X concept, as it developed during 1963 and 1964, was the idea of defending industrial and suburban centers against heavy USSR attacks during the 1970s.[4] The objective was to minimize overall damage to the country.

The cost of limiting damage against massive and sophisticated attacks was relatively high, and only part of the population was protected. From early 1965 to late 1967, increasing interest in potential "Nth Country" or "light" attacks,[5] as well as developments in nuclear warhead technology,* led to a series of studies and deployment options. The Nth Country or area defense concept evolved from those studies as a defense against light attacks, along with concepts of terminal defense,[7] including defense of strategic forces. This effort culminated in the NIKE-X I-67 deployment concept,[8] the harbinger of the SENTINEL System.

During this time, there were significant changes in equipment concepts: the PAR was conceived and its development commenced, the autonomous MSR came into being, and the ZEUS DM-15C missile was extensively modified to eventually become the SPARTAN missile.

Defense Objectives

The evolution of NIKE-X was naturally shaped by the evolution of defense objectives, which were in turn shaped by prevailing economic, political, and technological factors. Initially, the objective was to blanket the Continental United States (CONUS) with a high-altitude ZEUS-type defense, backed up at urban centers by a close-in SPRINT defense.

By the time of the I-67 deployment study, defense objectives had crystallized into two major roles, with some equipment elements supporting both:

1. By minimizing the probability of penetration, the defense was to deny damage in relatively light attacks. As the attack force grew, the defense was to minimize population fatalities. Also, modularity allowed growth from the original deployments against light attacks to a damage-limiting defense against highly sophisticated threats from any source.
2. The defense was to ensure that a significant number of the Minuteman strategic missile force would survive a USSR attack.

Threat Description

An Nth Country, lacking an extensive industrial base, could only attack the U.S. with a limited number of relatively unsophisticated ICBMs and SLBMs. It was assumed that this limitation would remain quite stable, with the significant variants being the offensive force level, RV vulnerability, and the number of SLBMs.

The NIKE-X I-67 Study assumed that up through 1980 the Chinese Peoples' Republic (CPR) threat would simply be a single large, blunt warhead accompanied by a tank and hardware pieces. Both the warhead and the tank had

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*Applicable to ZEUS or modified ZEUS missiles.

large radar cross sections, since no attempt was made to conceal either. After 1980, the CPR RVs would grow moderately in sophistication and significantly in numbers.

Although the later NIKE-X developments basically considered that the USSR threat would be directed against Minuteman forces, NIKE-X nonetheless was a factor in area defense because it had to defend the country against accidental launches of USSR ICBMs. The postulated USSR threat, although more sophisticated than the early threat, determined the eventual NIKE-X response with long-range interceptors.

Operational Concepts

At the beginning of this development period, it was considered that the modified ZEUS missile would support the terminal defense of industrial and urban centers. ZEUS missiles would disrupt "penetration aids" (decoys, chaff, etc.) and allow the MAR to gather data on RVs as early as possible.

By the mid-1960s, the emphasis was to reduce the cost of defense, so new directions for NIKE-X were evolving. At the same time, developments in warhead technology altered the earlier concepts about the modified ZEUS and gave it a significant capability for killing RV/warheads during attacks that included penetration aids. By this time the possibility of light attacks was being considered, although concern about sophisticated attacks remained dominant.

These changes in emphasis eventually led to a less powerful MAR, designated TACMAR, which could search for and track the basic NIKE-X threats at long ranges. It could react early enough for modified ZEUS to intercept threats and protect almost all of CONUS from the unsophisticated threats. Around urban centers ZEUS would be backed by SPRINT, which gave the cities two levels of defense. Because Nth Country threats involved moderate to small RVs without penetration aids, a VHF radar was required for long-range detection of these attackers, thus complementing the TACMAR.

In addition, to defend the U.S. against attacks from any direction and for terminal defense, the proposed typical NIKE-X deployments consisted of TACMARs, VHF radars, and ZEUS/SPRINT/MSR sites. (The MTR-TTR combination of ZEUS intercept was no longer required.)[7]

Next, further evaluation of these basic ideas led to the NIKE-X Deployment Study (DEPEX), which organized the defense against attack from an Nth Country and light attacks from the Soviet Union.[9] The basic objective was still to protect population and industrial centers. Particular attention was given to countering the ballistic missiles the CPR might eventually develop. The defensive deployment was to grow so it could meet the more massive and sophisticated ballistic missile threats arriving from any quarter. The DEPEX concept by and large retained the basic characteristics described above, and added a four-phase deployment sequence. The first phase was about as described in the above deployment options, but more extensive, while in the next three phases the terminal defenses grew in steps.

Increasing interest in very light deployments, at least during the initial stage of deployment, led to the DEPEX "Phase 0," which, for the most part, used modified ZEUS missiles, VHF radars, MSRs, and a few SPRINTs.[9] In addition, system studies showed that somewhat higher frequencies for the long-range search radars would strike the most cost-effective balance between susceptibility to nuclear effects and the long-range detection and track of objects with small radar cross sections. Concurrently, interest in defending the Strategic Offensive Forces became stronger.

This concept embodied the objective of denying damage to an early CPR attack and provided a moderate high-level terminal defense for Minuteman forces.[8] It also allowed for growth to heavy terminal defense.

By this time, the needed long-range characteristics were embodied in a new UHF radar called PAR. The design of the modified ZEUS was stabilized and the missile was renamed SPARTAN.

The I-67 deployment used a few PARs, moderate numbers of MSRs, and many SPARTANs and SPRINTs. The MSR and SPRINT missile system defended the Minuteman bases and were also collocated with each PAR site. The remaining MSRs and SPARTANs were strategically located throughout CONUS.

In this system, PARs carried out long-range surveillance and target tracking. In area defense, SPARTAN served as the primary interceptor, tracked and guided by the MSR. SPRINTs were to be used only to defend PARs, urban areas near the PARs, and Minuteman silos.

Generally, targets would be detected first by the PARs. After they were tracked for some seconds, their trajectories and impact points would be determined and the defense battery would be designated. In SPARTAN engagements, information on target intercept would be continually refined and passed to the Missile Defense Center battery assigned the engagement. This battery would launch and guide interceptors to the appropriate point. The concept was a good cost-effective balance between radars (PAR), radar resources (tracking requirements), and lethal effects from the large-yield SPARTAN warhead.

I-67 deployment concepts represented the first real effort to set up a nationwide ABM command and control system and set forth the functional logic of a defensive engagement. The PAR would operate somewhat independently, with built-in rules governing normal search assignment, detection, verification, and track initialization. The MSR was more closely coordinated (between MSRs) within a Missile Defense Center region. In fact, one facet of NIKE-X at this point was the increasing degree of intersite netting that furnished CONUS-wide coverage with a few search radars.

With minor modifications, the I-67 deployment and its operating concept led directly to SENTINEL and later to SAFEGUARD, as discussed in Chapters 3 and 4, respectively. Many SAFEGUARD features and characteristics had their origin in the I-67 deployment concept of NIKE-X, which marked a fundamental milestone in the evolution of SAFEGUARD.

Modified SPARTAN

Between 1968 and 1971, there were extensive studies of improving the SPARTAN interceptor in its assigned role and in a role against more sophisticated attacks.[10] This effort is mentioned here because it falls into the studies associated with area defense.

The study explored the utility of a high-performance (higher than SPARTAN), long-range, exo- and endoatmospheric interceptor that would significantly reduce the number of MSR/missile sites required to defend CONUS. New tactics and advanced intercept concepts were also studied. However, cost-effectiveness considerations terminated the effort in 1971.

DEFENSE OF STRATEGIC FORCES— TERMINAL HARDSITE DEFENSE

Between 1963 and 1969, Bell Laboratories postulated several systems for defending hardened U.S. ICBM sites. The systems evolved in response to specifications of the threat and trial deployments, and they were examined from the standpoint of cost, component availability, and effectiveness in achieving objectives.

The primary objective of hardsite defense was to deter enemy attacks on the U.S. strategic ICBM offensive force. If deterrence failed, the defense was to save enough Minuteman boosters that the U.S. could carry out its post-attack policy. The defense was to be effective against an advanced-technology threat including penetration aids. Existing technology and components were to be used in the proposed deployments as fully as possible.

One of the first two hardsite systems proposed was designed to protect sites in urban areas;[1] the other to defend sites at remote locations. A hardened site could be a command and communication facility at a SAC base or a cluster of ICBM silos. In a later study, only hardened silos having the Titan II and Minuteman forces and the hardened defense elements were to be defended.[2] In this work other contractors' schemes were also reviewed. They ranged from area/terminal defenses similar to the Bell Laboratories concept to proposals for the autonomous defense of each silo (called "hardpoint" defense).

The last major Bell Laboratories study of hardsite systems resulted in the proposed movable radar, or Virtual Radar Defense (VIRADE) system, which furnished extended terminal coverage through radar netting.[11] In this approach, the radar antenna and transmitter would be transported by rail and moved frequently among a large number of hardened radar sites. VIRADE was an alternative to fixed radars and was intended to increase the radar attack price. It recognized the practical limits and cost of increasing radar hardness, introducing redundancy, or using decoy radars to force the attacker to increase the "throw weight" of his offensive missiles.

Each hardsite study indicated that MSR technology would be adequate, and each study increased the radar hardness levels. Early in these studies it was recognized that both data processing and hardsite requirements for radar netting and resource allocation would be complex. Computers would have to use faster circuitry and different organizational schemes to achieve the required throughput. The interceptor proposed for each system was the SPRINT. Interceptors with improved performance would counter a more sophisticated attacking vehicle, which could maneuver to increase its chances of penetrating the NIKE-X defenses.[12]

The defense system design took into account uncertainties faced by the attacker. These uncertainties were caused by the disturbed environment created by his warhead bursts, target vulnerability, and the presence of an active defense. Defense parameters that affected system requirements included sure-safe and sure-kill hardness levels for radars and silos, single-shot warhead kill probabilities, peak traffic rates, and the attacker's targeting doctrine. From these considerations and knowledge of the Soviet ICBM force, a threat was specified. The ICBM force was sized, assumptions were made about Multiple Independently Targeted RVs (MIRVs), only high weight-to-drag RVs were included, and trajectory geometries were bounded. The attacker's payload was estimated, his booster availability/reliability was computed, and his warhead yield and vulnerability to interceptor bursts were estimated.

The threat was enhanced by penetration aids which included tank fragments, precursor bursts, chaff clouds, traffic decoys, ECM, and maneuvering RVs. Many possible ways to distinguish warheads from penetration aids were considered, and many were found unsuitable.[13]

PARALLEL ELEMENT PROCESSING ENSEMBLE

As studies of ballistic missile defense systems progressed, the postulated threats expanded greatly in terms of the number of objects arriving simultaneously and the sophistication of the penetration aids. This increase in threat influenced ABM design and especially increased the estimate of throughput needed for ABM data processors.

In response, a new concept of architecture for the ABM data processor was suggested.[14]

Because a large part of the processing associated with radar tracking and discrimination required that the same set of algorithms be repeatedly applied to each object, parallel elements might carry on the processing. In 1964, research began on a content-addressable memory invented by Lee and Paull of Bell Laboratories. This memory offered an approach to the needed parallel processing, and a follow-on development program supported by the Advanced Ballistic Missile Defense Agency (ABMDA) led to the Parallel Element Processing Ensemble (PEPE) concept.

PEPE was a programmable, special-purpose computing machine that augmented conventional sequential computing in ABM data processing. Processing capacity was largely independent of traffic because an independent parallel element was assigned to each object in track. Each parallel element was, in fact, a small digital computer, with an arithmetic unit and memory. In addition, each contained a special-purpose input unit called a "correlator," which associated radar replies with the appropriate track by simultaneously comparing each radar reply with predicted track positions. Most of the control circuitry was in an ensemble control unit, which was connected in turn to a more conventional "host" sequential digital computer. The host computer stored instructions for the parallel ensemble, sequenced through them, and passed them to the ensemble control unit. The host computer also did the processing that could be most effeciently handled by a sequential computer.[15]

By the mid-1960s, a study was under way to adapt PEPE to ABM. The intent was to realistically assess feasibility and cost factors. Several studies were launched, primarily in the areas of software development and testing.

Hardware Feasibility

Using readily available components, a processor with 16 elements was built with integrated circuits and tested with an IBM 360/65 as a host computer. This "IC Model" of PEPE was used in the demonstration tests discussed below. A study which showed the feasibility of using more advanced large-scale integrated circuits in PEPE was completed toward the end of the development project.[16]

Software Development

Since the job to be done by parallel processing elements would be done the same way by a sequential computer, similar programming methods could be used. A parallel version of FORTRAN, P-FOR, became PEPE's basic programming language. P-FOR was supported by a compiler and an assembler to convert programs into machine code. Also, programs could be written for input to the assembler using PAL, the Parallel Assembly Language.

The language and software system were available well before any hardware so that programs could be tested by simulation. The P44 precompiler converted each operation on parallel data in a P-FOR program into a DO loop on an array in a standard FORTRAN program. The FORTRAN program could be readily tested on any machine with FORTRAN capability.

In addition to P44, which tested P-FOR programs at the source level, the Parallel ABM System Simulation (PASS) simulated operation at the machine level. PASS Tests I to IV, each testing a broader system, were planned. PASS I and II demonstrated PEPE's capability for basic ABM processing and were completed. PASS III and IV were replaced by tests defined by ABMDA, as noted below.

Application Studies

To identify problems and evaluate the advantages of PEPE, several specific applications were studied:[17]

- SAFEGUARD. Routines planned for SAFEGUARD as developed in NIKE-X simulations were converted to parallel form in PASS I and II.[18]

- VIRADE. As discussed previously under Defense of Strategic Forces, the VIRADE concept added the problems of changing sites to the basic ABM problems.[19]
- ABMDA defined tests. For a final evaluation of PEPE as part of the Bell Laboratories development program, ABMDA defined two systems: Zero Order Software (ZOS) and Preliminary Hardsite Defense (PHSD). These replaced PASS III and IV. The final PHSD demonstration was against a threat defined by General Research Corporation and transmitted to Bell Laboratories by data link from Santa Barbara, California in interrupted real time. The PEPE system used in this test was the 16-element IC model supplemented by sequential simulation, and it achieved essentially all the test objectives.[20]

Lessons Learned

- The ability of PEPE to carry a large, constantly growing portion of SAFEGUARD data processing was established. The threat level defined for the current SAFEGUARD System did not make PEPE cost effective. Its cost effectiveness would have to be established for a given threat, for a given ABM system, and with the current state of the processor art considered.
- The feasibility of increasing system capability by removing processing from a sequential computer and assigning it to a parallel processor was established.
- The high level language, P-FOR, was found to be a powerful tool in rapidly programming a complex system.

REENTRY MEASUREMENTS PROGRAMS A, B, AND C

The NIKE-X Reentry Measurements Program (RMP), which spanned the interval from 1960 to 1970, had the objective of developing discriminants for conical RVs. The program used a straightforward phenomenological approach, with tabulated comparisons of radar observable characteristics as functions of vehicle size, shape, and ablator material.

To complete the program, a broad spectrum of targets was observed by the radar, optical, and infrared sensors[21] at the Eastern Test Range (ETR), Kwajalein Test Site (KTS),[22,23] and White Sands Missile Range (WSMR).[24] Most of the RMP flights were full-scale reentry tests flown into the Kwajalein Test Range. The NIKE-X program supplied many of the unique targets. Other targets came from the Air Force Advanced Ballistic Reentry Systems (ABRES) Studies, SAC Evaluation Missions, and the Navy Polaris Program.

The RMP general test requirements were coordinated through the Tri-Agency Technical Coordination and Operations Group (TATCOG), an Army, Navy, and Air Force committee that set test objectives and planned coordination. The responsibilities and contributions of the various RMP groups were divided as follows:

1. Bell Laboratories. Specified program objectives, reentry hardware performance requirements, and target delivery (trajectory and deployment) requirements. Operated the NIKE radar sensors and EC121 optical aircraft. Reduced and analyzed collected data.
2. Army. Procured target vehicles and delivery systems through the Air Force. Coordinated test requirements, program objectives, and schedules. Provided the Kwajalein Test Range support. Coordinated interservice data exchanges.
3. Air Force. Provided the reentry hardware, booster systems, and the ETR facilities; i.e., delivered targets to KTS. Exchanged technical data and coordinated their reentry study program, ABRES, to support mutual-interest missions.
4. Navy. Cooperated in providing SLBM targets. Coordinated mission planning and data exchange.
5. Lincoln Laboratory. Supplied technical consultation and coordinated design of reentry experiments and data analysis exchange. Operated additional sensors (data sources) of the PRESS facilities at KTS.

Test Objectives

The RMP was divided into several significant phases. Initially, from 1960 to 1964, the NIKE-X Field Measurement Program (FMP)[22,25,26] developed sensor techniques and discrimination technology. The prime objectives developed then, which were changed very little in the follow-on RMP, were to determine:

- The observables associated with various targets, which would define the sensor techniques for obtaining adequate discrimination measurements
- The relationship between various target types and sensor measurements to define effective discrimination techniques.[27]

From approximately 1964 through 1966, the experiments labeled RMP-A [23,26,28] were concerned with the class of material used in RVs.[22,23] The primary objective was to search for and evaluate discriminants.[29]

The RMP-B program (1966-1970) [23,28] sought to establish basic theoretical understanding of reentry phenomena so that experimental measurements and discrimination techniques could be extrapolated to other possible threat sizes and variations.[30–32] Another area of RMP-B was the qualitative confirmation, through on-board instrumentation,[33] of basic reentry phenomena that could not be measured from the ground.

RMP-C was to consider advanced RVs. Before the target requirements were specified, the program was terminated about 1970.

Target Vehicle Summary

The RMP used a series of reentry measurements vehicles, tactical offensive weapons with penetration aids, and vehicles developed for future offensive weapons.[34] The Reentry Measurements Vehicles (RMVs) were uniquely developed for the RMP.

Missions and Data Reports

Bell Laboratories issued a Target Measurements Report (TMR) on each reentry measurement mission. These documents briefly summarized the operation and outlined pertinent factual information. Data available for continued analysis were listed, and plots, photographs, and available reentry identification information were included. The TMR data reports are available at the Reentry Data Facility at Calspan Corporation, Buffalo, N. Y., a data repository maintained by the Army.

MULTIFUNCTION ARRAY RADARS

The MAR-I Program

In the early stages of NIKE-X, 1963-1964, the Multifunction Array Radar (MAR) was foremost among the relatively new radar concepts. This radar was to be the major NIKE-X sensor, able to perform in many operational modes in a high-traffic environment and to carry out endo- and exoatmospheric engagements. The MAR's principal task was to form and steer the multibeam clusters that would perform the radar missions of search, track, discrimination, and guidance.[35]

By that time, studies of phased array radars had progressed to the point where the fundamentals of their antennas and beamforming were well understood. A number of arrays had been built to demonstrate some of their basic capabilities. Prior to MAR, however, these sensors had been designed for a single function, principally that of target acquisition and tracking.

By 1963 the NIKE-X program had reaped substantial benefits from two experimental linear arrays, one employing the time delay steering proposed by Sylvania, the other using a novel modulation scanning technique developed by the General Electric Company.[36] Early tests of these two arrays formed a technical base from which a complete array radar feasibility effort was launched. This radar complex was identified as MAR-I. The design, construction, installation, and testing of MAR-I took place in the 1961-65 time period. A close-up view of the installation at WSMR is shown in Figure 2-5.

Development tests of the radar, scheduled into 1965, determined how well the equipment met design objectives and furnished data for design improvements to the NIKE-X tactical model (MAR-II) planned for installation at Kwajalein. The development program included extensive antenna pattern measurements and beam stability checks to evaluate the

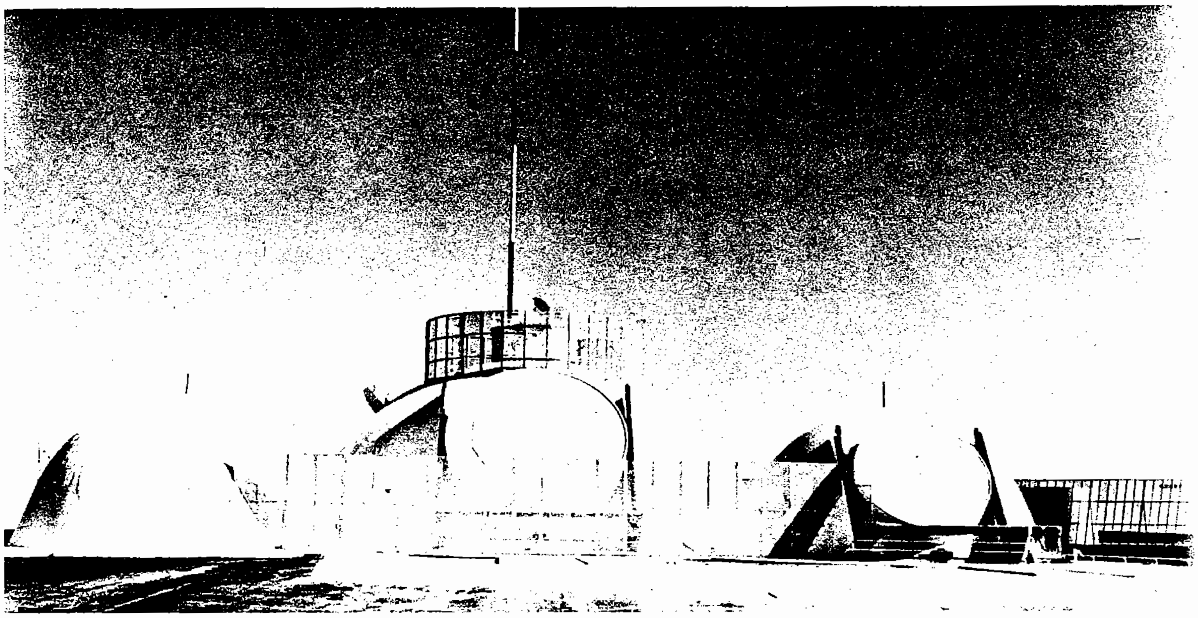


Figure 2-5.' Close-up View of MAR-I at White Sands Missile Range

beamforming and steering concepts. Dynamic tracking accuracy and multiple beam operation tests were also included.

Major contractors and their responsibilities were:

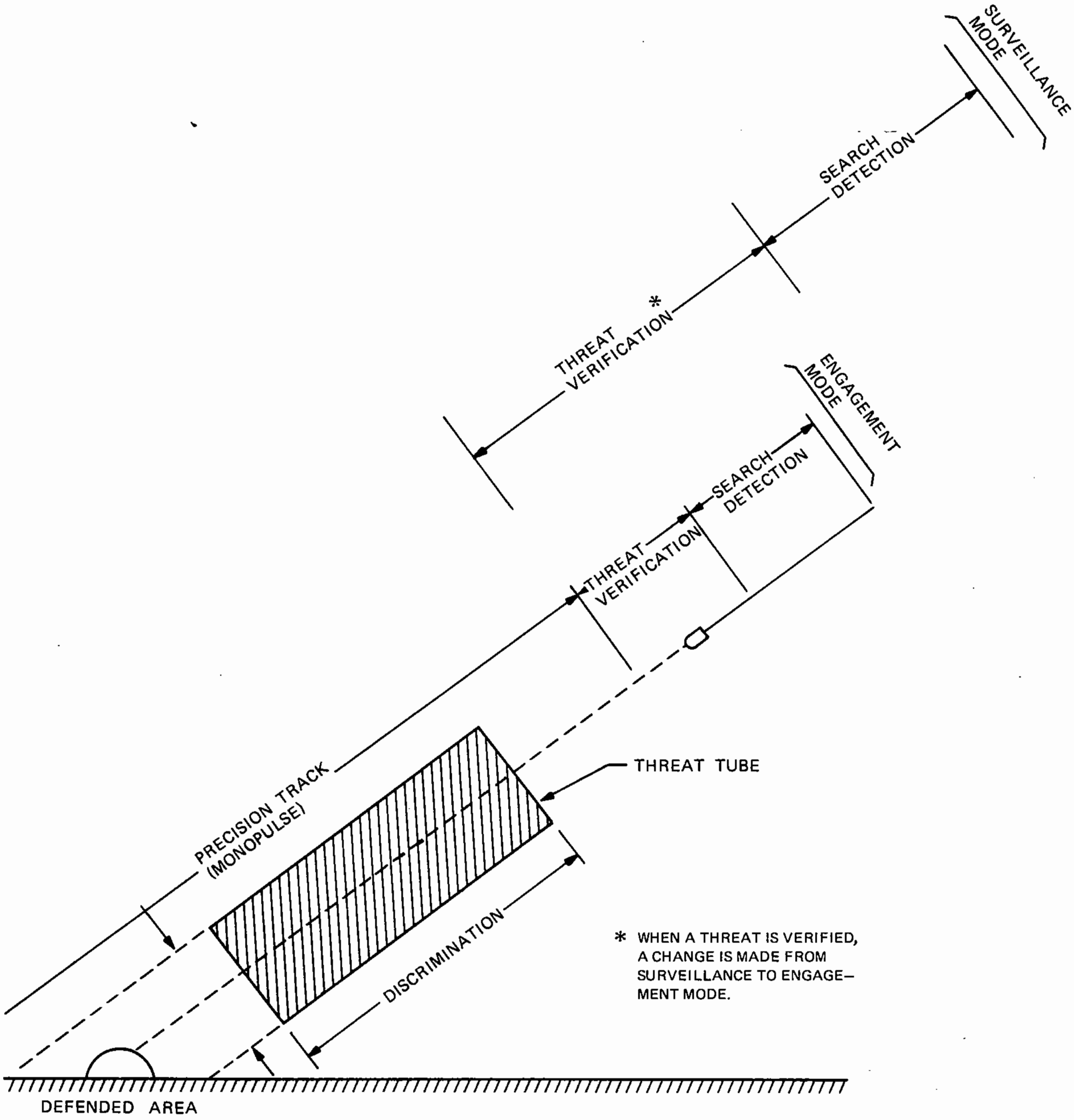
1. Western Electric. Acted as prime contractor for the MAR-I project under contract DA-30-069-AMC-333(Y).
2. Bell Laboratories. Held overall responsibility for project management, including design, development, building construction, test site operation, and system evaluation.
3. Sylvania Electronic Systems, East Waltham, Mass. Developed a multifunction array radar by designing, constructing, installing, and testing MAR-I electronic equipment.
4. Sperry Rand Univac, St. Paul, Minn. Designed the MAR-I Phase II digital computer, the associated Control Switch and Buffer (CSB), and the computer programming.

Western Electric and Bell Laboratories also designed and constructed some of the MAR-I equipment.

Functional Capabilities

The MAR-I at White Sands was designed to perform the functions shown in Figure 2-6 and to demonstrate fully automatic operation.[35] Manual override and a full manual capability were included to allow flexibility in testing. A tactical system would operate in two modes: surveillance (the normal mode) and engagement (which began after a target had been detected and classified as a threat to the defended area). The automatic elimination of targets as non-threatening, based on impact predictions or discrimination, was never implemented in this radar.

In the surveillance mode, the system performed two functions: search (and detection) and verification tracking. In the engagement mode, the system performed four functions: search (and detection), verification tracking, precision tracking, and discrimination sensing. Except when restricted by the operator, MAR-I automatically carried out verification tracking assignments on all targets detected in the search beam.



* WHEN A THREAT IS VERIFIED, A CHANGE IS MADE FROM SURVEILLANCE TO ENGAGEMENT MODE.

Figure 2-6. MAR Functional Capabilities

After verification, a precision tracker was assigned to threats and used the target position estimates generated by the verification tracker. Except for a coded pulse that increased range resolution, precision tracking was essentially the same as verification tracking. A sub-beam cluster, positioned either automatically or manually to cover a threat tube, obtained discrimination data. Threat tubes were cylindrical volumes whose axes were parallel to the velocity vector of the target. A Coherent Signal Processing System (CSPS) for acquiring discrimination data was developed but never installed in MAR-I. It was added to the Discrimination Radar (DR) at Kwajalein to support the Reentry Measurements Program (RMP).

System Description

Operational Concept

MAR-I operations reflected the two modes, surveillance and engagement, in which a tactical system would function.[35] In the surveillance mode, the radar beam scanned the total coverage volume in less than 20 seconds. When a target was detected, the radar returns were examined automatically to extract target position and range rate (radial velocity) data. A verification track on the target began when the range rate and position predictions satisfied preselected criteria for range velocity and track initiation volume. Search scanning continued independently of the other functions.

An operator could overrule the automatic function to initiate verification tracking manually on a target of his choice. In either case, the successful verification of a threat changed the mode from surveillance to engagement. In the engagement mode, search and verification tracking continued at a faster search scan rate. In addition, the precision tracking and discrimination functions became available.

Discrimination data were obtained by either manually or automatically positioning the radar coverage of a threat tube. Each threat tube was divided into subtubes, each formed by a separate radar beam. The widths and center-to-center spacings of the beams were controlled as functions of range to provide constant-volume coverage independent of range. The discrimination transmitter beam was a single beam broadened to illuminate the entire threat tube.

A precision tracker was assigned and given target position estimates from the verification tracker. Verification tracking was thus a prerequisite for precision tracking and terminated after the precision tracker locked on the target. Except for a pulse-compression waveform that increased range resolution, the two track processes were essentially the same.

MAR-I was divided into ten major subsystems, as shown in Figure 2-7. They are briefly described below.[36]

Transmitter Antenna

The transmitter antenna consisted of active elements forming a circular planar array, with elements arranged as the vertices of equilateral triangles. Each element was fed by an individual power amplifier in the transmitter. The transmitter array was housed in a concrete dome structure so that the array normal was elevated 38.5 degrees above horizontal. MAR-I had one transmitter array.

Receiver Antenna

The receiver antenna consisted of elements in a circular array, each element followed by a low noise preamplifier which was part of the receiver. MAR-I had one receiver array.

Transmitter

The final power amplifiers were specially-designed high-gain traveling-wave tubes. Delay matrices consisting of switching diodes and strip lines performed beamforming and steering. Search, track, and discrimination pulses at different frequencies were transmitted in a single pulse chain.

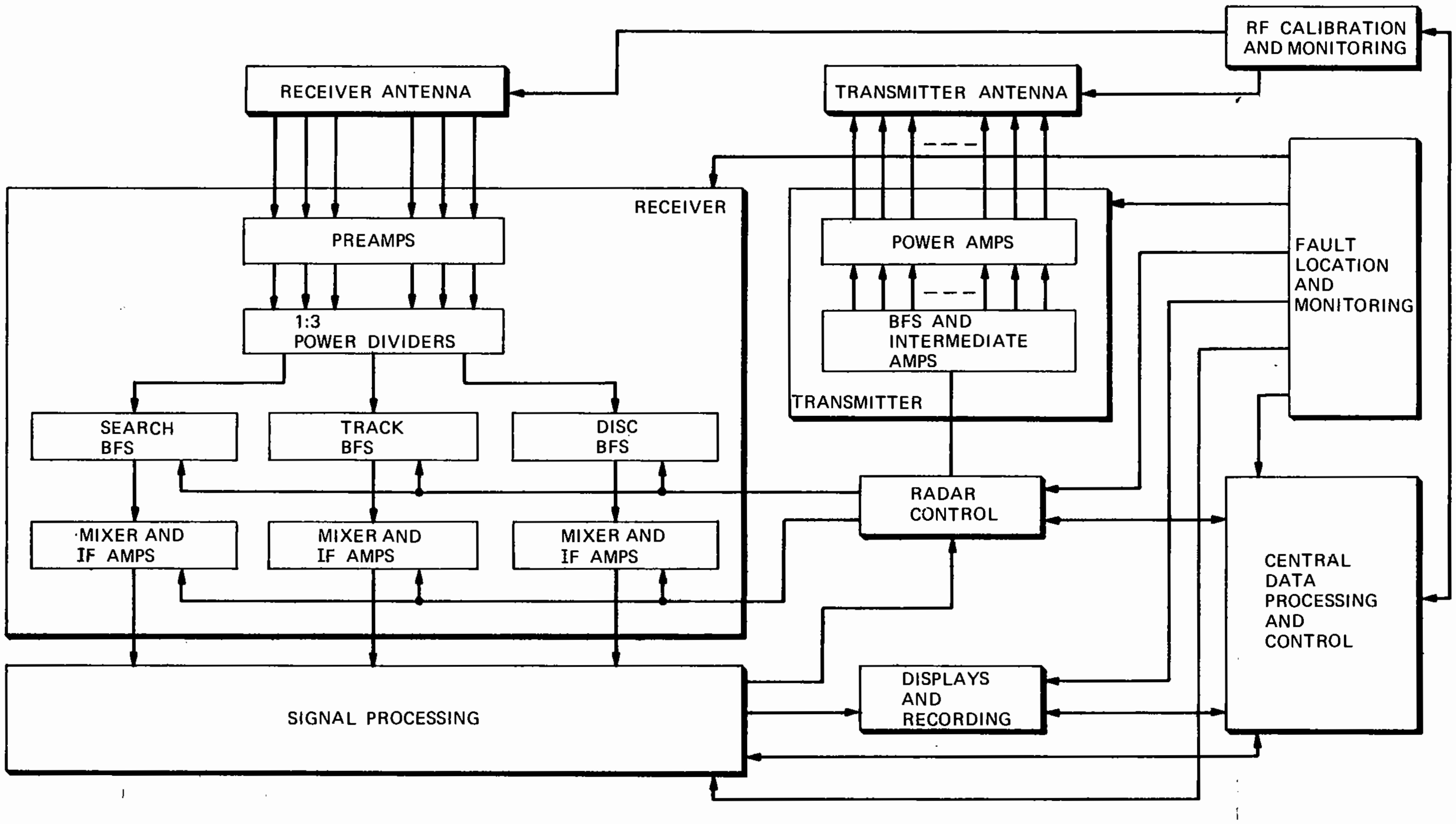


Figure 2-7. MAR-I Functional Block Diagram

Receiver

The receiver operated on three separate channels, one each for the search, track, and discrimination functions. Each channel had its own beamforming and steering circuits and its own unique beam and cluster configuration. The incoming signals from the antenna elements were fed through individual preamplifiers to power dividers which provided signals to the three channels. After beamforming and steering, the three mixing circuits (search, track, and discrimination) converted the RF signals to IF signals at different frequencies. These signals were then amplified in the IF amplifiers and sent to signal processing.

Signal Processing

Signals were processed in two basic units: the Search Signal Processor (SSP) and the Video Pulse Converter (VPC). The SSP indicated initial target detection and determined range, range rate (by doppler shift), and angular position. These parameters were fed to displays, recorders, and central data processing and control.

The VPC processed the outputs of the receiver track detectors and video amplifiers, converted the desired information to digital form, and converted search and discrimination video to digital form for test purposes. The pulse-compression networks for the precision track and discrimination functions were part of the signal processing subsystem.

Radar Control

Radar control, under instructions from central data processing and control, coordinated and controlled some of the activities of MAR-I. It generated and selected local oscillator frequencies and modulation parameters and controlled the beamforming and steering networks.

Displays and Recording

Operators at display consoles monitored system operations and performed some MAR-I functions which would have been automatic in a tactical MAR. The MAR-I display and recording subsystem had four operator positions, which monitored and reported on system status, controlled search and track assignments, positioned the discrimination cluster for sub-beam selection, and controlled recording.

Fault Location and Monitoring

MAR-I used a Fault Location and Monitoring (FLAM) subsystem for more efficient maintenance and to minimize down time. The subsystem monitored the system to detect faults, indicated the existence and rack location of each detected fault, and automatically recorded fault occurrences.

RF Calibration and Monitoring

The RF calibration and monitoring subsystem measured the overall amplitude and phase transfer characteristics of individual channels in the phased array. Various routines were measured for all combinations of input channels and beam outputs, and faulty components were located by these measurements. In most cases measurements did not interfere with normal operations. In the transmitter, the transmitted search pulses were used for monitoring; in the receiver, a calibration pulse was inserted during ranging dead time just before the next transmitted pulse.

Central Data Processing and Control

The Central Data Processing (CDP) and Control Subsystem had three basic units: Control Switch and Buffer (CSB), Tape Buffer System (TBS), and General Purpose Digital Computer (GPDC). The CDP sorted and routed all data flowing between the GPDC and the other units of MAR-I and also performed system timing.

The TBS served as a buffer memory between the GPDC and input/output devices. Output devices were magnetic tape units, flexwriters, and a high-speed line printer. The former two units were also used as input devices.

The GPDC processed large quantities of real-time data, and the computer operated in the fixed-point parallel binary mode with a 24-bit word format. Instructions were single address with a minimum execution time of 2.5 microseconds.

Multifunction Array Radar (MAR-II)

As discussed earlier in this chapter, NIKE-X was to be an autonomous system capable of fully-automatic, instantaneous, and effective response to a wide variety of offensive tactics and intensities of ballistic missile attack. Its main radar was to be the MAR. The MAR combined search, verification track, discrimination, precision track, and defensive missile track and guidance into a single phased array operating at L-band.

By mid-1967, the ABM defense objectives of NIKE-X were directed to defending CONUS against light attacks. This shift from local defense against high-traffic, sophisticated penetration-aided attacks culminated in a decision to concentrate on the lower cost autonomous MSR as the primary terminal defense sensor. On this decision the development of MAR and its Kwajalein prototype (MAR-II) was terminated.

Initially, it was planned that NIKE-X would be tested at the Kwajalein Missile Range and involve two phased-array radars: the MSR and the MAR.[37] The latter was to have reduced capability, but could be retrofitted to full MAR capability later. The Kwajalein version of the MAR, designated MAR-II, was to be a single-faced (single transmitting antenna array and single receiving antenna array) radar.

To retrofit MAR-II with minimum down time, all of its transmitter and receiver elements and associated cabling would be installed initially. To reach full MAR capability, the additional transmitting and receiving hardware, waveform generation equipment, signal processors, etc., would be installed, checked, and then connected to the antenna elements.

TACMAR

Originally, two versions of the MAR were to be used in NIKE-X. The MAR was to be a higher powered radar, with a full complement of transmitting and receiving antenna elements. The second version, TACMAR,[5,38] had only half as many active antenna elements as MAR for both transmitting and receiving. TACMAR thus had approximately half the power output, lower receiver performance, and a proportionately lower range. It could produce fewer waveforms and therefore had a reduced discrimination capability. This radar was designed to be cost effective in the less demanding defense against an early, relatively unsophisticated threat. It was to be used for high-confidence, early detection of ensemble attacks, for detecting RVs with small radar cross sections at intermediate ranges, and for supporting ZEUS area defense and SPRINT local defense.[9] If the need developed, TACMAR could be augmented to full MAR capability.

MAR/TACMAR Subsystems

MAR and TACMAR were divided into six major subsystems, as shown in Figure 2-8. They are briefly described below.[5,38]

Antennas

In TACMAR, each of the two transmitting antenna arrays contained active elements arranged in a concentric hexagonal configuration with one element in the center. In addition, passive elements were mounted in the array face so that TACMAR could later be augmented to a full MAR.

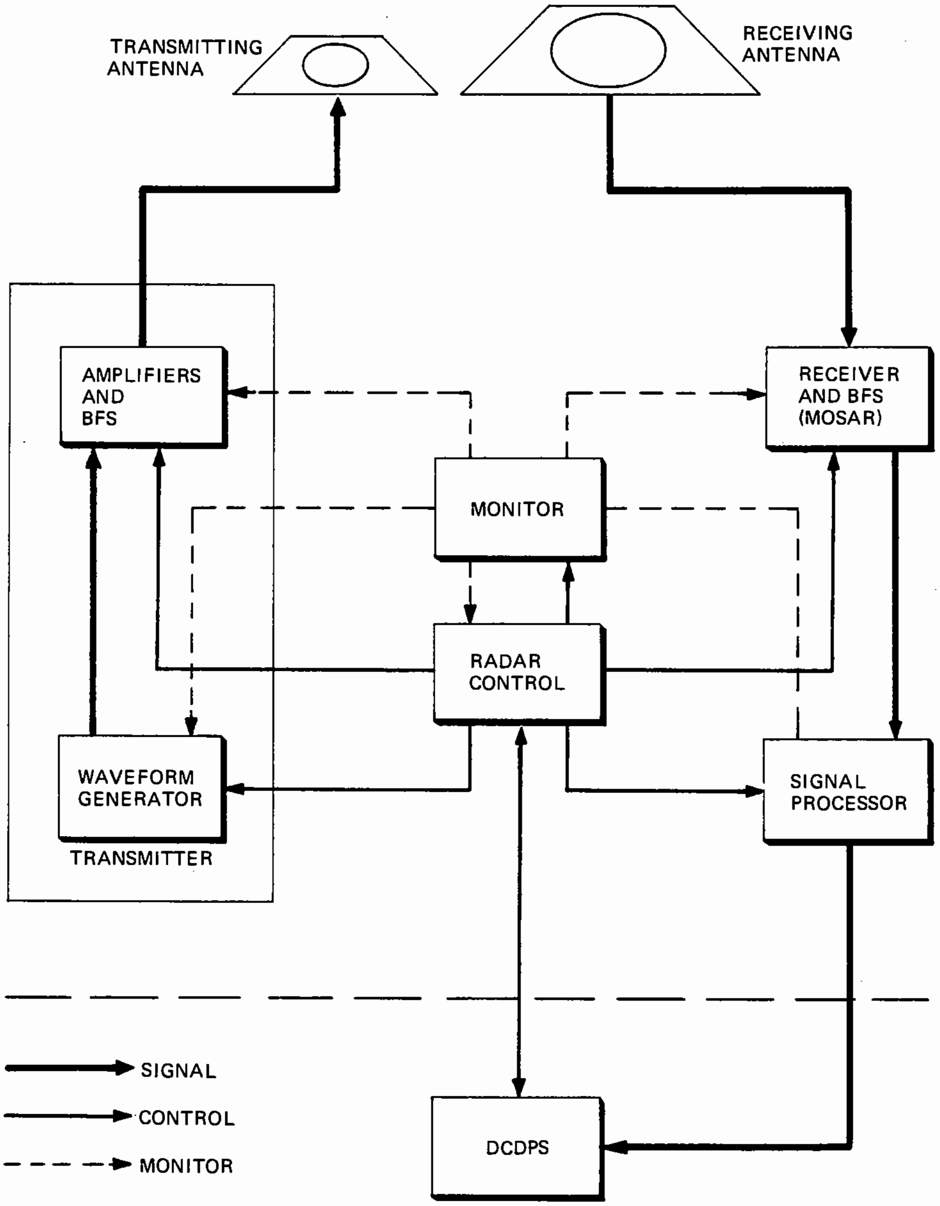


Figure 2-8. TACMAR Block Diagram

Transmitter

The transmitter chain generated and radiated high-power pulses and pulse trains with the correct waveforms for various radar functions. Real-time delay boards, with diode bit switches directed by radar control, formed and steered beams. After high-power amplification by traveling wave tubes, the signal went to the transmitting elements through an RF face selection switch.

Receiver

The output of each element of the receiving antenna array was connected to a preamplifier module. The module had a transistor amplifier, level control attenuators, a second transistor amplifier stage, and a phase equalizer unit. The output of the module was connected to the Beamforming and Steering (BFS) equipment which was of the fan-multiplex MOSAR type. The BFS circuits steered the multiple beams formed by the receiver. These circuits had an output for each of the 40 discrimination beams (nine of which formed the search cluster) and the three monopulse track beams. Digital inputs from radar control controlled the BFS equipment. The local oscillator signals, which were used in the mixers to reduce the received L-band signals to intermediate frequency, were formed in the exciter-stalo.

The input module of the BFS section included the face switch directed by radar control to switch receiver operation to either antenna-preamplifier face. The received signal output from the BFS section went to the signal processor.

Signal Processor

The signal processor accepted outputs from the receiver and converted them to forms for the radar function that the Defense Center Data Processing System (DCDPS) was analyzing. The signal processor also accepted pulses from the missile beacon and identified or rejected spurious signals introduced by noise, countermeasures, or sidelobes.

Radar Control

Radar control provided communications between the MAR and DCDPS. It executed DCDPS's Central Logic and Control (CLC) orders concerning pulse selection, transmitter and receiver BFS equipment, frequency selection, and power levels. Radar control furnished timing information to the subsystem elements and accepted fault location information, which it relayed to the monitor.

Monitor

The monitor detected system degradation, calibration drifts, or failures that required replacement of a unit. Also, if the failed unit was a critical item, the monitor took corrective action by switching in a redundant unit. System degradation was reported via displays and printouts. The monitor had two major parts: RF Calibration and Monitoring (RFCM) and Fault Location and Recording (FLAR).

Conclusion

By mid-1967, the ABM defense objectives of NIKE-X were directed to the area defense of CONUS against light attacks. This shift from local defense against high-traffic, sophisticated penetration-aided attacks culminated in a decision to concentrate on the lower cost, autonomous MSR as the primary radar for terminal defense. Hence, the development efforts on MAR, the Kwajalein prototype (MAR-II), and TACMAR were terminated.

As stated earlier, the fundamentals of phased-array antennas and beamforming were well understood when MAR-I was conceived, and the only real question concerned the application of phased arrays to a multiplicity of simultaneous functions. Thus, the paramount lesson learned from MAR-I was that the program verified the analytical predictability of array performance in a multifunction role.

Of equal, if not greater, importance was identifying the significant problems that resulted from attempting to verify hardware and software on site, with an operational system, without the support of either a hardware or software testbed. This was especially apparent with the array hardware. Unit level tests of either single elements or a small sampling of elements with their associated hardware appeared to be trouble-free. However, when these tests were integrated into the complete system consisting of thousands of elements with their associated signal and power cabling, adverse interactions occurred. A hardware testbed for simulating the physical and electrical characteristics of a full array might have averted the problem. Software testing presented a similar problem, since development and test were done by computer simulations of the expected data processor-radar hardware interface. A software testbed that duplicated the interfaces would no doubt have uncovered most of the problems with the on-site software installation. Partly because of this MAR-I experience, the Tactical Software Control Site (TSCS) concept was adopted for SAFEGUARD. TSCS called for the development, integration, and evaluation of tactical software in a testbed that duplicated the on-site data processors and radar interface hardware.

GUARDIAN (FORMERLY CAMAR) PROGRAM

During the mid-1960s, measurements taken by field radars on reentering bodies had shown an enormous growth in both quantity and sophistication. This information strongly stimulated research in discrimination techniques. Despite vigorous efforts to develop a better theoretical understanding of the fundamental phenomena involved in reentry, the physics of it remained largely an empirical science. By 1968 the success of discrimination research created the need to construct a real-time discrimination capability and to demonstrate its effectiveness in a realistic traffic environment. To demonstrate discrimination capability required a radar and data-processing facility that could perform a variety of interactive functions. It was not sufficient merely to implement, in real time, the simple target-oriented discrimination techniques that were successful in post-flight data analyses, because a credible ABM discrimination depends on a sequence of interrelated events, such as,

- Determining the bounds of the threatening complex to predict the bounds and location of threat tubes to be searched for RVs
- The automatic techniques which acquire and track objects as they emerge from tank breakup clutter or chaff clouds
- The ability to cope with large numbers of traffic decoys and deployment hardware, so that the more likely RV objects can be identified and scheduled for sophisticated discrimination processing
- The ability to maintain track reliability in the presence of crossing targets and nuclear perturbations
- Applying the sophisticated discrimination waveforms and associated signal processing to finally discriminate the RVs
- Real-time management of site resources (radar, data processing, and missile stockpile) to effectively allocate them in the presence of traffic overloads.

A program (initially labeled CAMAR, for Common Aperture Multifunction Array Radar, and renamed GUARDIAN) was started to identify the needs of the ABM community and significantly advance understanding in these areas of the discrimination system problem.

Program Objectives

The intent of the GUARDIAN (CAMAR) program was to produce the technological base and experience from which an urban terminal or hardsite defense system could be developed. The program involved the development and implementation of a system testbed facility at Bell Laboratories, Whippany, and a radar and data processor at Kwajalein that could search, track, discriminate, and intercept actual penetration-aided threats.

GUARDIAN's basic thesis was that the various ABM system functions could not be developed outside the context of the integrated system.

Furthermore, because of their complicated interdependence, these functions, taken as a whole, could not be developed, integrated, and evaluated through the usual approach of a prototype field site demonstration. Therefore, to develop and evaluate the hardware/software forming the integrated system, it was planned that a high-fidelity testbed be built at Bell Laboratories in Whippany, N. J. All low-level radar subsystems and a complete Data Processing and Control Computer (DPCC) were to be incorporated in the testbed. To drive the testbed, an extensive radar simulator and threat generator were to be developed.

Thus, the GUARDIAN proposition was (1) that the exploratory development planned for GUARDIAN could only be accomplished with a flexible, high fidelity testbed and (2) that the field site pseudo-prototype would have two roles: to measure the environment and characterize radar performance in supporting the testbed development, and to "certify" testbed results through demonstration exercises.

With these objectives, two distinct phases were planned for the Kwajalein experience. The first was the Measurement and Recording (MR) role and the second the Discrimination Demonstration (DD) role. The MR role, primarily a real-time recording activity, was to supply supporting data for developing the testbed and discrimination algorithms. The DD roles were primarily concerned with demonstrating, in real time, functions developed with the aid of the testbed.

Development Progress

By early 1968 the requirements for the testbed and its target and radar environment driver had been established, and the testbed was under development. This involved planning the interconnection of the data processor, the low-level radar subsystems, and the radar target/environment simulator. Target threats and specific target environments were defined early in the program. The time-phased sequence of missions to exercise and evaluate the system had also been planned.

As a consequence of the NIKE-X I-67 (SENTINEL) decision, the very high traffic, regional coverage capability of the MAR was no longer needed. Therefore, in April 1968, the MAR/TACMAR development and the MAR-II prototype work at Kwajalein were redirected to the GUARDIAN program. MAR's basic elements were used in designing CAMAR, the field site radar of the GUARDIAN program.[39] The major subsystems of CAMAR were:

- Array Subsystem. This used a common aperture that functioned as both transmitter and receiver. A beam steering translator controlled the phase shifters and converted steering orders from the Data Processing Control Computer.
- Transmitter Subsystem. The waveform generator, exciter, and stalo were controlled by the data processor. The radar control processor selected from among six waveforms and associated signal processors.
- Receiver Subsystem. The receiver input was a low-noise parametric amplifier. The receiver was to form a three-beam cluster for search and designation and a four-beam monopulse cluster that could be broadened for track.
- Signal and Report Processor. Individual processors were provided for the six waveforms.

Development Plan

GUARDIAN's MR role was scheduled for early 1972 and the DD role by late 1973.[40,41] The test and evaluation phase was to consist of two parts:

1. Testing the radar to ensure that it met requirements
2. Evaluating the entire radar-computer system to establish that it performed the DD role as intended.

Demise of the GUARDIAN Program

By early 1969 the program received the name GUARDIAN; its radar continued to be designated as CAMAR. During this period serious consideration was given to modifying the testbed objectives to directly support deployment of advanced hardsite defense systems.[42] This implied a possible change in the GUARDIAN radar. Therefore, design of hardware and software sensitive to the choice of radar frequency was curtailed from mid-June onward.[43] This was essentially the end of the GUARDIAN program. Shortly thereafter the Army decided that design of a terminal ABM would proceed in directions different from the GUARDIAN program in two significant ways:

1. A prototype of a site-defense system would be developed.
2. Recognizing the inadequacy of the technological and phenomenological data base of the discrimination and bulk filter functions, the Lincoln Laboratories discrimination development and demonstration effort, employing the Kiernan Reentry Measurement Site (KREMS) at Roi-Namur, was to be accelerated.

With this redirection toward a directly deployable system design, the GUARDIAN exploratory program was set aside.