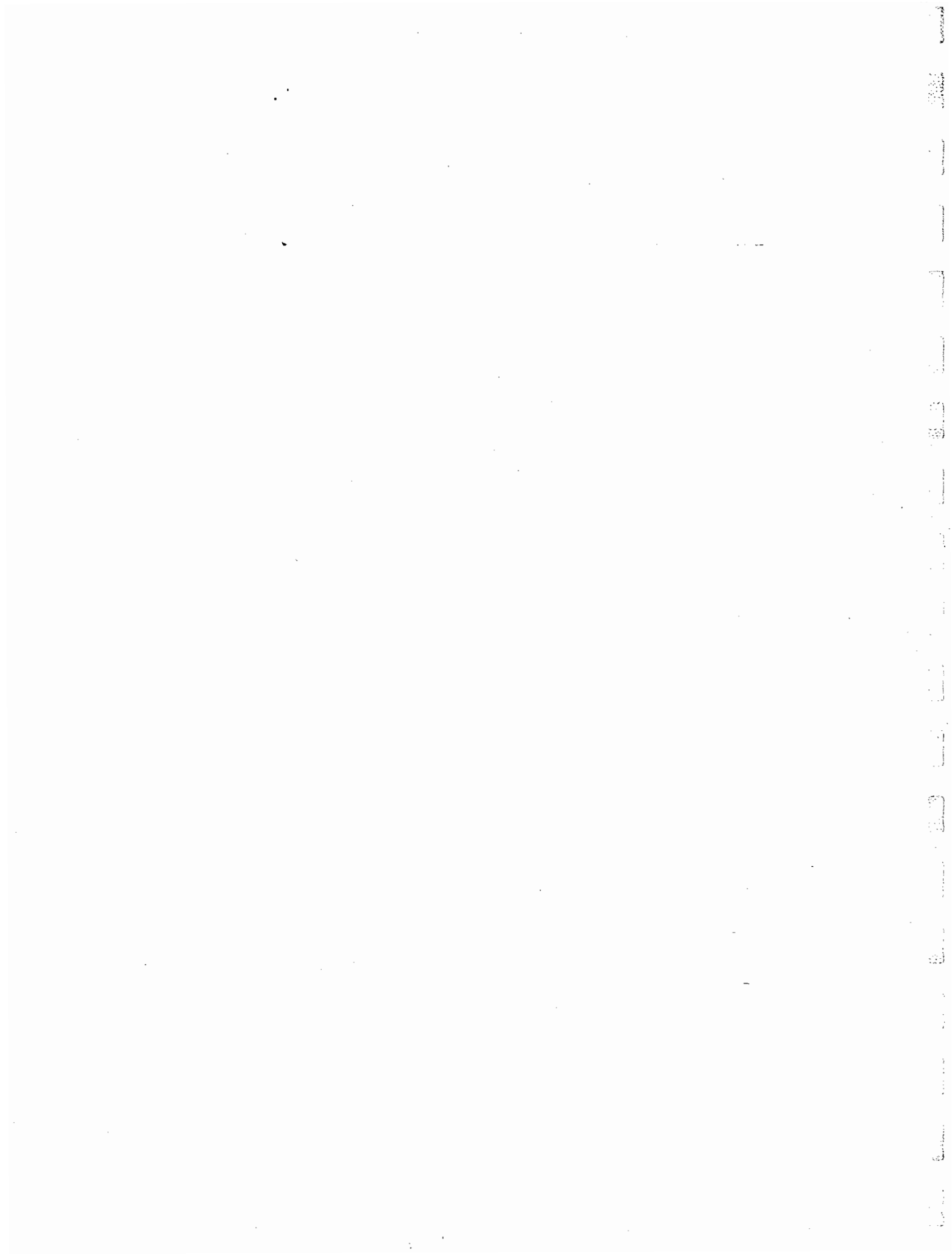


Part I.

HISTORY OF ABM DEVELOPMENT



Part I.

HISTORY OF ABM DEVELOPMENT

In March 1955, a small Bell Laboratories military system development group working with a team from Douglas Aircraft Company (now McDonnell-Douglas), had just completed a study of a single-stage, solid-propellant missile for possible air defense. When Army Ordnance asked Bell Laboratories to start an 18-month study of a new forward-looking, anti-aircraft defense system for the Zone of the Interior to defend against future target threats in the 1960-1970 time period, a system team already was available.

The initial thought was to place primary emphasis on the super air-breathing-type target while also keeping in mind ballistic targets and the desire to defend against the extremely difficult Intercontinental Ballistic Missile (ICBM) with a reasonable extension of current radar and missile technology. In other words, the system originally to be designated as NIKE II was not to be considered as a solution to the ICBM defense problem, but rather as a step toward its ultimate solution. However, discussions with the Army in June 1955 brought to light the increasing concern over the possibility of an ICBM threat, and Bell Laboratories was asked to place primary emphasis in this area. Consequently, the NIKE II Study would focus on ICBM defense, but still include the full spectrum of future target threats.

NIKE II STUDY

The relatively small study team available to carry out the NIKE II work was actually a well-coordinated task group of Bell Laboratories and Douglas Aircraft Company people who met at regular intervals to review completed tasks and outline future objectives. Messrs. C. A. Warren and J. W. Schaefer coordinated the overall systems work supported by Bell Laboratories' Mathematical Research Department, whose efforts were coordinated by Messrs. D. P. Ling and R. C. Prim. At the Douglas Aircraft Company, Mr. J. L. Bromberg was responsible for the project coordination, supported by Messrs. R. L. Johnson, M. Hunter, N. Weiler, and J. Tschirgi.

Initially, the objective was to explore the possibility of a common anti-aircraft defense system to cover all future high-altitude threats without substantially compromising the overall defense. It was felt that any anti-aircraft defense designed for the extreme ICBM targets would overlap on a system capable of handling the future air-breathing, high-performance targets. Consequently, by adding certain specialized elements of one to the other, there was the attractive possibility of having an anti-aircraft system capable of attacking any future air target.

The spectrum of possible future target threats (1960-1970 time period) considered for the Army study is shown in Figure I-1. It covered a wide area of performance capability from the maximum speed of the air-breathing ramjet out to ICBM speed of 24,000 ft/sec, and at altitudes far beyond 100,000 feet. For the ballistic targets, the short-range, 150-mile, 5000-ft/sec rocket of the V2-type set the lower boundary.

The Army authorized funding of \$1.65 million on Army Ordnance Contract DA-30-069-ORD-1082 for the 18-month study effort. This funding was to cover not only the system study effort, but also exploratory hardware development in those areas of radar and missile technology that could be defined as critical to successful development of a NIKE II System. A year later, an additional \$1.8 million was added for expediting exploratory hardware work.

ABM Defense Requirements

The first full status report on the NIKE II System Study was presented to Army Ordnance at Redstone Arsenal December 2, 1955, about seven months after beginning the study. It is interesting to note here how many solutions proposed in this preliminary report, after only one third of the study was completed, remain basic even today to any ICBM defense. Some highlights presented at this status review follow.

To handle the full range of threat, a common data-gathering system was proposed using a defensive missile with interchangeable noses as shown in Figure I-2. One nose, for use in long-range intercepts of the future air-breathing targets, would contain an active seeker. The second nose would have no seeker, but would contain

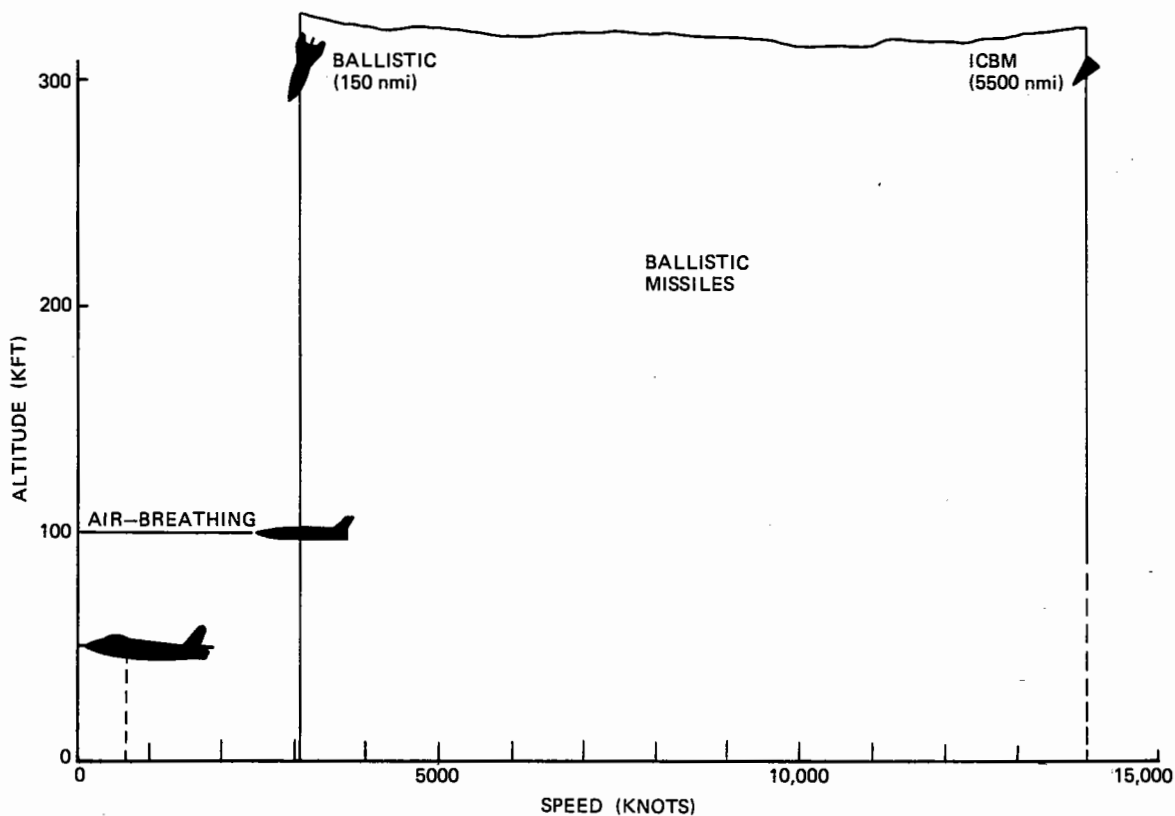


Figure I-1. Spectrum of Target Threats

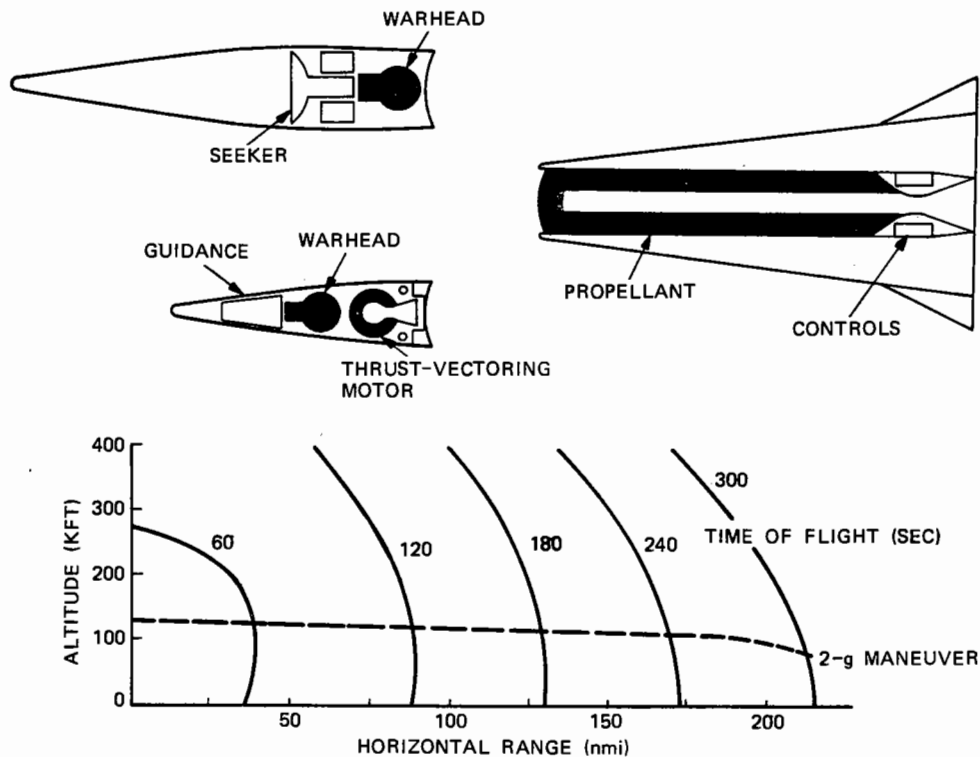


Figure I-2. Defensive Missile with Interchangeable Noses

a jet-control mechanism to provide maneuverability at altitudes above 120,000 feet. This nose would be used when engaging ballistic targets.

By comparison to World War II air defense objectives, where a 10- to 15-percent attrition rate was acceptable, the nuclear-warhead threat required defense levels of 95- to 100-percent attrition against a tough-to-kill reentry target. Studies showed that using a 50-kiloton nuclear warhead in the defensive missile required relatively small miss distances to kill the enemy warhead. The use of a high-yield warhead did not relax the need for a guidance system of high accuracy.

One of the first questions in the initial study concerned the point in the offensive missile's trajectory where intercept should take place.

Consideration was given to making the intercept near the middle of the trajectory. However, not only would this necessitate a defensive missile as formidable as the offensive weapon, but it would require gathering information on the offensive missile almost at its point of launch. With the obvious advantage of choice of launch time belonging to the offense, it did not appear feasible or economical to attempt mid-course intercepts. Consequently, we proposed that the intercepts be much closer to the point of impact. (See Figure I-3 for ICBM trajectory.)

Further studies indicated that the most attractive guidance method was a command system based on extension of the NIKE-AJAX/HERCULES Systems. The use of homing seemed precluded by the extremely high closing rate of over 5

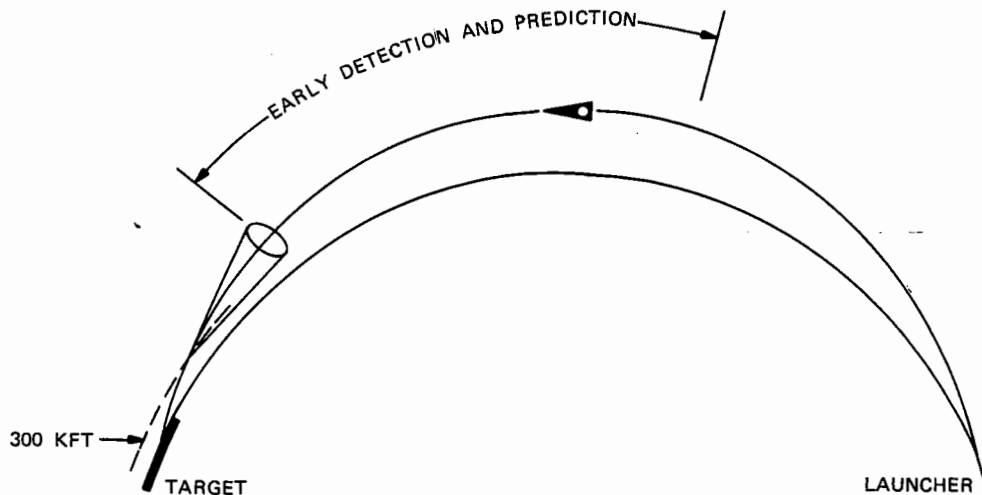


Figure I-3. ICBM Trajectory

miles per second, necessitating homing ranges that did not appear attainable on so small a target as a ballistic reentry body (only one one-thousandth the radar size of an aircraft). The terminal nature of the defense also made command guidance feasible and attractive.

Ballistic missiles entering the atmosphere would suffer deceleration of up to 60 g's at altitudes dependent on the shape of the reentry nose. A comparison of ballistic target characteristics is given in Figure I-4. The guidance problem and related missile maneuverability requirements could be eased, as proposed by Bell Laboratories' Mathematical Department, through the use of analytical prediction of ICBM deceleration, well in advance of the actual high-g deceleration.

An extensive communications network, data processing, computation, and tactical control would be necessary to the functioning of the ABM defense system. Local radars in the vicinity of the defended area and forward radars for initial detection would require integration with an extensive network of communications. The importance and complexity of fast response were emphasized strongly with speeds so high and reaction times so short that all operations would have to be

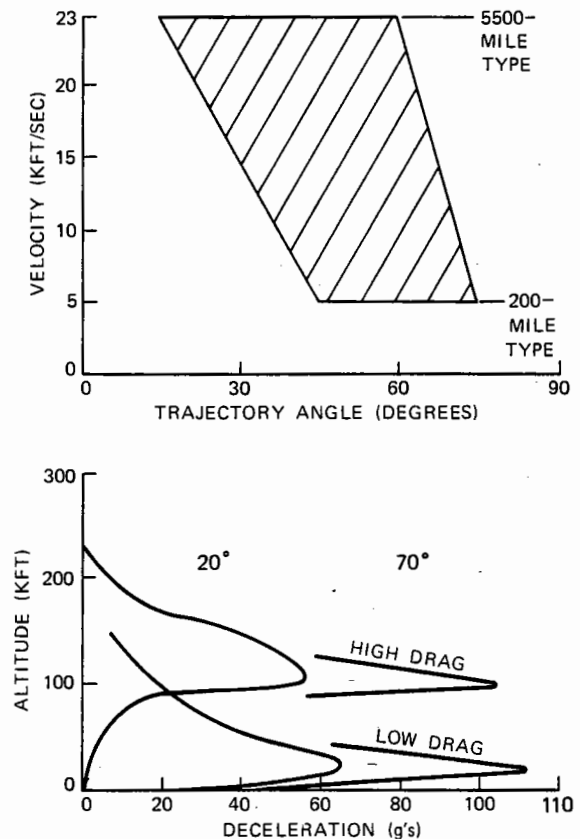


Figure I-4. Ballistic Target Characteristics

automatic with only the power of veto exercised by man. Dependence on a 10- to 15-minute early warning could be relatively loose and flexible, but once a target was acquired, all system elements would have to function as an integrated whole to successfully meet mission objectives.

A major concern pointed out in this first report was the problem of separating radar decoys from warheads. Chaff or balloon decoys having high drag-to-mass ratios would be held back by the atmosphere and separated, but rods or jacks cut to the defensive radar frequency might be made to have approximately the same drag-to-mass ratio as the warheads. Rate of arrival of ICBMs over a target area and unresolved decoys could present high traffic levels requiring a target tracking and guidance system capable of engaging up to 20 targets per minute.

On December 28, 1955, Lt. Gen. J. M. Gavin, Army Deputy Chief of Staff for Research and Development (R&D), visited Whippany for a review of all the NIKE programs. A somewhat shortened version of the NIKE II status report was presented. General Gavin was impressed with the study to date and gave it top priority, particularly for defense capability against ICBMs. Messrs. F. R. Lack, Vice President of Western Electric, and J. B. Fisk, Bell Laboratories Executive Vice President, W. C. Tinus, R. R. Hough, L. W. Morrison, and C. A. Warren were among those present at this meeting.

Additional Defense Considerations

On January 4, 1956, a similar NIKE II briefing was given by Mr. R. R. Hough of Bell Laboratories to the Army Policy Council. At this briefing, Mr. Hough responded to an Army request for information concerning what could be done to provide an interim solution to the intermediate and long-range ballistic missile defense problem. It was pointed out that regardless of the approach taken, information gathering was the difficult part of the problem. Furthermore, a high level of defense was essential and a marginal interim capability might not be worth extensive effort. Also, any interim solution should

be directed along lines that would lead to the final solution.

A long-range, high-data-rate acquisition radar was essential to any ballistic missile defense solution, and if development could start immediately on this critical element, a possible interim ICBM defense might be possible with the NIKE B missile and system. Mr. Hough reported that Bell Laboratories was currently studying the problem of ICBM interim capability with NIKE B and would report back to the Army within the next two months on this defense possibility. A comparison of early Antiballistic Missile (ABM) sizes is given in Figure I-5.

The Air Force was also interested in ABM defense, and in the fall of 1955, an ARDC-TR-56-11 technical request was made to industry for a 12-month ABM defense study. In this period, the roles and mission of the Army were defined as "terminal" defense and those of the Air Force as "area" defense. Since the ABM concept covered both roles,* Bell Laboratories recognized that any successful ABM system would have to combine area and terminal defense within one

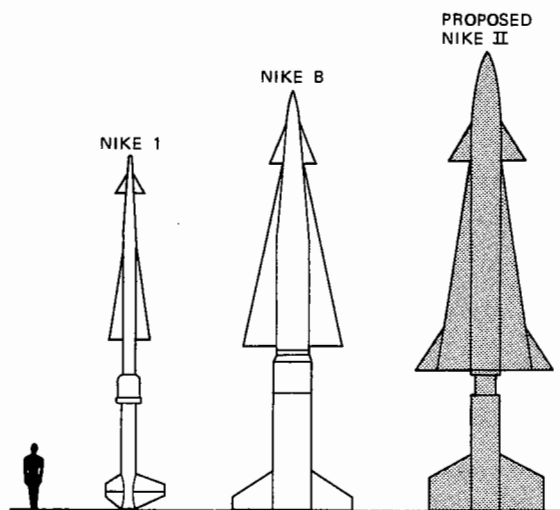


Figure I-5. Comparative Sizes of Early ABM Missiles

*Area defense involved the long-range acquisition radars tied together by a communications network, while terminal defense involved the missiles, local tracking radars, and computers.

integrated system approach. We therefore bid on the Air Force's 12-month study on the basis that the additional effort for the Air Force would be concentrated on the Forward Acquisition Radars (FARs) and the communications network. However, the results of the complete ABM study would be made available to both the Army and the Air Force.

The Air Force study effort was for about \$0.5 million in comparison to more than \$3.0 million for the Army, which also covered exploratory development. Air Force Contract AF33(616)-3285 with Western Electric was authorized on November 15, 1955, and was directed specifically to Anti-ICBM (AICBM) defense only. Two other defense contractors, Boeing and Lockheed, were among those selected in this Air Force competitive study.

As the NIKE II study and the complementary Air Force study proceeded through the first six months of 1956, Bell Laboratories and Douglas were requested to make a number of presentations, not only to the Army and Air Force, but to a number of high-level Department of Defense (DOD) and special defense panels as well. These briefings included:

- NIKE II and Study of Early Solution to ICBM Defense — Briefing for Dr. C. C. Furnas, Assistant Secretary of Defense Research and Development, March 30, 1956.
- Air Force AICBM Weapon Study First Status Report — Air Force Scientific Advisory Board, May 2, 1956.
- NIKE II — Presentation before Dr. Murphree's Anti-Missile DOD Defense Committee, September 17, 1956.

Proposed ABM System

The defense problem and the early system proposed as a solution against future threats, including the ICBM, as presented to the Assistant Secretary of Defense for R&D on March 30,

1956, involved a number of significant features. The defensive missile with the interchangeable noses for the air threat (seeker) or ICBM threat (thrust-vectoring motor for outside atmosphere) was proposed. (See Figure I-2.) Early acquisition of the ICBMs would be obtained by a series of Forward Acquisition Radars with fan beams well north of the defended areas, as shown in Figure I-6. The overall system is illustrated in Figure I-7. The local high-data-rate acquisition radar shown pictorially in Figure I-8 was based on the Luneberg lens antenna principle (Figure I-9). The possible characteristics of this radar are given in Table I-1.

Table I-1
AICBM Radar Characteristics

Coverage	120° azimuth x 60° elevation
Data Interval	1 sec
Repetition Rate	120 pps
Radio Frequency	500 MHz
Power	
Peak	5000 kW
Average	300 kW (each of two)
Transmit Antenna	
Aperture	2 ft x 120 ft
Beam	60° x 1°
Gain	27 dB
Receive Antenna	
Aperture	120 ft diameter
Beam	1° x 1°
Gain	43 dB
Range of ICBM	600 nautical miles

At this same meeting, at the request of the Army and DOD, a possible Interim AICBM Study using the NIKE B missile and system was presented. The system and guidance plan proposed is illustrated in Figures I-10 through I-16.

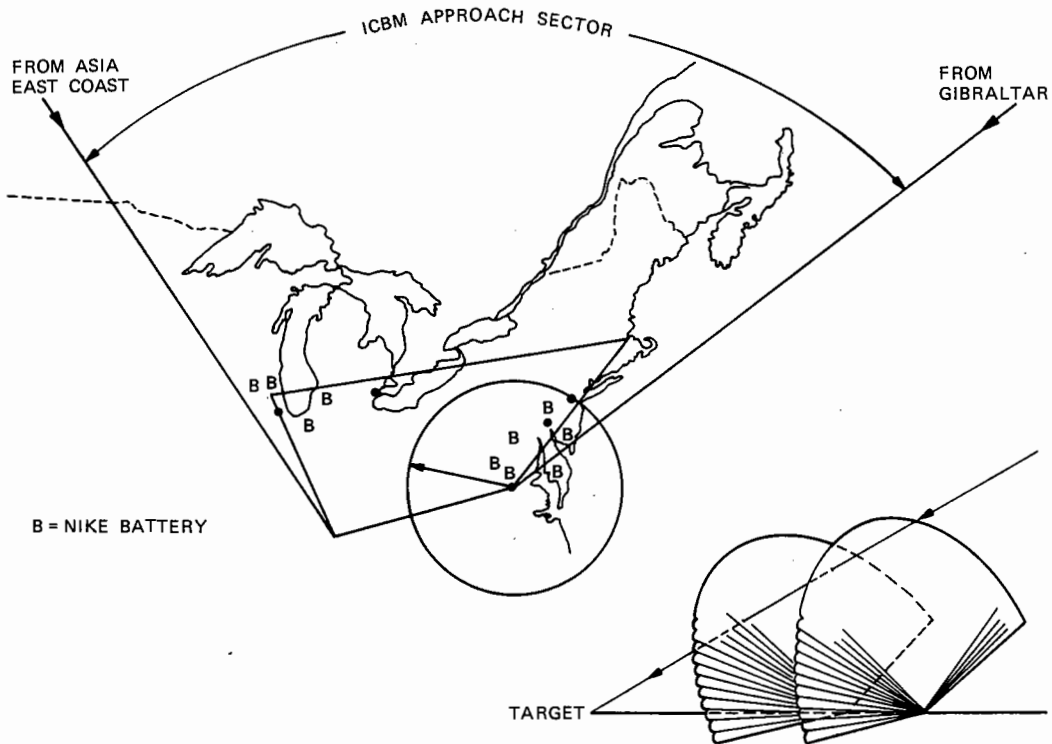


Figure I-6. Deployment for ICBM Defense

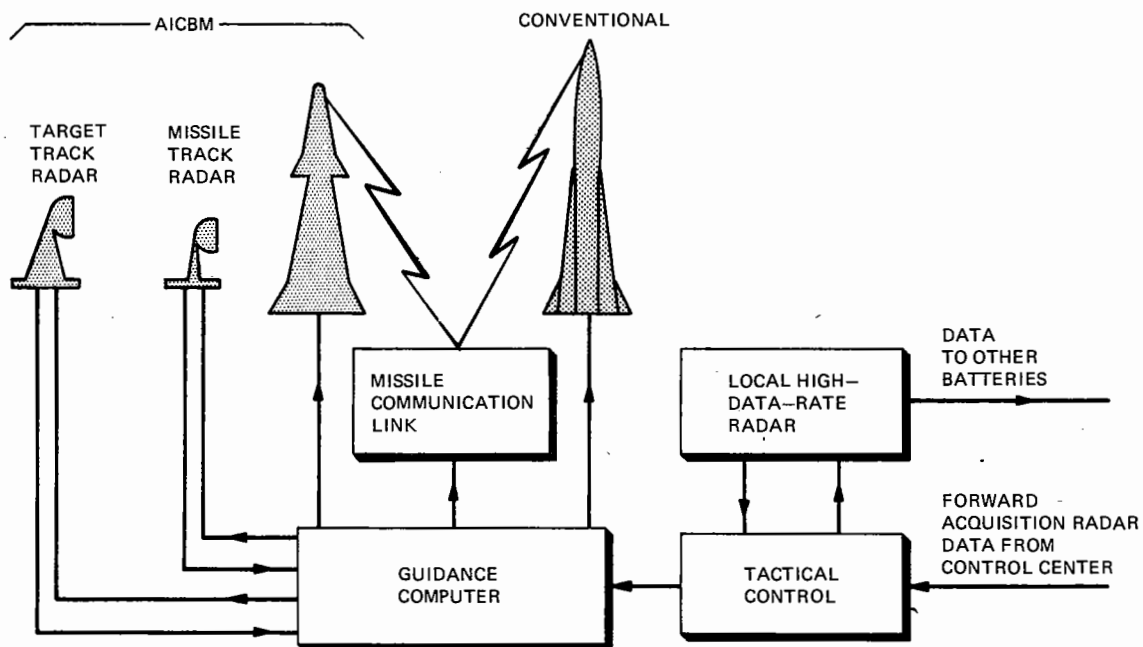


Figure I-7. ABM Battery

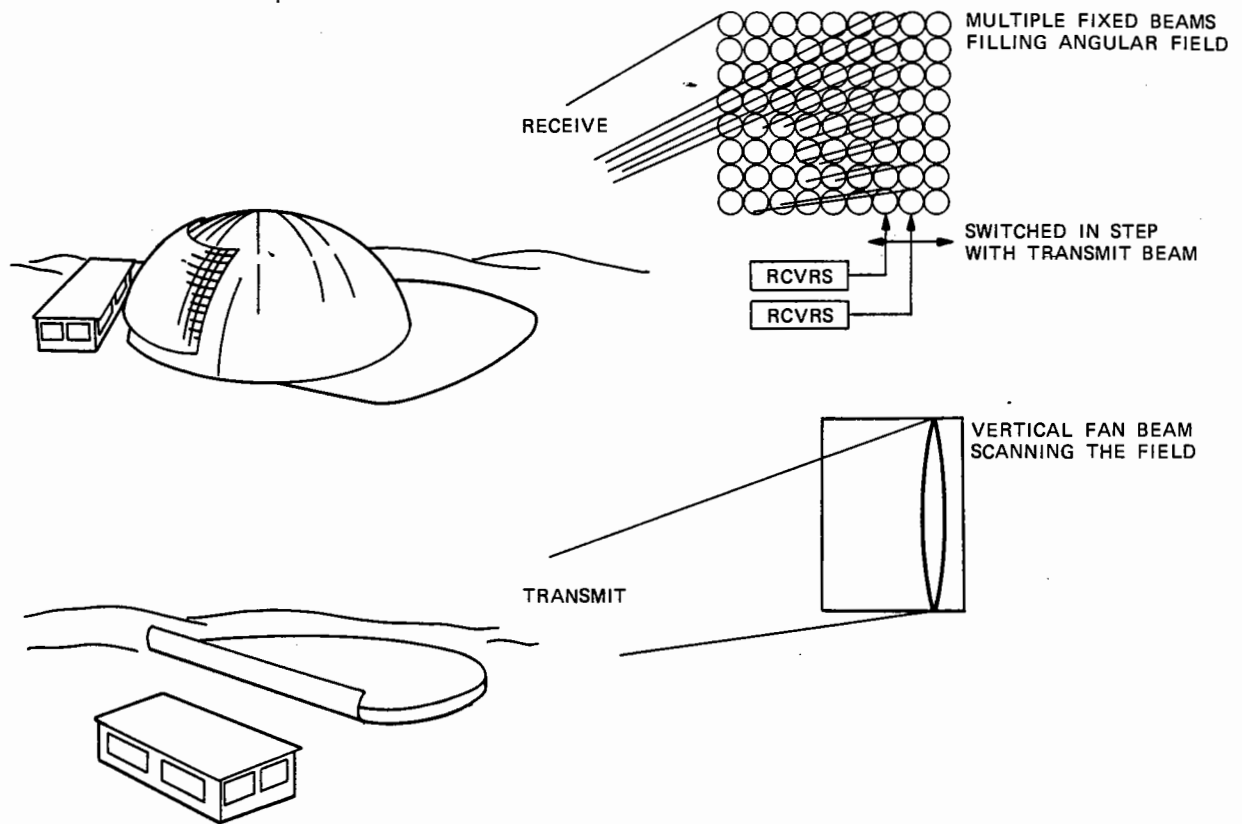


Figure I-8. AICBM Acquisition Radar

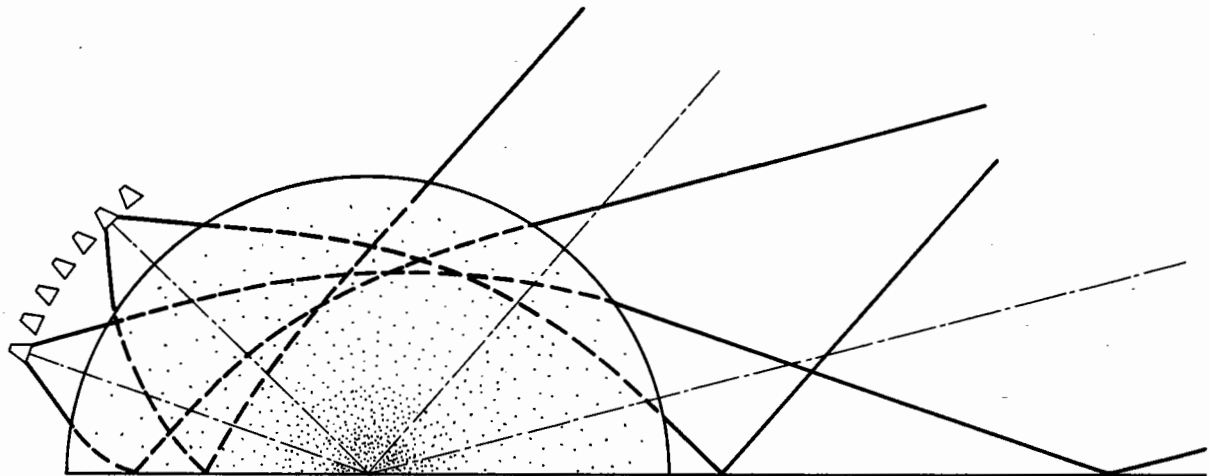


Figure I-9. Luneberg Lens Antenna

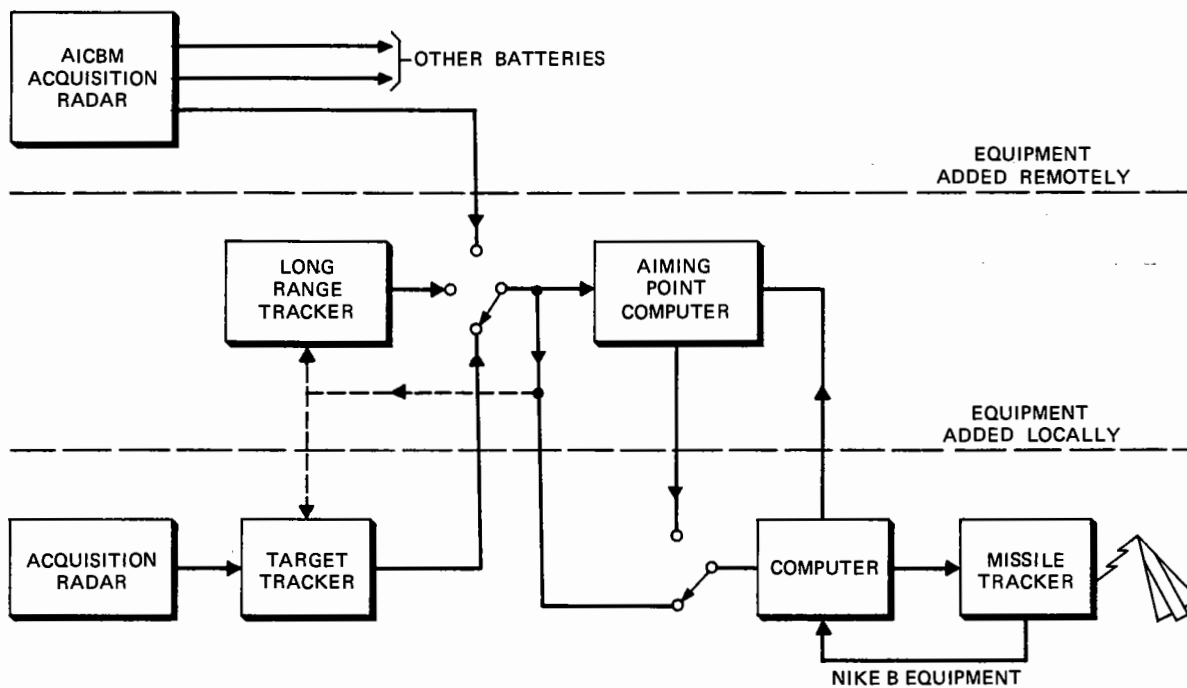


Figure I-10. NIKE B System

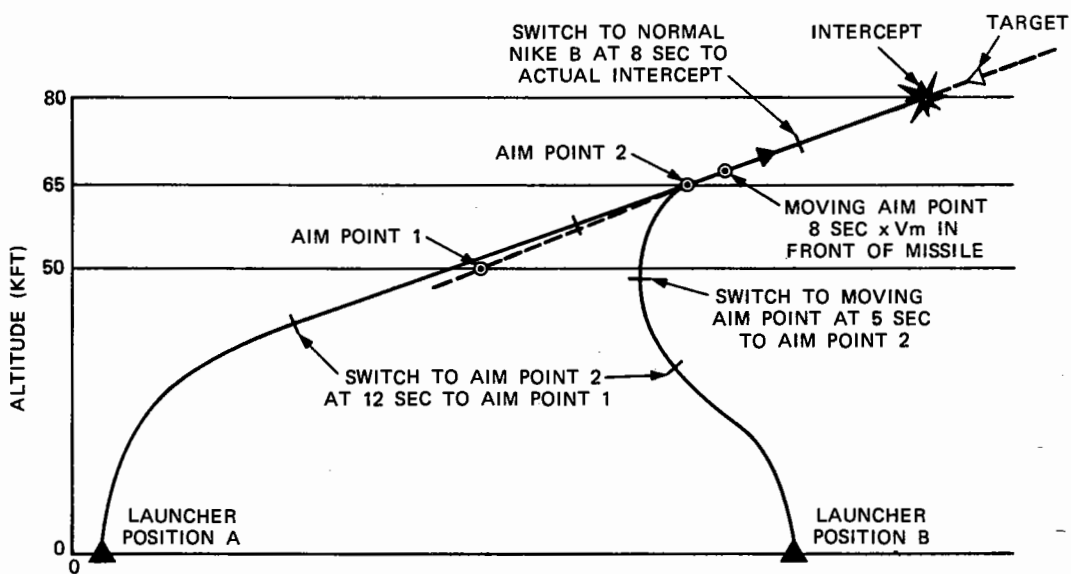


Figure I-11. Mechanization of Parallel Approach for ICBM Targets

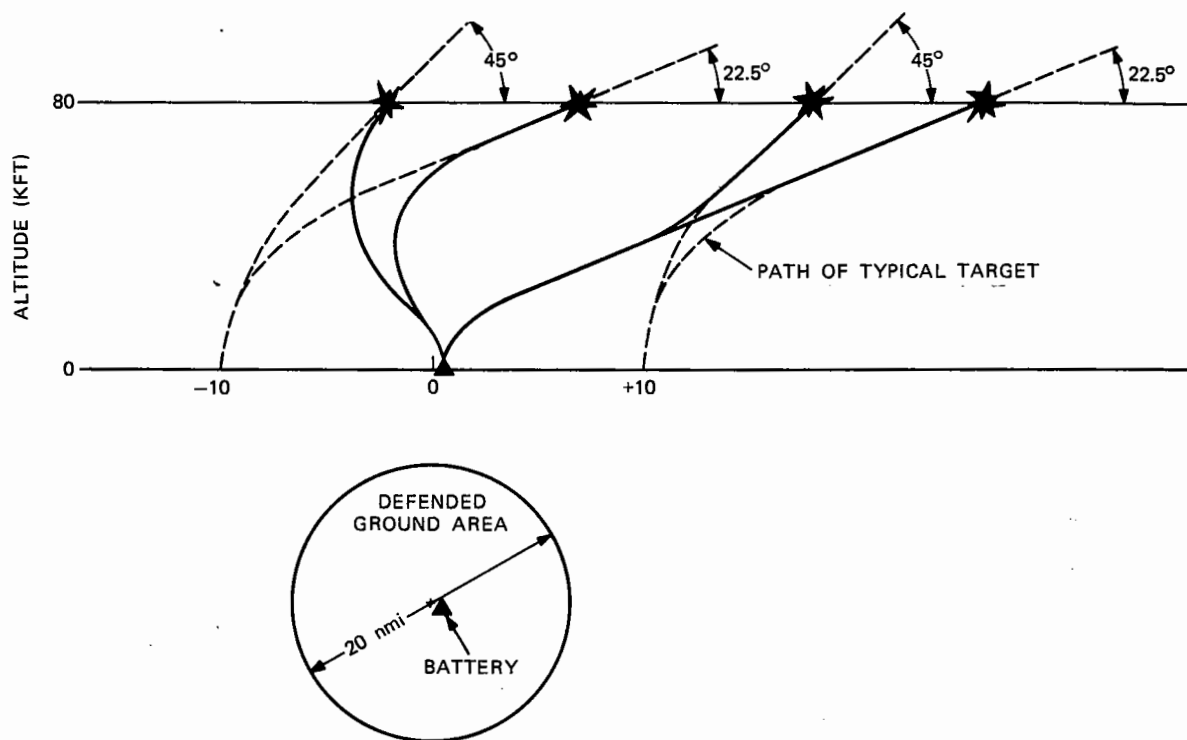


Figure I-12. Battery Capability vs. Target Angle

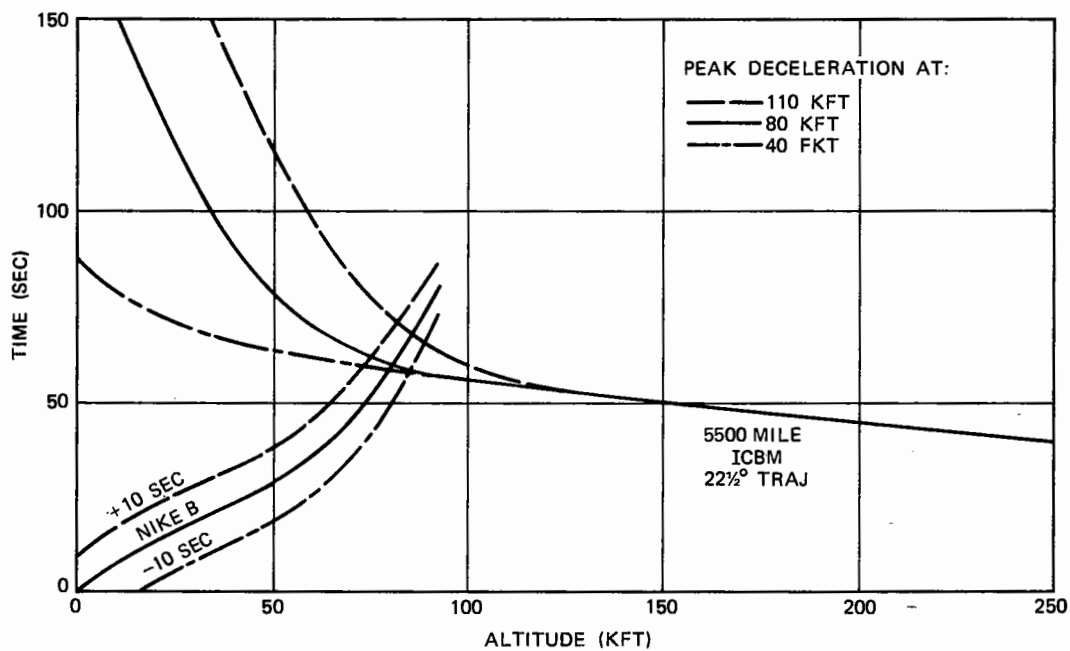


Figure I-13. Variation from Nominal Intercept

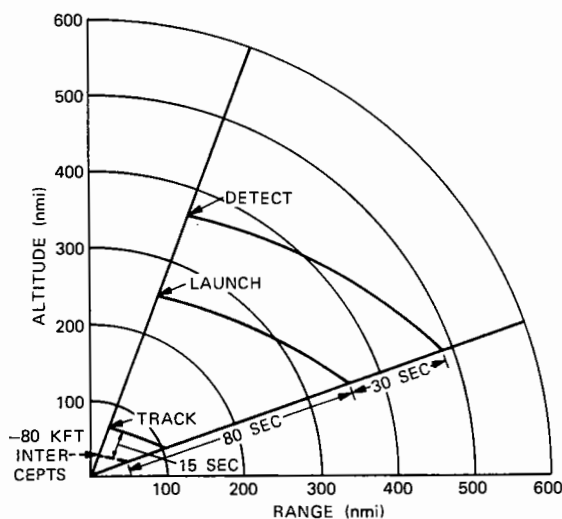


Figure I-14. Radar Range Requirements

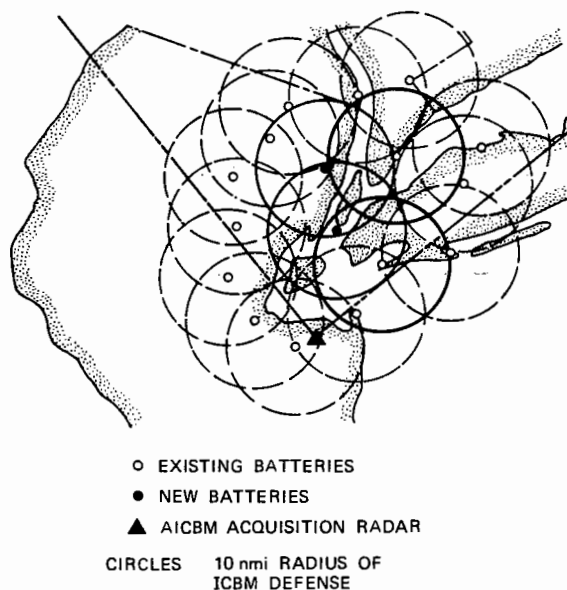


Figure I-15. ICBM Coverage in New York Area

CHARACTERISTICS

FREQUENCY 4500 MHz \pm 250
 PEAK POWER 3000 kW
 PULSE WIDTH 3.0 μ SEC
 RECEIVER NF 7.0 dB
 ANTENNA GAIN 47 dB
 ANTENNA SIZE 20 FT DIAMETER PARABOLIC DISH
 TRACKING ACCURACY SAME AS NIKE B TRACK

ESTIMATED RANGE PERFORMANCE

RADAR CROSS SECTION (m ²)	RANGE (nmi)
16	800
1	400
0.1	220
0.01	125

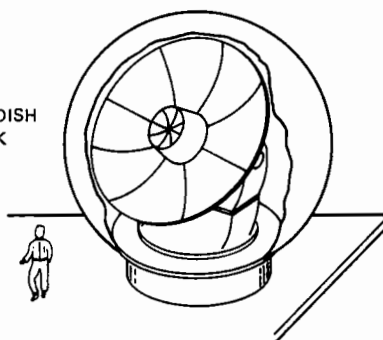


Figure I-16. Long-Range Track Radar

During the period of this NIKE II and Air Force AICBM study, there were many scientists in the various government agencies and in universities who believed it was impossible to intercept a target going 24,000 ft/second, comparing it to "hitting a bullet with a bullet." Recognizing that guidance of a defensive missile to accurately intercept ICBMs was a challenge, an analog simulation room used in testing the NIKE-AJAX and HERCULES Systems at Bell Laboratories in Whippany was modified to handle ICBM intercepts. After some 50,000 intercept runs under varying threat parameters and intercept altitudes, it was convincingly demonstrated that ICBMs

could be accurately intercepted when the guidance was properly scaled to the high-speed target. Furthermore, through the use of analytical prediction tested in these simulations, the 60-g slowdown of the ICBM could be adequately handled by a defensive missile of much lower steering capability. Following a series of visits to Bell Laboratories by DOD and military groups to witness these simulations, the question of being able to accurately intercept an ICBM was no longer seriously challenged — although it was not until six years later that full-scale intercepts of actual ICBM targets were confirmed in tests at Kwajalein Island in the Pacific.

Results of NIKE II Study

In October 1956, the results of the NIKE II 18-month study were presented in the Pentagon to Lt. Gen. J. M. Gavin and the Army General Staff. The final written report on NIKE II* was published March 1, 1957. The report included both the defense against air-breathing targets with a seeker-nose missile and the defense against ICBMs with a separable thrust-vectoring nose for intercepts outside the atmosphere. In this final

report, the Luneberg lens-type of acquisition radar was fully refined and proposed for two applications. It would be used for both the forward acquisition coverage called FAR and for a high-data-rate (2 seconds) Local Acquisition Radar (LAR) within the defended area to provide hemispheric coverage and multi-tracking of 50 to 100 targets. The plan of integration is shown in Figure I-17. Artist views of the acquisition radars as proposed are shown in Figures I-18 and I-19 and the weapon battery in Figure I-20. The ICBM defensive missile shown in Figure I-21 would carry a 400-pound nuclear warhead and provide 10-g maneuverability at 100,000 feet. The thrust-vectoring nose would be required for end-game steering at altitudes above 80,000 feet.

*System Study, NIKE-ZEUS Guided Missile System, Bell Laboratories Report, Vol 1 Requirements and Vol 2 Appendices, March 1, 1957, (SECRET).

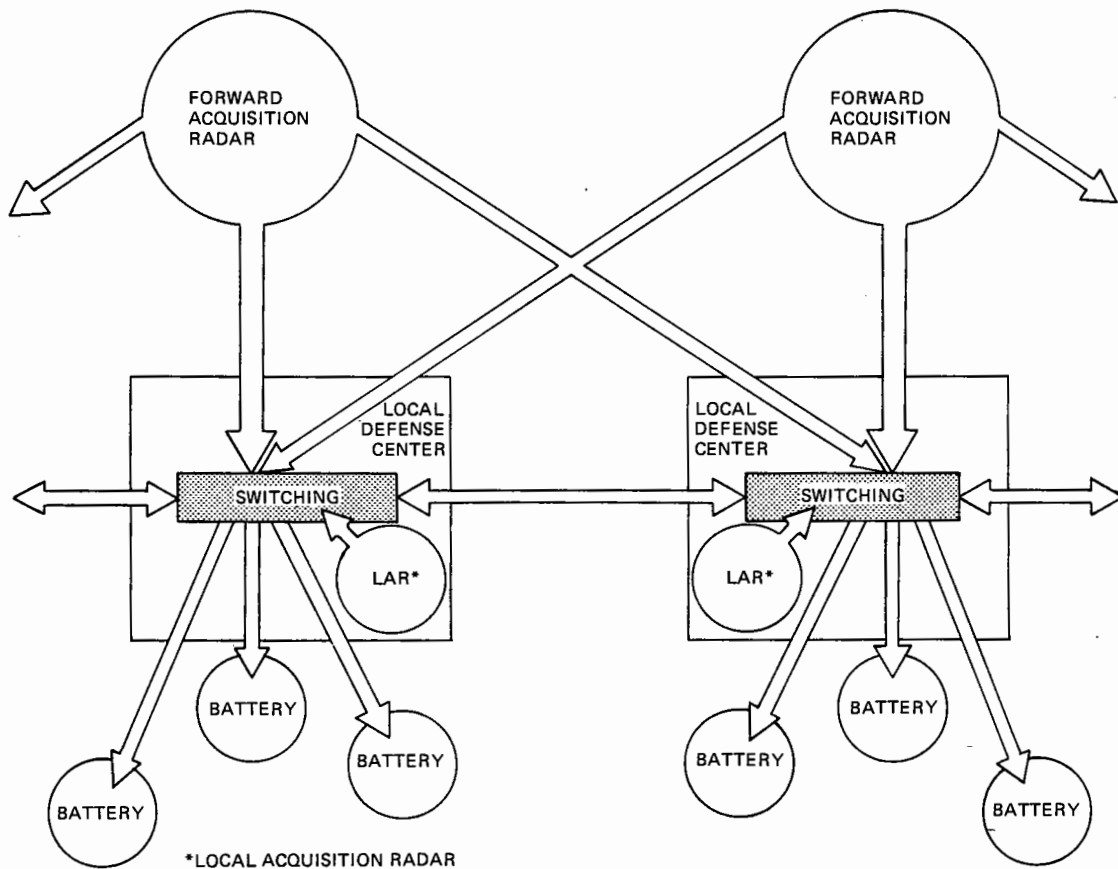


Figure I-17. NIKE II Plan of Integration

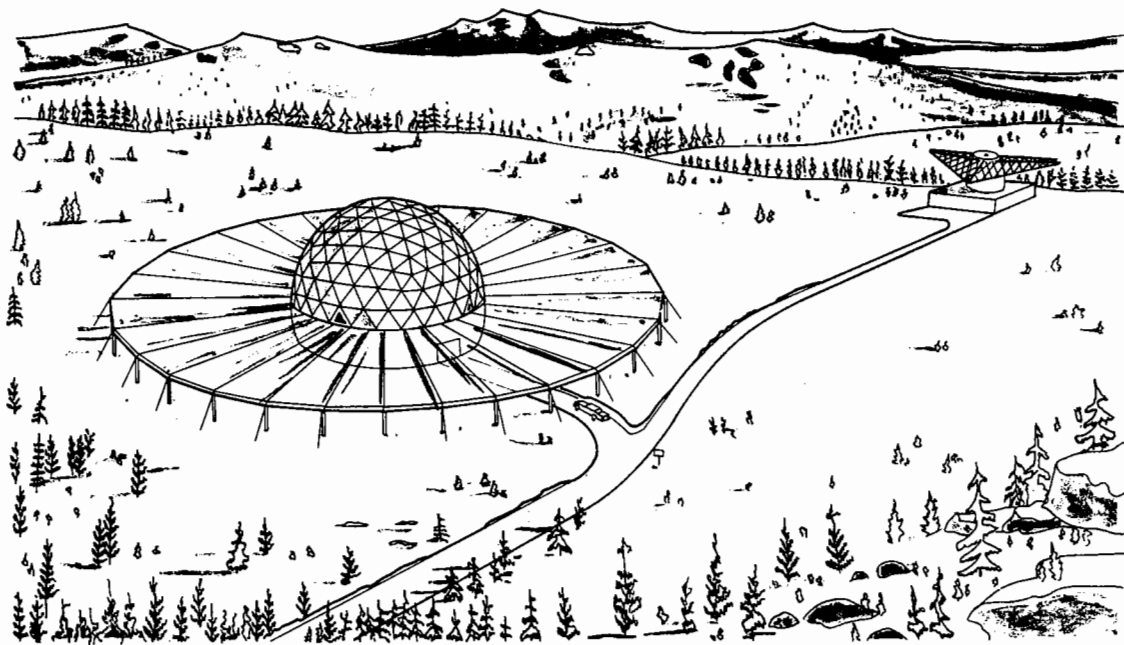


Figure I-18. Proposed Forward Acquisition Radar

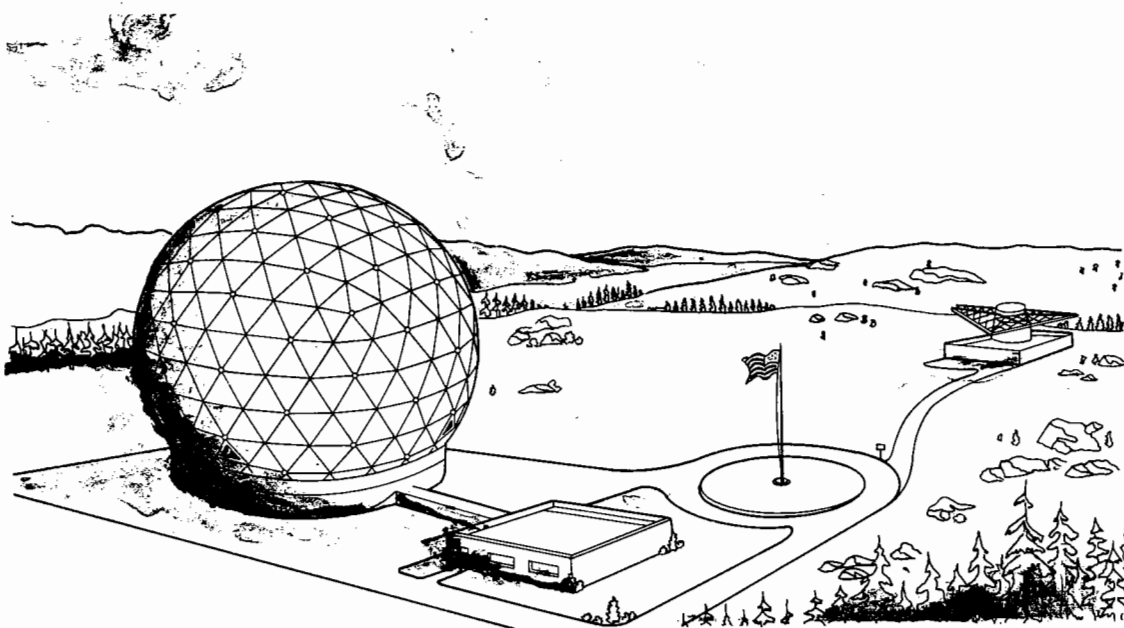


Figure I-19. Proposed Local Acquisition Radar

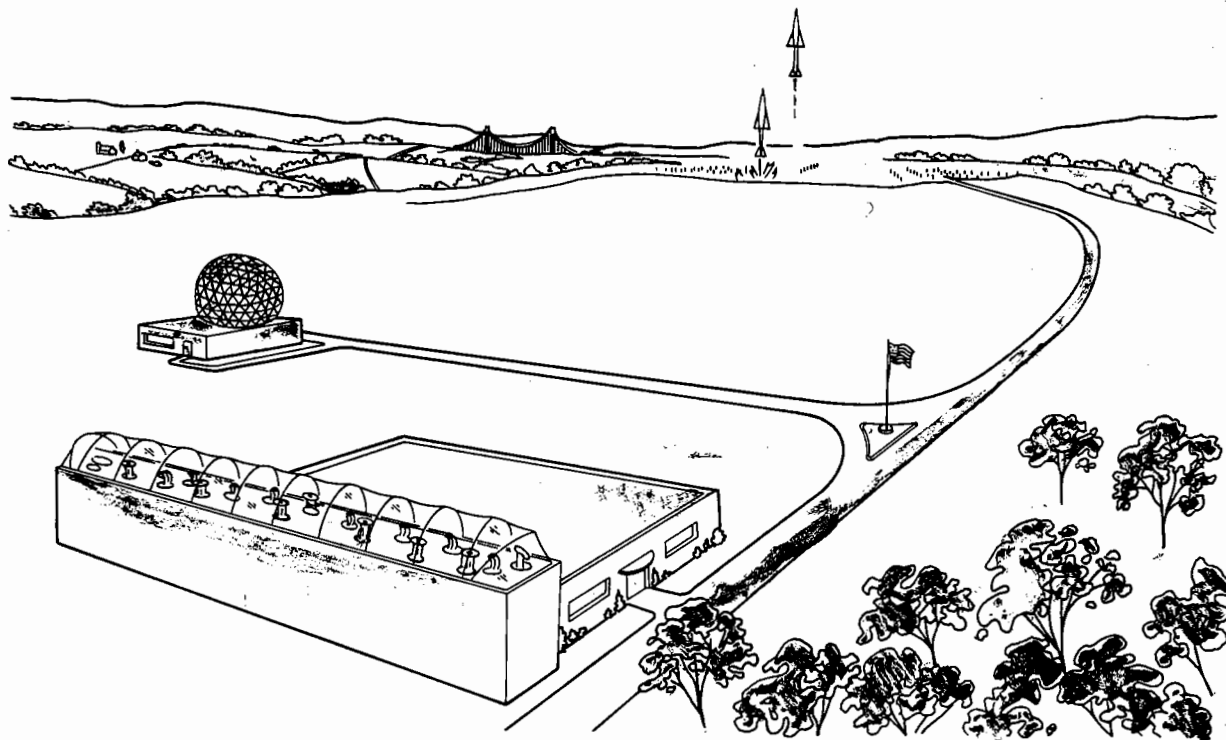


Figure I-20. Weapon Battery Installation

In late 1956, a report on the same system was given to the Air Force upon completion of the year's study. As mentioned earlier, the additional effort for the Air Force was applied to studies of the forward data gathering and on the communications network required for connection to local defense elements.

In reporting on an ABM communications system for both the Air Force and Army final March 1957 studies, the following general features were proposed:

- The system should be completely automatic with all elements electronic and capable of operating at high speed. A communications message-numbering plan should be used, based on the destination of the data (FAR to specific battery).
- The system should use intermediate switching to reduce the number of channels required for a full Continental United States (CONUS) defense network.
- Multi-alternate routing should be used to provide reliability.
- Error checking should be incorporated to ensure accuracy in transmission.
- Each message should be acknowledged to increase reliability.
- Voice-bandwidth channels should be used universally. (A proposed communication route was presented for defense of the northeastern United States.)

As part of the final March 1957 report, a complete Development Test Plan for the proposed system was included, covering a six-year period from initial development to system demonstration tests against real ICBM targets at a remote testing range.

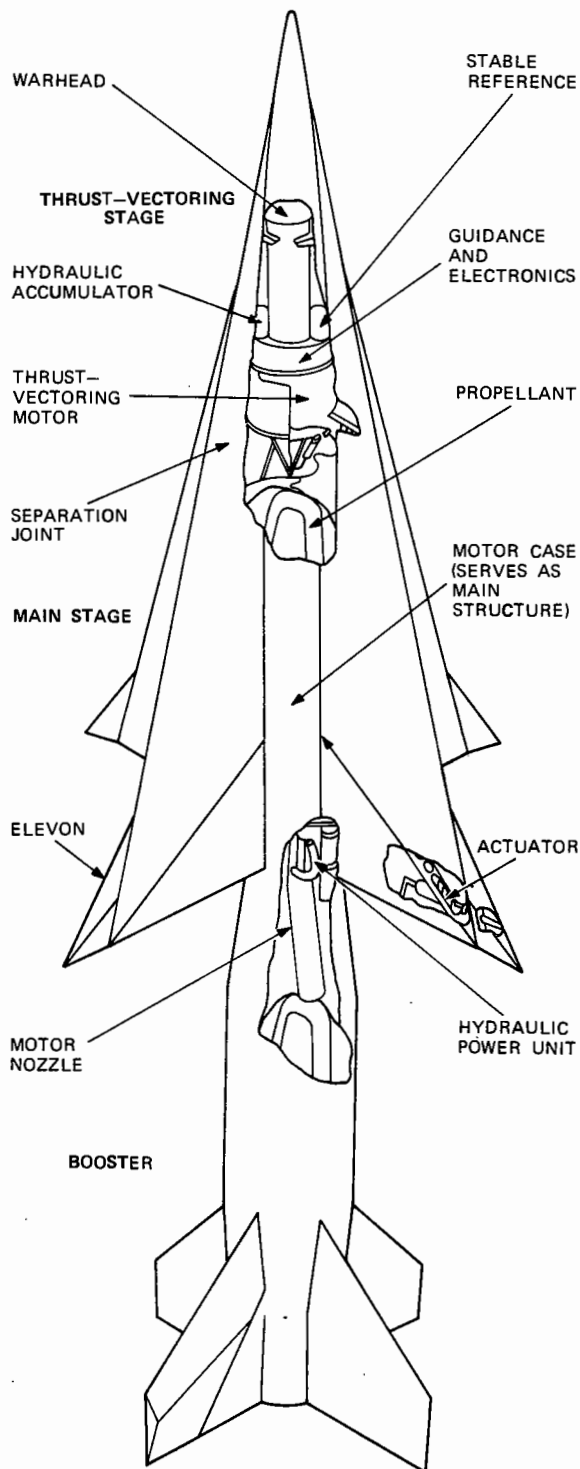


Figure I-21. The Defensive Missile

AICBM Report

During the period of these studies, there was intense rivalry between the Army and the Air Force for the mission of ICBM defense. Our work at Bell Laboratories resulted in one system concept, with the additional Air Force effort affording an opportunity to study the overall communications network, including problems of data processing and data transmission. General Hertford of the Army had no objections to including appropriate parts of the results of the NIKE II study in our study report to the Air Force. In actual practice, the combined study effort proved somewhat embarrassing since, in presentations to top DOD and special antimissile committees, the same Bell Laboratories/McDonnell-Douglas system concept was presented by both the Army and the Air Force.

After the AICBM report was made to the Air Force, they established a task group to review the Bell Laboratories/McDonnell-Douglas system and those of the other two contractors. The Air Force Air Research and Development Command (ARDC) Report of January 1957 informally indicated that they would like Bell Laboratories to continue their contract for another six months at a level of about \$200,000 to cover further analysis of decoy work. Since a major effort on AICBM was continuing for the Army, the actual supplementary extended study for the Air Force was for only \$90,000 directed specifically to decoy discrimination. (Roles were subsequently redefined giving responsibility for AICBM effort to the Army.)

AICBM DEVELOPMENT CONTRACT — NIKE II/NIKE-ZEUS

In February 1957, the Army awarded Western Electric/Bell Laboratories prime contractor system responsibility for development of an AICBM defense system and changed its name from NIKE II to NIKE-ZEUS. With the growing concern for the ICBM threat, Bell Laboratories

concentrated solely on the ICBM defensive missile, hence terminating work on the seeker nose for air-breathing targets. The level of research and development effort for the first year was to be about \$12 million, including subcontract work by McDonnell-Douglas on the missile, RCA on the transmitter, and Goodyear Aircraft Company on the antenna structure.

Major changes were made in certain elements of the NIKE-ZEUS System from that described in the March 1957 report during the early development phase.

Discrimination Radar

One of the major research and development problems mentioned in both AICBM reports to the Army and Air Force was the task of separating the reentry body from the various decoys and junk that might accompany it. Consequently, research and systems work continued on this high-priority problem as development work on the overall system was initiated. The Target Track Radars (TTRs) in the proposed NIKE-ZEUS System would have to see all the objects in a cloud assigned to them by the Acquisition Radar and track one of the objects (preferably one near the center of the cloud). At the same time, the radar would have to systematically examine all received signals from the cloud of objects at a high data rate to permit a wideband frequency analysis of the radar return signals. The implementation for scanning would be such that once the reentry body was identified, precise automatic position and velocity tracking of the target would have to be established in a few seconds by the TTR.

Note that at this particular time, radar measurements of incoming ICBMs were not available, since the first successful ICBMs were not flown until the 1959-1960 time period. Consequently, such discrimination possibilities as scintillation, radar size, and slowdown were proposed among other methods whose success might depend on the ability of the TTRs to obtain the high data rate mentioned. Thus, three methods were considered to increase

the angular field of radar coverage for examining an incoming cloud: (1) scanning the TTR beam, (2) increasing the TTR beamwidth, and (3) providing additional receiver beams in the same TTR focusing structure. The first method was dropped, because the intermittent data would seriously limit radar data rate and would present a problem in tracking one of the objects while scanning the cloud. The second method of a larger beam was not practical because of the serious loss in radar range and accuracy. The third method was then proposed as a modification to the TTR, and was named the "Fly's Eye" Antenna.

The principle of the Fly's Eye Antenna is shown in Figure I-22, where an array of antenna feedhorns is clustered about the monopulse horns which would be used for accurately tracking the target after discrimination. The center monopulse horns would transmit and receive in the conventional manner. The cluster of horns located on the main reflector would act as range-only receivers and provide a field of view of about $4\frac{1}{2}$ by $4\frac{1}{2}$ degrees, as shown in Figures I-23 and I-24. A separate transmitting antenna slaved to the large TTR mount would provide the illumination for the range-only receivers. To avoid the losses caused by the hole in the main reflector, a grating of vertical wires would be stretched across the horn openings and the secondary reflector would be designed to shift the polarization from horizontal to vertical.

With these changes, and with pulse-collapsing chirp techniques for fine range resolution together with multiple range-tracking circuits, high-data-rate signature outputs on objects in a cloud would be provided for radar signature and aerodynamic discrimination. These discrimination circuits would accept the individual gated signals from the multiple range-tracking equipment and perform tests based on differences in amplitude, frequency spectrum, radar frequency sensitivity, ionization, aerodynamic-slowdown characteristics, etc.

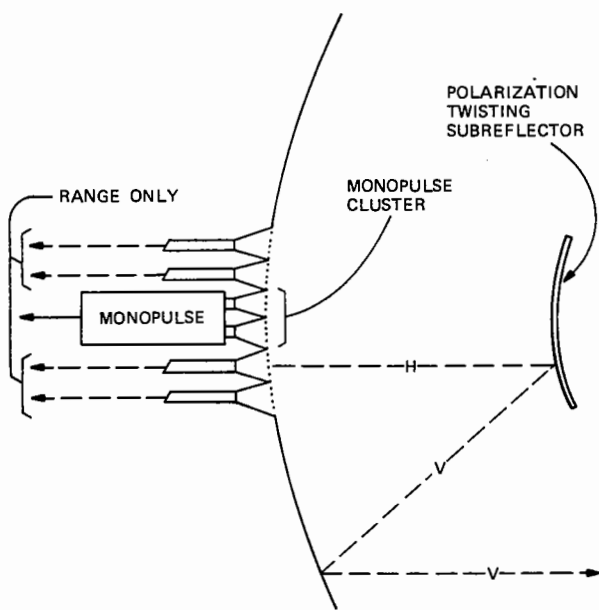


Figure I-22. Fly's Eye Antenna

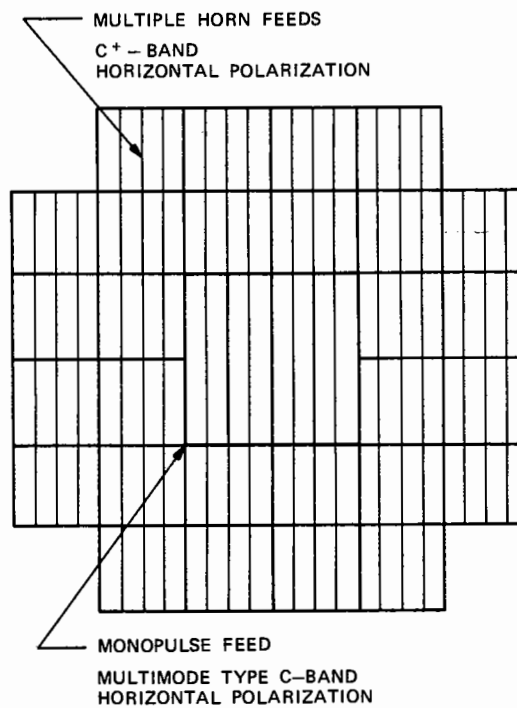


Figure I-23. Fly's Eye Antenna Feedhorn Structure

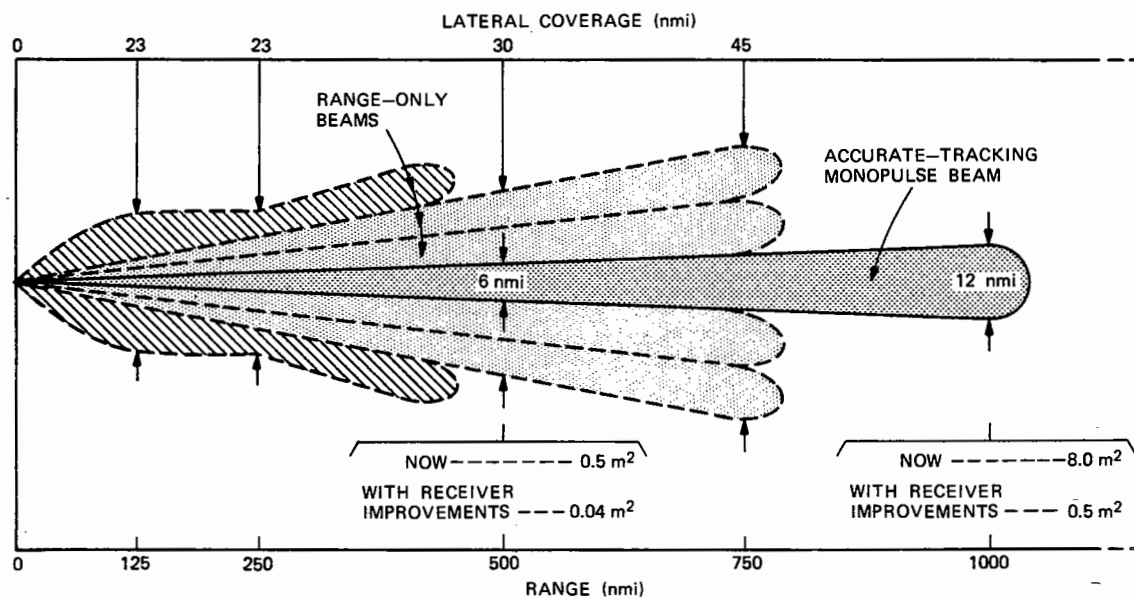


Figure I-24. Fly's Eye Antenna Coverage

On further study of various threat possibilities, the Fly's Eye TTR concept had the major drawback of having a multi-function requirement in a mechanical dish-type radar. Where more than one Reentry Vehicle (RV) was in a cloud of objects, the discrimination function would have to be terminated once the first RV was acquired and precision-tracked for intercept. Furthermore, off-angle data on objects would not be sufficiently accurate for fast acquisition of an RV once it was selected for intercept. The decision therefore was made to have a completely separate Discrimination Radar (DR) and time-share the TTRs to provide precision track of designated targets 6 to 10 seconds before intercept.

The DR became the ZEUS System's instrument to select attacking warheads from debris and accompanying decoys. (For a full description of this radar, see the NIKE-ZEUS System description in Chapter 1 of Part II.) To perform the discrimination functions, the DR would examine a threatening cloud of objects designated by the Acquisition Radar. Radar returns would be processed by an associated DR data processor. The unique feature of this radar was a Cassegrain-type antenna with a movable subreflector that permitted the radar to continuously widen its antenna beam and maintain cloud coverage as the range decreased. The radar could also provide angle information on all objects off the beam, so that defensive missiles could be launched using this data and, prior to intercept, the data could be transferred to a precision TTR for automatic acquisition of the designated target. The radar was to be designed for operation in the L-band with 40 megawatts of peak power from a low-noise maser RF amplifier. The beamwidth was to be continuously variable from 2 to 20 degrees. A cutaway view of the DR antenna together with its range and angle coverage is shown in Figure I-25.

As proposed, the characteristics of the DR returns would be compared with the reentry body radar characteristics stored in the DR data processor. Velocity data obtained by tracking

individual objects would also be used by the data processor to measure the slowdown and determine the ballistic coefficient of the objects. Requirements were established for range-tracking up to 100 tracks with three-coordinate data on 10 tracks. Later system studies of threat scenarios indicated a need for 3 DRs, 6 TTRs, and 12 Missile Track Radars (MTRs) in a firing battery.

Acquisition Radar

The ZEUS System Study Report included a Forward Acquisition Radar (FAR) and a Local Acquisition Radar (LAR) near the firing battery. Further system studies, however, raised serious questions about the defense of the FARs. Systems people raised the question that if the few FARs were integrated and were important elements of the ICBM defense, then each should be defended n times as well as any of the single batteries associated with it (where n is the number of batteries integrated with a single FAR). With the FARs located primarily in Canada, serious questions were raised on just how essential the FAR installations were to the defense. As a result of these studies, the FARs were eliminated and all search and acquisition functions were assigned to the LARs at each battery. The LAR design, however, was changed from a spherical design to a hemispherical Luneberg lens, as proposed for the FAR, since the hemispheric lens could be made less sensitive to nuclear weapon overpressure effects.

In establishing the 500-MHz frequency of the ZEUS Acquisition Radar (ZAR) during the 18-month study, all important radar parameters known at that time and their sensitivity to frequency were taken into account. However, the effect from nuclear burst at very high altitude was not yet known. The existence of this threat was later shown theoretically and partially verified by the high-altitude nuclear test program at Johnston Island.

It became clear through further study that radar-signal attenuation due to nuclear burst

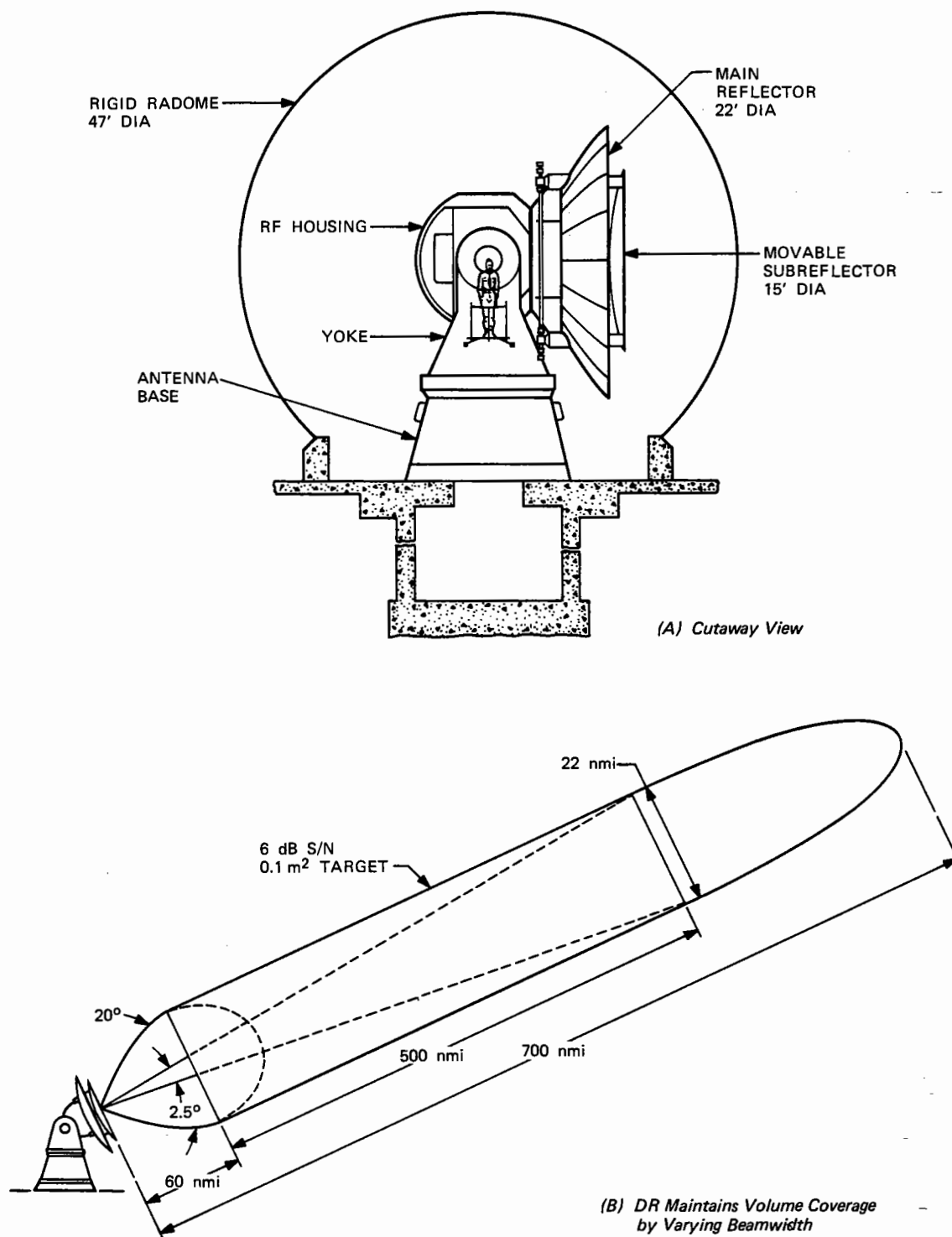


Figure I-25. Discrimination Radar

effects is reduced by the square of the radar frequency. This new factor was taken into account in balancing the optimum frequency of the ZAR. The tactical design chosen was modified for 1000 MHz, although all prototype radars under-way for White Sands Missile Range (WSMR) and Kwajalein were left in the 450-MHz range. While a tactical design radar was never constructed at 1000 MHz, design effort and manufacturing plans for the Luneberg lens dielectric material, receivers, and transmitters were changed to the higher frequency.

ZEUS Missile

The missile design proposed in the 18-month study was to have a jethead-type nose for ballistic missile defense and an active-seeker nose for future air threats. With the new emphasis concentrated on ballistic defense, the seeker development was dropped as mentioned before. The antimissile missile as originally proposed had the aerodynamic control system packaged around the second-stage nozzle for controlling elevons on the main fins entirely separate from the control system for the jetavator motor in the nose section. It soon became apparent that substantial simplification could be achieved by changing to forward aerodynamic canard control combined with thrust-vectoring control. With such a change, two control systems were reduced to one, and all electronic controls would be in the nose section — a major simplification.

This change, however, required that thrust control be obtained by exhausting the thrust motor's hot gases through the aerodynamic control fins. Although the change greatly simplified the electronics and hydraulic control system, the problem was transferred to the mechanical designers who had to design 180-degree reversal exhaust systems through the fins capable of withstanding extreme temperatures for the 12-second operation of the thrust motor. Many failures resulted in the step-by-step solution to this problem, which involved complex surfaces of tungsten and carbon materials. In the end, a highly reli-

able system resulted, but not without pain to the McDonnell-Douglas engineers.

Further Meetings on NIKE-ZEUS System

A complete summary of all the presentations made to high-level personnel in the government during the development years of NIKE-ZEUS would fill many pages. A sample of presentations in 1959 is given below.

- A NIKE-ZEUS meeting at Bell Laboratories, Whippany, in March 1959. The following people attended:
W. A. Holaday — DOD Missile Director
Dr. H. Skifter — DOD
Maj. General D. E. Beach — Dept. of Army
Maj. General W. W. Dick — Dept. of Army
Brig. General A. J. Pierce — North American Air Defense Command (NORAD)
Representatives from AT&T, Western Electric, Bell Laboratories, and McDonnell-Douglas.
- Briefing for Dr. Herbert York and his DOD staff on April 15, 1959, in Washington, D. C. covering possible degradation of system capabilities in the presence of various counter-measures.
- Similar meeting with presidential advisor Dr. James Killian's staff on April 24, 1959, in Washington.
- Army Policy Committee briefing by Army and Bell Laboratories representatives on May 6, 1959, in the Pentagon.
- Lt. Gen. C. E. Hart, Commander-in-Chief of the Army Air Defense Command (ARADCOM) briefed on May 19, 1959; General E. E. Partridge, Commander-in-Chief of NORAD and Air Marshal Sleman, Deputy Commander of NORAD briefed on May 20, 1959.

FIELD TESTING THE NIKE-ZEUS SYSTEM

Suitable locations for field testing the high-performance subsystems of ZEUS and for testing the overall NIKE-ZEUS System represented major new challenges to DOD, the Army Missile Command, and the system prime contractor. Some of the background in arriving at these worldwide test locations is briefly covered here.

Early testing of the ZEUS missile in the fall of 1959 was necessary to establish the extent of the aerodynamic heating problem in such a

high-velocity missile. White Sands Missile Range was selected for these critical tests using a modified HERCULES missile radar for tracking. However, the test flights had to be limited to aerodynamic control below 100,000 feet to keep within the 100-mile limit of the range. Of particular concern was the very long carry range of heavy missile parts in case of missile failure when testing outside the atmosphere with the jet-head thrust control.

Many presentations were made to top DOD R&D officials by the Army and Bell Laboratories showing the very low probability of any missile parts landing in a populated area. Some consideration was given to clearing a 25-mile extension of the range, but even this would not permit full altitude testing of the missile. A decision was therefore made to provide a second missile test site at the Naval Test Range at Pt. Mugu, California. A ZEUS missile track radar, guidance computer, launching equipment, etc., had to be installed at Pt. Mugu to permit testing the ZEUS missile at high altitude outside the atmosphere. As it developed, Pt. Mugu proved to be a poor missile test site for ZEUS because of the severe range-safety restrictions imposed by the Navy resulting in fail-safe delays of only a fraction of a second. This led to a number of good missiles being destroyed early in flight without obtaining any useful data.

The importance of R&D effort and continued field testing for ICBM defense were given top priority in August 1957, when the USSR announced that it had successfully tested an ICBM shortly after placing Sputnik I into orbit. It became increasingly important to ready the ZEUS System for tracking our own incoming ICBMs as soon as they became operational in the Atlantic Test Range. We had to learn if we could successfully track a reentry body through slowdown and, in addition, what discrimination possibilities might be realized. These were questions critical to the success of the ZEUS System. Top priority was given to the installation of a ZEUS Target Track Radar (TTR) on Ascension Island, the target area planned for ICBM launches from Cape Canaveral, Florida. At Whippany, a similar TTR installation

was built simultaneously to provide a local prototype for correcting design problems.

In addition, a full-scale program was begun at White Sands Missile Range. This involved ZEUS missile firings and the installation of major components of the ZEUS System — the large spherical acquisition radar, the associated missile and track radars, and the ground guidance computer — to prove in the designs.

Still to be found, though, was a location where the entire NIKE-ZEUS System could be installed and eventually tested against real offensive targets. Since this one key site had yet to be selected, it was temporarily referred to as "Site X." In January 1958, Bell Laboratories, Western Electric, and Army planners began shopping for a suitable location. The logical place to look was the Atlantic Range area, where Antigua, Barbuda, and Ascension were the first locations considered. These islands, however, were not U.S. possessions and their potential use for missile firings was considered too sensitive. Another location had to be found. General E. Dooley of the Army Rocket and Guided Missile Agency (ARGMA) was the prime mover in arriving at a suitable test site.

Attention then shifted to the Pacific area. Planners pored over maps and studied data and photography of a dozen Pacific islands and atolls. As the study progressed, Kwajalein Atoll in the Marshall Islands began to look more and more attractive, for a number of reasons.

Kwajalein was not owned by the U.S., but it had been under American stewardship continuously since 1944. Kwajalein was once a Navy base, but appeared headed for phaseout. Although it was remote, Kwajalein was still within a day's flying time of Hawaii; Johnston Island, another possible test site, lay almost directly enroute. Most desirable of all, however, were Kwajalein's existing facilities and its geographic location. Kwajalein already had an airstrip, a harbor, housing areas, schools, a hospital, merchandising facilities, and more. In addition, Kwajalein was roughly 4800 miles from the West Coast, a range nearly ideal for testing NIKE-ZEUS against ICBM targets of opportunity to be launched from Vandenberg Air Force Base.

On February 12, 1959, on recommendation of ARGMA, supported by Bell Laboratories and Western Electric, DOD approved a test program for NIKE-ZEUS with Kwajalein as the down-range test site. The sponsoring Army organization would become a tenant on the naval base. Plans called for a Kwajalein-Johnston Island testing complex, with Jupiter Intermediate Range Ballistic Missiles (IRBMs) fired from Johnston Island toward Kwajalein. A year later, however, Dr. Herbert York (then Assistant Secretary of Defense for R&D) ruled that only Air Force Atlas ICBMs launched from Vandenberg would be used as target vehicles for NIKE-ZEUS. Thus, work on Johnston Island was halted. With the beginning of operations at Kwajalein, and for a number of years thereafter until Ascension Island closed, the NIKE-ZEUS System development and test activities were 12,000 miles apart on opposite sides of the globe.

With selection of Kwajalein, project managers, anxious to inspect the new site, chartered a Pan American DC-7 which touched down on Kwajalein on August 4, 1959. The 41 passengers aboard represented various Army agencies, Bell Laboratories, Western Electric, McDonnell-Douglas, and other subcontractors.

The initial work at Kwajalein belonged to the Army Corps of Engineers and their subcontractor, the Pacific Martin Zachry Company, who was responsible for the NIKE-ZEUS technical building and launch facilities. They were followed later by Western Electric equipment engineers and installers responsible for the NIKE-ZEUS installation. On October 1, 1960, Bell Laboratories announced the establishment of the Kwajalein Field Station, and four days later, Mr. R. W. Benfer of Bell Laboratories arrived as its first director.

HIGHLIGHTS OF NIKE-ZEUS R&D TEST RESULTS

ZEUS Missile Tests

The NIKE-ZEUS System Test Program required solution of numerous problems before successful intercept of live ICBM targets could be

accomplished. The ZEUS missile, operating in the lower altitude region with a peak velocity three times that of NIKE-HERCULES, presented aerodynamic heating problems even greater than an ICBM reentry body. During the 18-month initial study and exploratory development effort, McDonnell-Douglas aerodynamic engineers carried out wind tunnel tests at high-supersonic velocities and heat-tested various ablative coatings such as teflon and fiberglass to protect the missile structure. However, the extent of the problem was not fully appreciated until the early ZEUS missiles were flown at the White Sands Missile Range.

Catastrophic failure of these early flights occurred within a few seconds of the missile's reaching peak velocity, and ground cameras recorded what appeared to be a fire aboard the missile prior to its failure. A hydraulic oil fire was suspected and steps were taken to provide heat shields around the hydraulic power system for future missile flights. However, after these changes, fire was still observed in the nose section and missile failure occurred as before. It was not until missile pieces were recovered from the desert range and partially reassembled that the real problem was discovered.

It was clear from examining the four control fins that their large-diameter hardened-steel shafts were sliced off by aerodynamic heating which resulted in loss of control and missile destruction. The control fins were purposely shaped to have wide separation from the missile skin based on aerodynamic wind-tunnel data. After returning to the wind tunnel with much finer measurements of pressures under the fin surface, high pressure points were discovered that resulted in concentrated heat levels. On redesign, a teflon ramp was provided under the control fin giving close spacing. In addition, circular traps were provided to protect the control shaft, much like a radar engineer would design to protect the ball bearings in a shaft from RF power. With these changes, the major aerodynamic problem was solved, opening the way to successful ZEUS missile firings. This ramp design and close

spacing for the control fins was adopted by Martin designers for the SPRINT missile some six years later. As a result, even though SPRINT's velocity was higher at lower altitudes, with much greater aerodynamic heating, the same basic design was successful in protecting its control fins.

The other major step forward in missile design was providing aerodynamic and thrust control from the same control fins. The problem of handling the hot gases of the third-stage motor through a manifold system into the control fins was solved by extensive ground testing with many configurations of tungsten and carbon materials. As a result, relatively few failures of the jet control system occurred in early flights at high altitudes from the Pt. Mugu range.

One important lesson learned from the ZEUS development firings, and reaffirmed years later with SPRINT, is that there is no substitute for missile testing over a ground range where the pieces can be recovered and the cause of failure found. This is especially true where the state of missile art is being advanced significantly and where there is a limit to the number of missile-borne sensors capable of detecting the cause of failures. A summary of these early ZEUS missile firings is given in Table I-2.

TTR-Whippany/Ascension

The first attempt of the TTR at Ascension Island to track an ICBM (Titan) fired from Cape Canaveral took place on March 29, 1961. This attempt failed because the TTR computer did not properly translate trajectory data from Cape Canaveral to position the antenna needle beam. However, on May 28, 1961, an ICBM from Cape Canaveral was tracked along its trajectory down the Atlantic Missile Range. These initial tracking tests were not perfect, but for the first time they did permit analysis of target characteristics and measured our ability to track such high-speed targets.

Concurrently, a similar TTR at Bell Laboratories, Whippany, was used to investigate these early automatic tracking problems. On May 6, 1961, the Whippany TTR successfully tracked the Echo satellite at distances up to 1400 miles. Later in the year, four ICBMs (two Atlas and two Titan) were successfully tracked by the Ascension TTR with continuous tracks of up to 100 seconds. In the last tracking, the Atlas had a nose cone designed for NIKE-ZEUS tests at Kwajalein. The nose cone had the same radar

Table I-2
Summary of Early ZEUS Firings

	No Test	Failures	Partial Success	Full Success	Total
WSMR PT. MUGU KWAJALEIN	Development Firings				
	-	15	7	34	56
	-	5	4	10	19
	-	2	1	1	4
	Total				79
WSMR KWAJALEIN	Missile Performance in System Tests				
	2	3	0	11	16
	5	12	7	28	52
	Total				68
	Total Firings				147

cross section as a regular Atlas nose, but it also had special shaping to reduce the plasma-sheath effect on radio signal propagation. This was required for a radio doppler miss-distance indicator to be used later in system tests at Kwajalein.

White Sands Missile Range Tests

Initial operation of the ZEUS Acquisition Radar (ZAR) as a system was accomplished at WSMR in June 1961. Typical targets were automatically acquired and tracked in three dimensions. The targets included balloons, aircraft, parachutes deployed from Highball missiles, and HERCULES missiles. These three-dimension tracks were transferred to Battery Control, where they were automatically acquired by the TTR subsystem.

Such tests were historic in that the ZAR was the first track-while-scan radar system to successfully cover the entire hemisphere surrounding a radar position, detect the objects in that space, remember their past positions, and predict where the objects would next be in three dimensions — all automatically, beginning with initial detection. Even today, considering the advances with phased-array radar systems, the ZAR represents the most efficient wired-logic system for detection, report sorting, track initiation, and track processing ever developed. Its stacked-array receivers on three rotating arms also provided the highest data rate (measured for full hemispheric coverage) yet achieved, and is not matched even by today's phased-array systems.

The TTR radar at WSMR was made operational without difficulty, based on previous testing with a similar design at Whippany and Ascension. The other major subsystem was the Battery Control Building, which contained two Missile Track Radars, the Target Intercept Computer, and data communication equipments. The ZEUS missile had been under development at WSMR for the previous two years, using modified HERCULES equipment for ground guidance.

All elements of NIKE-ZEUS were checked out and system demonstrations begun in November

1961. On December 14, 1961, a major ABM system milestone was passed with the successful interception by a ZEUS missile of a NIKE-HERCULES target missile. A second successful ZEUS system test against a HERCULES missile was carried out in March 1962. Major attention then shifted to the forthcoming system tests at Kwajalein against ICBM targets.

NIKE-ZEUS System Tests at Kwajalein

The entire NIKE-ZEUS System, consisting of the hemispheric ZEUS Acquisition Radar (ZAR), two Target Track Radars (TTRs), one Discrimination Radar (DR), three Missile Track Radars (MTRs), and Battery Control Equipment with Target Intercept Computer and four ZEUS launch cells, was installed on Kwajalein and ready for the first test of intercepting an ICBM on June 26, 1962. The photographs in Figures I-26 and I-27 show this installation.

In the first attempt (probably in the world) to intercept an ICBM fired 4500 miles down range from Vandenberg Air Force Base, the ZAR started tracking the tank at 446 nautical miles and immediately transferred the track to a TTR. The TTR transferred from the tank to the nose cone (the RV) at 131 nautical miles. When the tank began to break up, a clutter mode of operation was initiated in which any significant departure of the RV from a predicted trajectory would indicate that debris had taken over the tracking gate. The radar would then use extrapolated data to "coast" the range gate so as to reacquire the RV after it passed through the tank clutter. Unfortunately, in this first test, the clutter mode did not properly indicate when tracking of the RV was lost. However, the ZEUS missile would not have achieved intercept because of malfunction.

Although this first system test was a failure, it did emphasize the need for sound logic and reliable circuitry to properly track RVs through severe tank clutter. This early lesson carried through to the current tactical SAFEGUARD System tests at Meck Island, where tracking through



Figure I-26. NIKE-ZEUS System Installation at Kwajalein, Looking Toward Lagoon



Figure I-27. NIKE-ZEUS System Installation at Kwajalein, Aerial View

clutter has been satisfactorily demonstrated under even more stringent conditions.

The first partially successful intercept of an Atlas D ICBM occurred on July 19, 1962, with the ZEUS missile coming within 2 kilometers of the target vehicle at intercept. The large miss distance resulted from the ZEUS missile losing hydraulic power due to excessive roll during the last 10 seconds before intercept. The second ICBM intercept — this one fully successful — took place on December 12, 1962, with a miss distance well within acceptable limits. A two-missile salvo was planned for the first time with this test, but the second missile failed because of an instrument failure.

Another two-missile salvo intercept of an ICBM was attempted on December 22, 1962. In this test, the first missile missed the target by 200 meters at a range of 55 nautical miles. Again, dual interception did not occur because of a failure with the second missile.

A summary of the live-intercept system tests of ZEUS, extending through November 1963, is given in Table I-3. Of 13 system tests, nine were successful, three were partially successful, and only the first failed. Photographs of some of

these intercepts are shown in Figures I-28 through I-31.

With completion of the above live-target system tests and the decision not to deploy the NIKE-ZEUS System, no further live ICBM target tests were carried out. However, further tests under the Satellite Test Program and system tests against taped live targets or simulated ICBMs continued at Kwajalein for another year and a half until June 1965.

Miss-Distance Indicator for ZEUS Tests

Miss distance between target and defensive missile at the instant of commanded warhead burst is the principal measure of performance of an AICBM system. To avoid suspicion of any self-generated miss distance within the ZEUS System, considerable effort was directed at finding an independent miss-distance recorder for the ZEUS System Tests at Kwajalein. One method pursued involved a radioactive source in the ICBM nose cone and a detection system in the ZEUS missile. This work was carried out starting in April 1961 on subcontract with the Giannini Control Corporation. However, a simpler radio-doppler, Miss-Distance Indicator (MDI) was adopted

Table I-3
Summary of Live Target Systems Tests

Mission Number	Date	Target	Remarks
K1	6-26-62	Atlas D	Failure
K2	7-19-62	Atlas D	Partial success
K6	12-12-62	Atlas D	Success (first missile in salvo)
K7	12-22-62	Atlas D	Success (first missile in salvo)
K8	2-13-63	Atlas D	Partial success
K10	2-28-63	Atlas D	Partial success
K17	3-30-63	Titan I	Success
K21	4-13-63	Titan I	Success
K15	6-12-63	Atlas D	Success
K23	7-4-63	Atlas E	Success
K26	8-15-63	Titan I	Success
K28	8-24-63	Atlas E	Success
K24	11-14-63	Titan I	Success

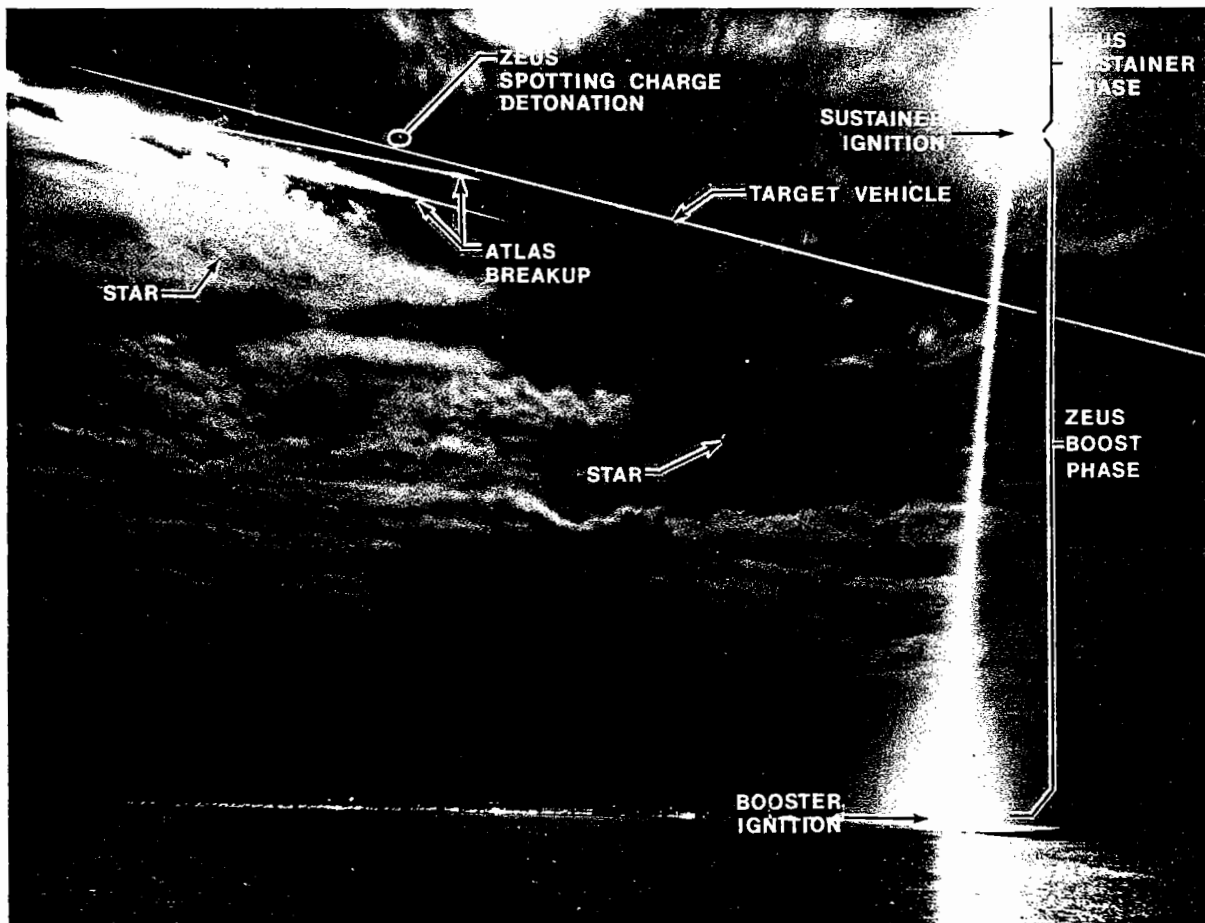


Figure I-28. A 75-second time exposure of the K-2 Atlas D intercept at Kwajalein on July 19, 1962.
Picture was taken from Carlson Island (5 miles northwest of Kwajalein).

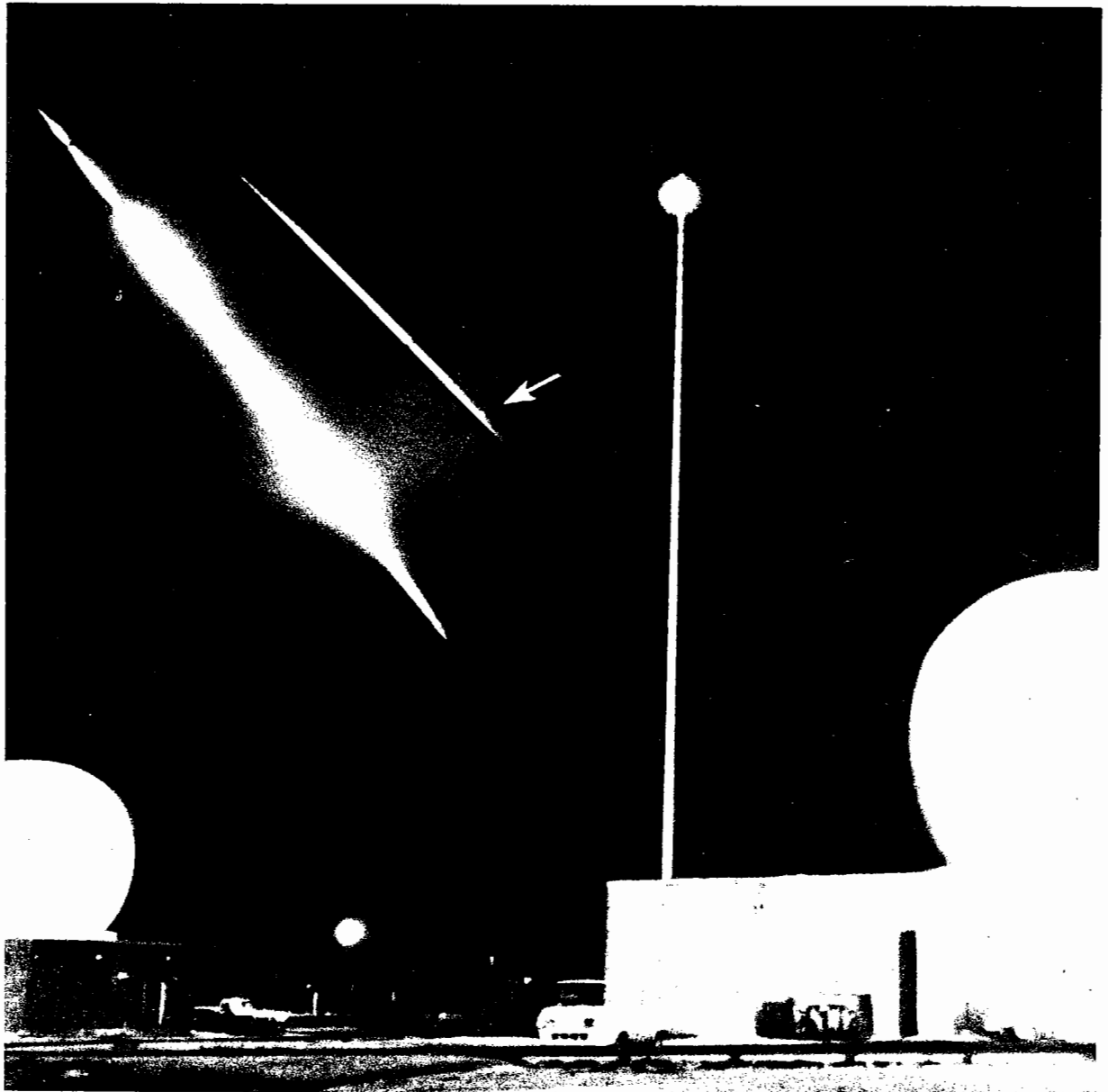


Figure I-29. View of the August 15, 1963, K-26 Titan I intercept test at Kwajalein. The ZEUS thrust-vector motor trail and spotting detonation (arrow) mark the successful intercept.

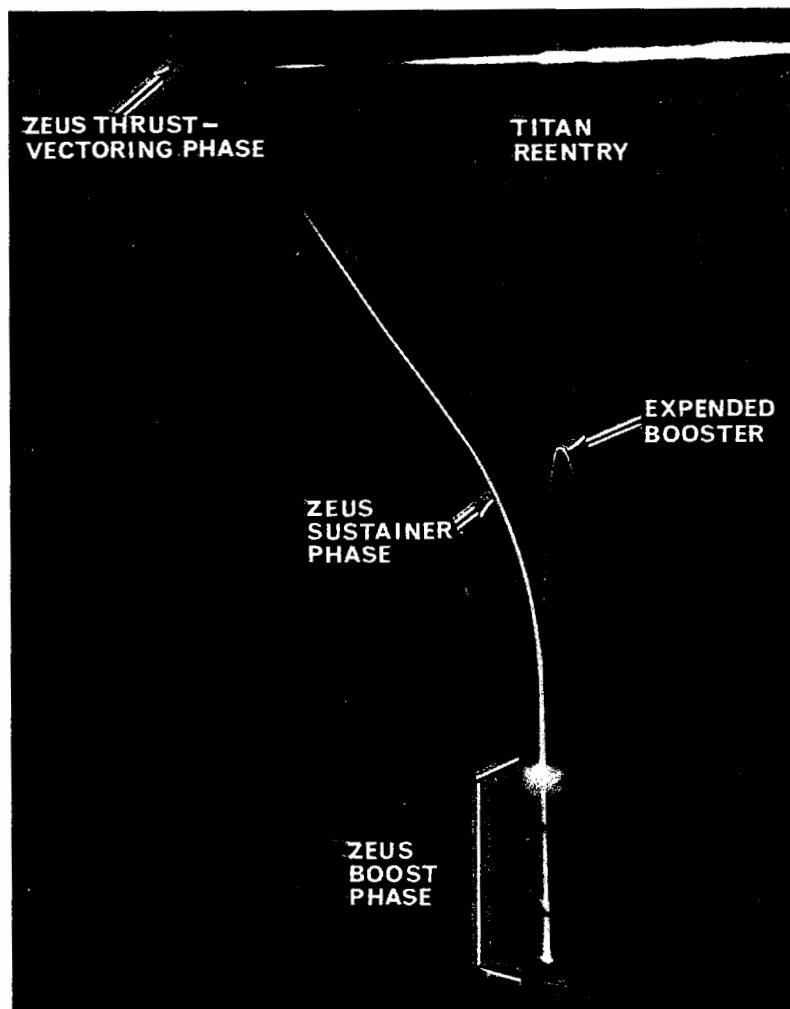


Figure I-30. A 120-second time exposure of the March 30, 1963, K-17 intercept test at Kwajalein. This was the first intercept test to be conducted against a Titan I-boosted target vehicle.

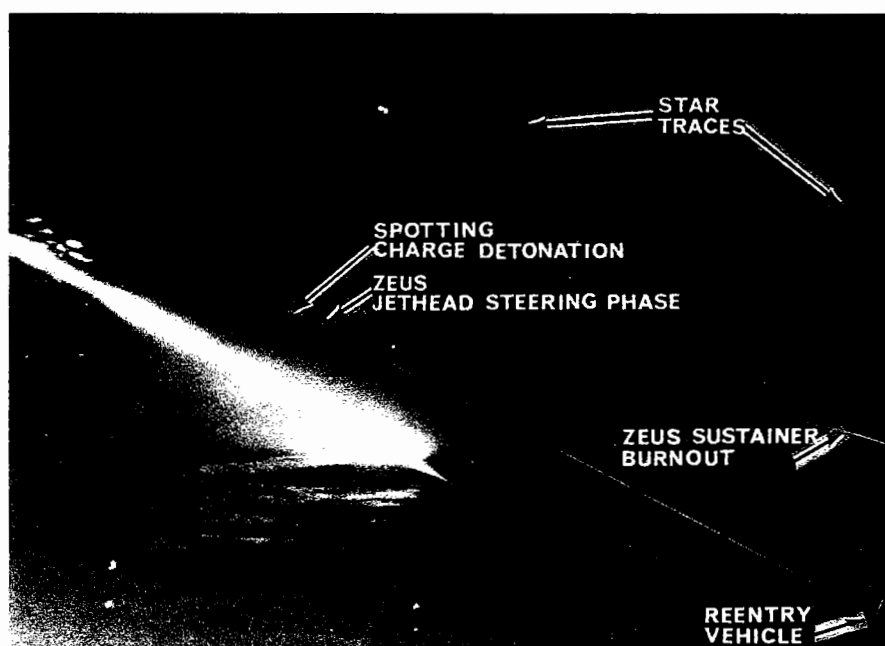
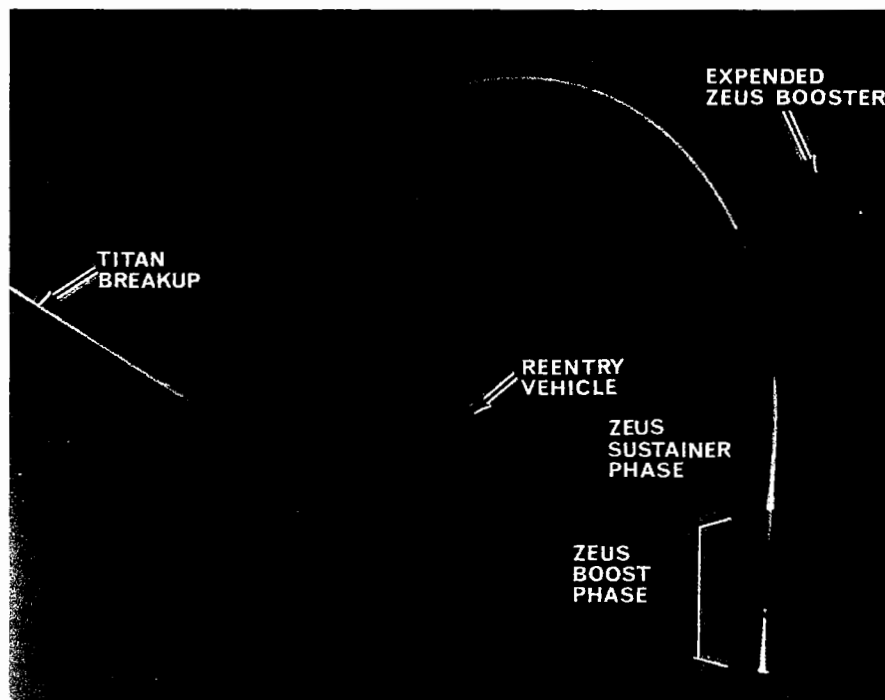


Figure I-31. Two 120-second time exposures of intercept test K-21 conducted April 13, 1963.
 Top: Overall view of test taken from Enubuj (Carlson) Island.
 Bottom: View showing successful intercept (spotting charge detonation) taken from Ennylabegan (Carlos) Island.

after its successful development by the Physical Science Laboratory (PSL) of New Mexico State University.

Well in advance of the ZEUS System Tests in 1960, PSL was contracted to adapt a Navy AN/US Q-11 radio-doppler, miss-distance measuring set to the environment of Highball and Speedball test-rocket targets being developed for ZEUS tests, and to extend this adaption to the ICBM target environment. The success of this system was dependent on tests carried out in December 1961, in the Atlantic Missile Range, which proved that a signal from a UHF radio transmitter in a reentering ICBM nose cone could penetrate the surrounding plasma sheath. The miss-distance instrumentation planned required such a transmitter in the ICBM and a compatible receiver in the ZEUS missile. The resultant shape of the doppler signal telemetered to ground during intercept, when correlated to the burst-command time, provided an independent measurement of miss distance. This system was made ready for the ZEUS Systems Tests at Kwajalein for live ICBM targets and provided quite accurate measurements matching reasonably well with self-generated miss-distance numbers within the ZEUS equipment.

Consideration was given to adapting the same MDI System for the SAFEGUARD System Tests on Meck. However, the cost of converting the signals to the new telemetry S-band, adapting the system to the much tougher SPRINT environment, and a new requirement for encrypting signals from missile to ground led the Army to cancel this effort. Independent miss distances in the SAFEGUARD tests were obtained from ZEUS TTR tracks of target and missile, combined with optical measurements.

SATELLITE TEST PROGRAM

At request of the Secretary of Defense, the Army was asked in early 1962 to prepare the ZEUS System on Kwajalein for the eventuality of having to intercept and destroy satellites. Bell Laboratories advised the Army that the ZEUS

System could be readied for a satellite-intercept demonstration at Kwajalein by May 1963.

Toward this goal, the first DM-15B series ZEUS missile, modified for satellite-intercept tests, was fired at White Sands Missile Range December 17, 1962. The missile successfully intercepted a designated stationary space point at an altitude of 100 nautical miles. This missile reached the highest altitude of any missile launched at White Sands to that date. The DM-15S series was modified for this high-altitude, long-range application to include a two-stage (instead of a single-stage) hydraulic pumping unit, a high-performance Polybutadiene Acrylic Acid (PBAA) booster propellant, and a 5-minute (instead of the normal 2-minute) battery capability. A second DM-15S series missile was fired at WSMR February 15, 1963. In this flight, intercept of space point occurred at an altitude of 151 nautical miles.

The third DM-15S, the first to be tested at Kwajalein, was fired March 21, 1963 to intercept a simulated satellite target at an altitude of 112 nautical miles. The flight was unsuccessful because the MTR failed to properly track the missile. A second missile was fired from Kwajalein April 19, 1963 to intercept a simulated satellite at 160 nautical miles. In this case, loss of beacon return 30 seconds before intercept prevented proper mission completion.

The first successful satellite intercept test and demonstration occurred May 24, 1963, at Kwajalein against a real target. The target was a special "Agena D" stage of the Air Force 162A series. This target was instrumented with the NIKE-ZEUS single-path doppler, miss-distance measuring equipment discussed earlier, and a Luneberg lens for radar augmentation. The TTR first acquired the satellite at long range, and the missile was launched after a period of precision tracking. A close intercept was achieved, well within what was expected to be the lethal range of the ZEUS nuclear warhead.

From this time on through 1964, satellite-intercept missiles were maintained at Kwajalein with one always checked out and in a state of readiness. Arrangements were made by the Army to make a ZEUS nuclear warhead available if called upon for a real satellite mission. (Army personnel on Kwajalein would be responsible for launching the missile in a real defensive operation.) Bell Laboratories and McDonnell-Douglas personnel went through many test runs to minimize the time required to launch such a missile. In addition, successful test intercepts were carried out against simulated satellites and booster space targets in 1964 as part of the training of Kwajalein test personnel. Fortunately, intercept and destruction of an enemy satellite were never ordered. After 1964, we were relieved of this "ready" requirement and were once more able to concentrate fully on the normal R&D test program.

DISCRIMINATION AND SUPPORTING RESEARCH ON ZEUS PROGRAM

As the ZEUS R&D program moved forward, continuing and expanded effort was carried out on the major problem of discrimination. To supplement its own internal effort, Bell Laboratories established subcontracts with Cornell Aeronautical Laboratories (now Calspan Corporation) and Avco Everett Research Laboratories. The principal types of discrimination under investigation in the early 1960's were aerodynamic slowdown, scintillation, polarization, frequency diversity, short pulse, and infrared/optical. Other supporting research was concerned with blast tests to determine the hardness of ZEUS ground facilities, atmospheric effects of nuclear bursts, plasma studies of reentry bodies, and warhead requirements.

The Avco Everett investigation concentrated on infrared, visual, and ultraviolet reentry effects and was carried out with the aid of the NIKE-ZEUS TTR on Ascension Island. Phase I, which began in early 1961, determined discrimination criteria with simple instrumentation in a

DC-6 aircraft operating out of Ascension. Optical/infrared data, particularly on wake spectra, were obtained on 14 of 17 ICBMs fired toward Ascension Island in 1961. Phase II started in early 1962, with more sophisticated instrumentation in the aircraft and on the ground. This permitted target designation between the TTR and the optical tracker in the aircraft so that the same object tracked by the TTR could be correlated with optical/infrared data. A HERCULES missile track radar installed on Ascension Island tracked the beacon in a new WV-2 aircraft equipped with a stable reference platform. Positional data on incoming objects could then be transmitted in both directions between aircraft and TTR. Later on, the same aircraft was used at Kwajalein to obtain additional data.

Although useful optical/infrared data were obtained in these tests, no solid discrimination criteria were uncovered to warrant adding optical airborne trackers to the ZEUS system. Furthermore, in attempting to correlate radar and airborne optical data, these tests forcefully demonstrated the practical problems of trying to incorporate such an airborne platform into a tactical system.

In 1961, Bell Laboratories carried out analysis of the effects of plasma on radar observation. It was hoped that the plasma (ionic layer) sheath caused by aerodynamic heating might provide additional means of discrimination against decoys. Other work at Bell Laboratories in this time period showed that extremely short pulses could determine the length of a target and thus provide a possible discriminant.

Major effort at Cornell Laboratories in 1961 and 1962 was directed at testing various radar signatures in the laboratory. These signatures included scintillation, polarization, and frequency diversity. Both Bell Laboratories and Cornell examined methods of incorporating a number of radar signatures into a combined "likelihood" number that would reveal if a given object was a warhead, since no one signature had proved powerful

enough to do this by itself. Other work at Cornell Laboratories, in cooperation with the Ballistic Research Laboratory, involved a study of Atlas booster fragmentation with high-speed cameras.

The discrimination studies and supporting research carried out during this period of the early 1960's provided the basis for continued effort in the years ahead. The lessons learned from the ZEUS program proved valuable in the on-going R&D work for future ABM systems.

ZEUS R&D TEAM

The ZEUS R&D program was a team effort directed by Bell Laboratories with 24 major subcontractors and 89 other subcontractors located in many areas of the country. There were also hundreds of additional suppliers who provided components directly to Western Electric and Bell Laboratories or their subcontractors. In addition to having overall system responsibility, Bell Laboratories designed many of the major system elements. The Western Electric Company in North Carolina manufactured the R&D models of system elements designed by Bell Laboratories and installed, tested, and operated the R&D models at all test sites.

Douglas Aircraft Company (now McDonnell-Douglas) was responsible for the design and development of the missile (less the Bell Laboratories guidance unit), the launcher, and associated ground handling equipment. The major subcontractors and their areas of activity are listed in Table I-4.

ZEUS MULTIFUNCTION ARRAY RADAR — MAR-I

In 1960, Bell Laboratories conducted fundamental investigations of phase-controlled scanning antenna arrays for possible application to the ZEUS System. The potential advantages of radars using such antennas as seen at that time were: (1) increased blast resistance capability, (2) greater power handling capability, (3) flexibility

of beam adjustment, and (4) capability of combining several functions in one radar. As discussed further under NIKE-X in Chapter 2 of Part II, phased arrays with their inertialess beams would provide greater capability against the high-traffic-level threat. This consideration became one of the principal technical reasons advanced in 1963 for not proceeding with tactical deployment of the original NIKE-ZEUS System. (There were, of course, many other reasons apart from strictly technical considerations in the 1962-1964 time period for not deploying an ABM system.)

In these forward-looking studies supported by the ZEUS Program, phased-array scanning was analyzed with respect to such factors as (1) element pattern directivity, (2) array pattern deterioration with scanning, (3) pointing-accuracy degradation with scan angle, and (4) frequency. The major steps involved in an engagement from acquisition of the target through intercept were quantitatively evaluated in terms of phased-array radar characteristics and the necessary data processing.

On November 18, 1960, at Redstone Arsenal, Bell Laboratories representatives gave a presentation to ARGMA on the subject of phased arrays in a terminal defense. The purpose of the meeting was to report on the study work performed to date and to provide a basis for a proposal to do exploratory phased-array work.

Authorization to proceed with the design of a prototype model of a phased array, based on the Bell Laboratories study, was granted June 1961. Western Electric had the prime contract and Bell Laboratories was responsible for supervising the design. Sylvania was selected as the major subcontractor for detailed design of the prototype model and fabrication of the model to be installed at WSMR. Sperry Rand Univac was given the responsibility for a Phase II digital computer as well as the programming for the prototype radar. Bell Laboratories was also responsible for major system elements including the large number of solid-state RF amplifiers.

Table I-4
Major NIKE-ZEUS Subcontractors

Company	Location	Area of Activity
Goodyear Aircraft Corporation	Akron, Ohio	ZAR Receiving and Transmitting Antennas DR Antenna Mount and MTR Reflector
Armstrong Cork Company Dow Chemical Company	Lancaster, Pa. } Midland, Mich. }	ZAR Lens Media
Continental Electronics Mfg. Co.	Dallas, Tex.	ZAR Transmitter
Texas Instruments, Inc.	Dallas, Tex.	Tactical Displays
Sperry Gyroscope Company	Great Neck, N. Y.	DR and TTR Transmitters
Vickers, Inc.	Waterbury, Conn.	DR and TTR Antenna Hydraulic Drives
Narmco Mfg. Co.	La Mesa, Cal.	DR and TTR Antenna Reflectors
Continental Can Co. Allis Chalmers	Chicago, Ill. Akron, Ohio	TTR Antenna Mount Steel Weldments for TTR Antenna Mount
Steel Products Engineering Co.	Springfield, Ohio	MTR Antenna Mount
Sperry Rand Univac	St. Paul, Minn.	Target Intercept Computer
Douglas Aircraft Company	Santa Monica, Cal.	Missile, Launcher, and Missile Handling Equipment
Thiokol Chemical Co.	Huntsville, Ala.	Booster and Sustainer
AiResearch Mfg. Co. Epsco West	Beverly Hills, Cal. Anaheim, Cal.	Missile Hydraulic Power Unit Test Equipment
Stromberg-Carlson	Rochester, N. Y.	Test Equipment
Lear Inc.	Grand Rapids, Mich.	Stable Platform
Burns and Roe, Inc.	New York, N. Y.	Architectural Engineering for the R & D program
New Mexico State University	University Park, N.M.	Test Targets
Airborne Instruments Laboratories	Mineola, N. Y.	ZAR Antenna Measurements
Cornell Aeronautical Laboratories	Buffalo, N. Y.	Decoy Discrimination Studies
Avco Everett Research Laboratory	Everett, Mass.	Infrared Decoy Discrimination Studies
Varian Associates	Palo Alto, Calif.	High-Power Klystrons for ZAR Transmitter

Originally, the prototype radar was named the ZEUS Multifunction Array Radar (ZMAR). Although not part of the ZEUS System at that time, it was considered exploratory effort that might be phased into the ZEUS System at a later date. Later, the radar was referred to as MAR-I. The basic concept was to employ four installations to provide 360 degrees in azimuth; however, only one hardened installation was installed at WSMR for evaluation. Ground breaking for the MAR-I technical facility took place at WSMR in March 1963. Construction of these facilities was the responsibility of the Army Corps of Engineers and their contractors. An aerial view of the installation is shown in Figure I-32.

One of the important lessons learned from the hardware installation and test of the MAR-I radar sensor was the need to thoroughly test in the

laboratory all the elements duplicated in large numbers in an array radar. A number of design faults resulting in poor reliability were uncovered in such elements as the Traveling Wave Tube (TWT) and its associated filament transformer. This resulted in an expensive redesign and replacement program because of the large number of such elements involved. With this background of experience, designers of the later phased-array radars, MSR and PAR, were required to run exhaustive laboratory performance and reliability tests on elements that were to be duplicated thousands of times in the full radar. Reference should be made to Chapter 8 of Part II on PAR, for discussion of the Limited Engineering Development Model (LEDMD) set up for this specific purpose at General Electric.

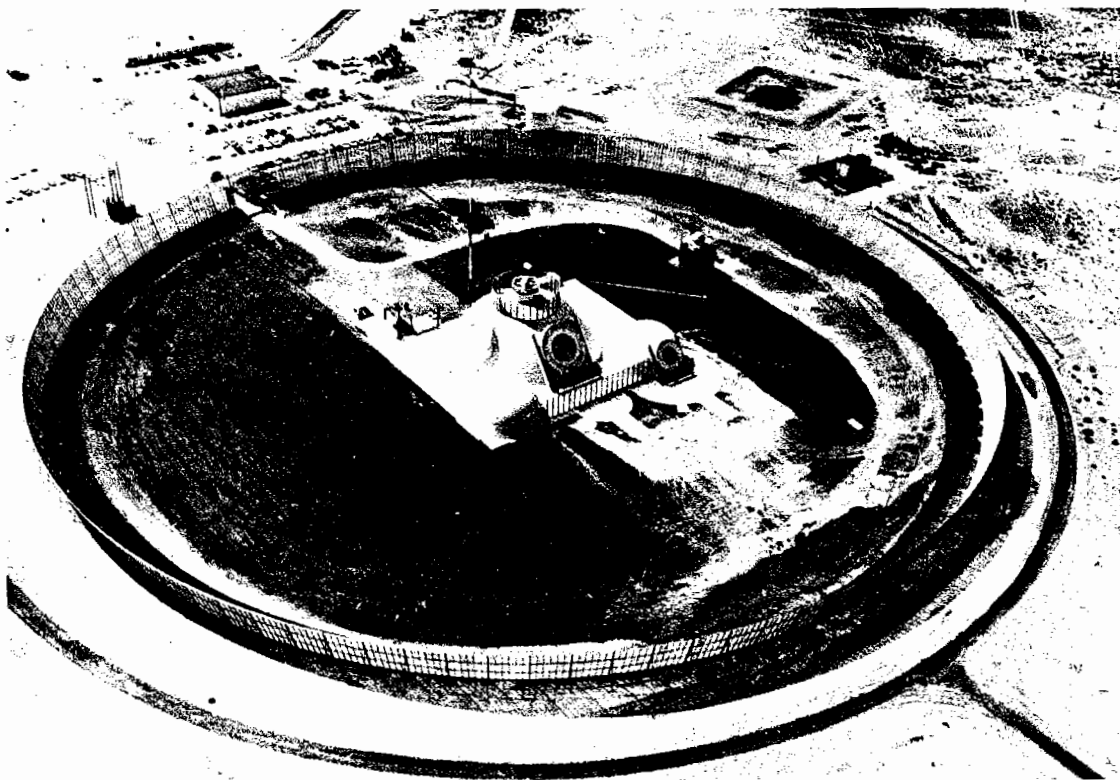


Figure I-32. Aerial View of MAR-I at White Sands Missile Range

The testing of the MAR-I at WSMR demonstrated the feasibility of using a phased-array radar for a multiplicity of simultaneous functions, and verified the analytical predictability of array performance in a multifunction role. Among the important test results in these demonstrations were:

- Extensive external antenna pattern measurements of single beams and multiple-beam clusters which closely matched both the internal antenna pattern measurements (using the element alignment network) and the patterns calculated from basic phase and amplitude data of the individual receive and transmit antenna elements
- Stability and repeatability of these antenna patterns over extended time periods
- The ability to form and steer various search, track, and discrimination beam clusters with desired precision
- Dynamic tracking accuracy of airborne and ballistic targets and satellites
- Absolute tracking accuracy from precision tracking of solar microwave radiation.

The system demonstrated the inherent broad frequency-bandwidth capability of arrays using time-delay steering in both the transmit and receive modes. It demonstrated the ability of microsecond switching in time and the use of multiple frequencies for separation of simultaneous radar functions using various beam-cluster arrangements. An important demonstration was the use of a centralized digital computer to control all radar functions and execute large-scale, real-time data processing. This included generation and execution of all the beam forming and tracking functions, full automatic system control with provision for manual intervention, search detection and verification, precision tracking in range and angle, fault monitoring, display, and numerous other simultaneous and sequential system operations. In general, these tests verified on a full-scale basis the satisfactory performance of a multifunction array radar in a real target environment. Further information on MAR-I characteristics is given in Chapter 2 on NIKE-X.

NIKE-X R&D SYSTEM

The Secretary of Defense on January 5, 1963 directed the priority development of an ABM defense system incorporating the most advanced components and techniques available. This new system was temporarily designated NIKE-X, pending selection of a more appropriate name. The Army NIKE-ZEUS Project Manager was assigned the task of implementing the new program. Bell Laboratories, as the system's development director on behalf of Western Electric Company, the prime contractor, was called upon to redefine the system taking full advantage of the latest technical state-of-the-art, moderated by economic restraints of production costs and time restraints of deployment schedules.

System Objectives

In carrying out this system responsibility, Bell Laboratories was to conduct studies and R&D work directed to this forward-looking anti-missile defense system which would include a combination of the high-performance SPRINT type missiles and a phased-array radar. The R&D Field Tests at Kwajalein, WSMR, and Ascension, as previously described, were to continue essentially as planned to provide fundamental information needed for the new system. The technical reasons for continuing development at this time, rather than deployment, involved a concern that the USSR could soon develop (by the early 1970's) the ability to mount a high-traffic threat with decoys and chaff that could only be discriminated endoatmospherically. However, there were many sensitive political reasons in the decision not to deploy the NIKE-ZEUS System in 1963. Among these were (1) the high cost of a complete defense for the country, (2) ABM defense would be de-stabilizing, and (3) the defense would provide only for principal cities and industrial regions, leaving major areas of the country undefended.

The basic plans for phased-array radar tests at WSMR to prove whether a single radar could perform acquisition, discrimination, and track

of targets and defensive missiles were underway in 1963. Furthermore, an advanced ABM study group at Bell Laboratories had shown the advantages of a high-acceleration, short-range SPRINT-type missile to defend a limited area when discrimination of the RV was delayed until it reached low altitude. Actually, by 1963, the basic concept of the NIKE-X System was well underway at Bell Laboratories with the objective of terminal defense of the larger U. S. cities against the sophisticated USSR attack postulated for the mid-1970's.

Already under study for NIKE-X was a much more powerful multifunction array radar than the MAR-I planned for WSMR tests. This radar, referred to as MAR-II, was assigned the role of search, track, and discrimination and was considered the centerpiece for city defense. A second smaller radar, called the Missile Site Radar or MSR, was proposed to provide multiple tracking of defensive missiles and short-range target tracking. Later on, as a result of further study involving the economics of ABM defense for smaller cities, the MSR role was increased to provide search, acquisition, and track of incoming targets and thus provide autonomous operation in the defense of smaller cities. The long-range NIKE-ZEUS missile was carried over to the NIKE-X System concept* to supplement the short-range SPRINT missile. Further information on the NIKE-X System and the threat postulated is given in Chapter 2.

SPRINT Missile Development

On October 1, 1962, three contractors were given study contracts by Bell Laboratories for the proposed new SPRINT-type missile. When their proposal arrived on February 1, 1963,

seven technical subcommittees composed of representatives from Bell Laboratories, Western Electric, and the Army Missile Command were appointed to examine the proposals and select the successful contractor for SPRINT development. On March 18, 1963, the Army announced the selection of Martin Marietta as the development contractor for the SPRINT missile. Development work was to be carried out in the Martin plant at Orlando, Florida; with initial testing of the missile at WSMR and subsequent system firings at Kwajalein.

What followed through the next twelve years was the successful development and test firing of a most challenging missile, when viewed from the state of missile technology in the early 1960's. The SPRINT missile, with its acceleration to high velocity within the dense atmosphere at low altitudes, produced such high aerodynamic heating that its skin surface could be cooled with an oxy-acetylene torch! There were several years of pure agony to the Martin and Bell Laboratories engineers in overcoming the many problems of the early flight program. However, in the end, these problems were overcome and a highly reliable SPRINT missile was available for the SAFEGUARD System Tests at Kwajalein. For a discussion of the characteristics and flight history of this development, refer to Chapter 9 on the SPRINT Missile Subsystem.

Missile Site Radar — MSR

Various configurations and parameters for the MSR were studied at Bell Laboratories. The agreed upon concept was an S-band, phased-array radar with a single transmitter or receiver time sharing a single phase-controlled antenna face. The ability to change direction of the beam very rapidly was established as a requirement to provide high traffic-handling capability. After competitive proposals were received from seven companies, the Raytheon Company, Wayland, Mass., was awarded a contract for development in December 1963. The initial Phase I effort combined engineering

*Principal features of the NIKE-X System concept were summarized in a paper, "NIKE-X, Design Approach and Preliminary Description" which was presented at the Anti-Missile Research and Advisory Council (AMRAC) Symposium, April 15, 1963, in Monterey, California.

personnel from Bell Laboratories and Raytheon to define the MSR in detail and highlight areas requiring maximum effort to meet development schedules. Varian Associates was selected to provide the high-power transmitter output tubes.

In early 1965, a decision was made to provide the MSR with its own data processing and command and control equipment to permit autonomous operation independent of a Defense Center in smaller city defense. Higher performance requirements were established for the MSR to carry out search, acquisition, and longer-range target tracking. The major change was a five-fold increase in average transmitter power. These changes were

formulated with Raytheon in June 1965. Once this was done, the schedule for power-on of a two-face MSR (the tactical version would have up to four faces) on Meck Island in the Kwajalein Atoll was set for May 1968. An artist's view of the proposed tactical installation is shown in Figure I-33.

The digital beam-forming and steering logic for the MSR was the responsibility of Raytheon. However, in the interest of standardization, the same type of hardware designed for the Bell Laboratories data processing equipment was supplied by Western Electric to meet Raytheon's logic requirements. Full details of the MSR development and performance are covered in Chapter 7.

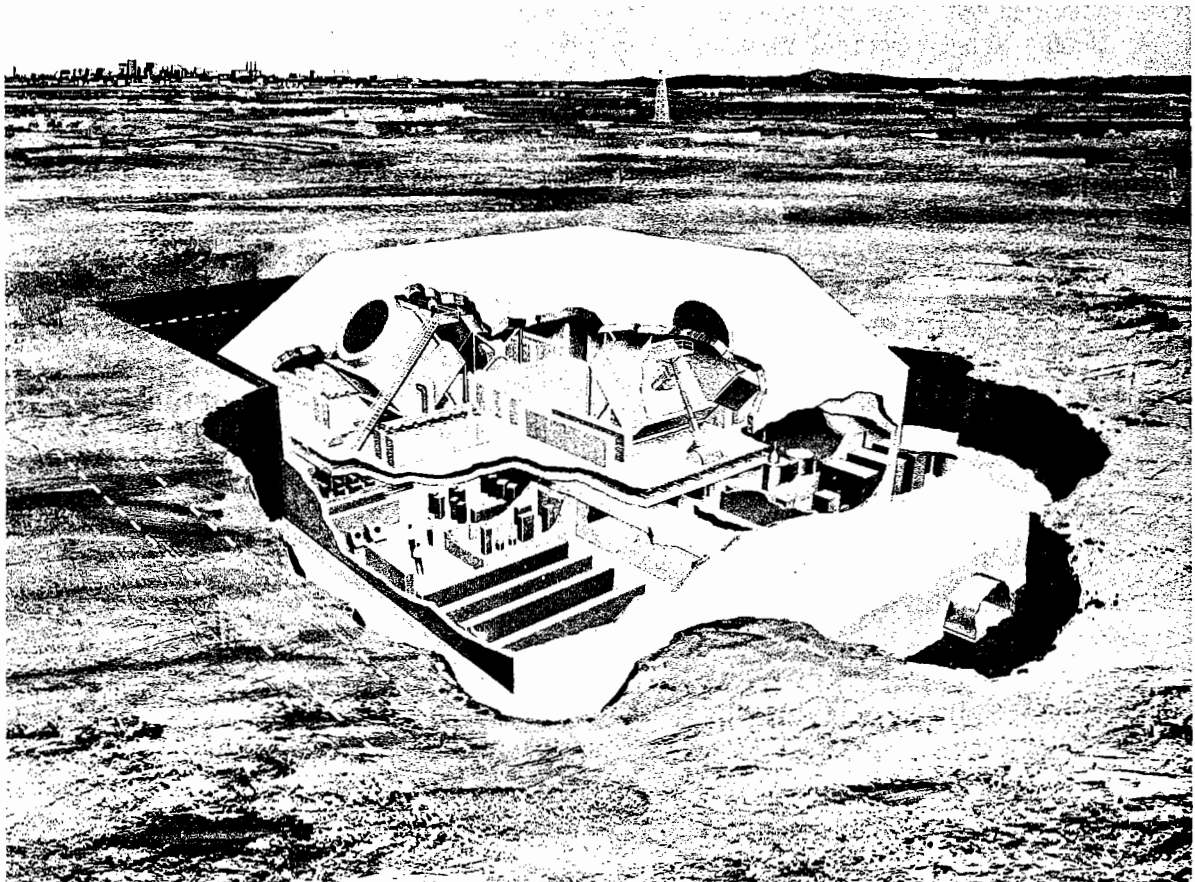


Figure I-33. Proposed Tactical MSR

Multifunction Array Radar — MAR-II

The L-band MAR-II of the NIKE-X System was specially designed for long-range search and acquisition and high-data-rate coverage for discrimination. Plans were established for installing a prototype model on Kwajalein (see artist's view in Figure I-34), while the MSR was to be located on Meck Island some 25 miles away. The high-power requirements for MAR (100 MW peak and 2 to 3 MW average per transmitter face) dictated separate transmitter and receiver array faces. Two transmitter and receiver array faces were planned to provide 180-degree coverage. From the start, two possible implementations of receiver beam-steering configurations were pursued in scale laboratory tests to determine which method would provide the optimum performance, consistent with high

reliability and lowest cost. One method involved time delay (actually phase delay, a Board-Steered System — BSS) and the other was a Modulation Scan Array Radar (MOSAR) technique developed by General Electric, Syracuse, New York as part of an R&D contract with Bell Laboratories.

Raytheon was awarded the contract for the development of the high-power transmitter. A key requirement of the transmitter was the need for a long-life, broad-band TWT used in large numbers to meet the high-power requirements. A team of tube engineers from Bell Laboratories' Murray Hill Laboratory with experience in building long-life TWT gun structures joined with Raytheon tube engineers in the development of the TWT with a goal of 50,000 hours of life. Although the L-band TWT was

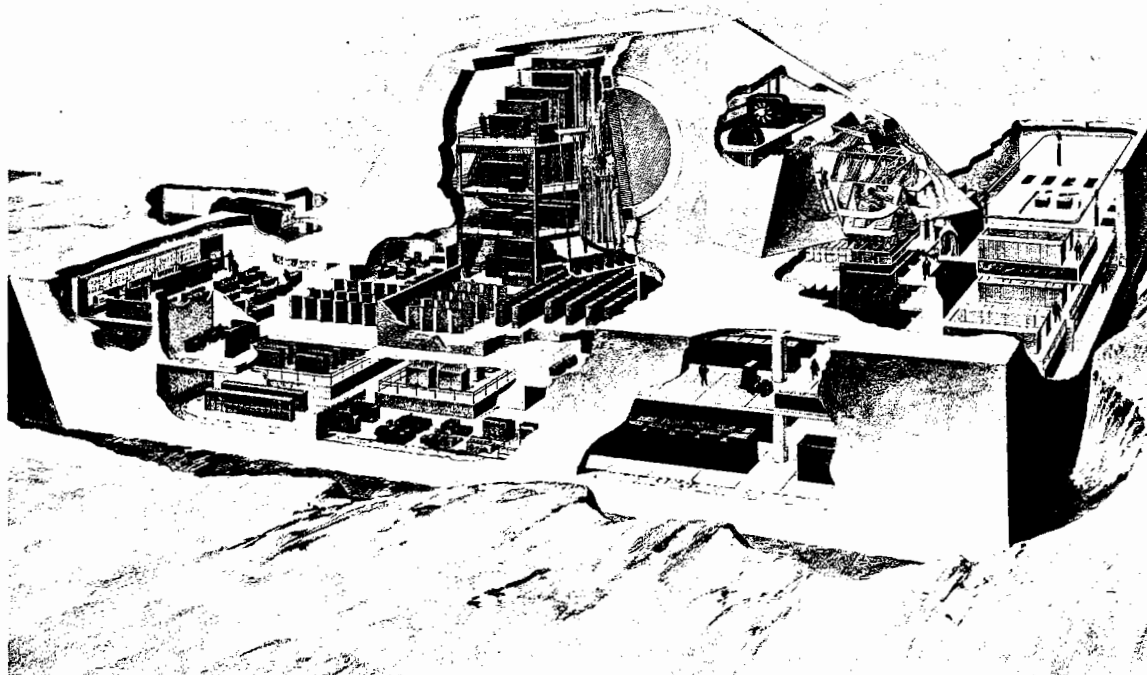


Figure I-34. MAR-II Planned for Kwajalein

not deployed because of the later cancellation of the MAR-II, Raytheon later scaled the tube down to the PAR UHF band and supplied it to General Electric. As deployed in the PAR today, the tube is indicating a life of 50,000 hours or more.

One of the features planned for the MAR-II was the ability to form multiple independent beams for search and, simultaneously, form separate clusters directed to different incoming clouds for discrimination. The transmitter beam width would be adjusted to match the receiver beam-cluster size.

The plans for time-delay steering (the board-steered system — BSS) employed phase delay in contrast to the MAR-I real-time delay steering. It was the BSS system that was compared to the MOSAR system from General Electric, resulting in a recommendation to the Army NIKE-X Project Office in March 1967 to drop further development of MOSAR and use the BSS for MAR-II. The final decision was based on the straightforward approach of BSS and a real concern for the complexity and cost of a full implementation of MOSAR. However, much credit should go to the General Electric engineers who developed an innovative steering system and made it work successfully in the laboratory reduced-scale tests.

The MAR-II system costs, because of the high-power requirements and complexity, were so high that even the deployment of an R&D prototype on Kwajalein had to be delayed in schedule and finally scaled down in January 1968. The scaled down model, referred to as TACMAR, was to initially leave out some of the transmitter and receiver modules, although these could be added later. However, by this time the original requirements for ABM defense had changed, as discussed below, and a less expensive Perimeter Acquisition Radar (PAR) was substituted for MAR/TACMAR in tactical deployment plans. In May 1968, the TACMAR prototype objectives for installation on Kwajalein were changed from a tactical design to an R&D field-site radar

referred to as CAMAR (and later GUARDIAN) to provide basic field data on discrimination. Further information on the GUARDIAN/CAMAR objectives is given in Chapter 2 on NIKE-X. However, the project then supported by the Advanced Ballistic Missile Defense Agency (ABMDA), was cancelled in August 1969.

Data Processing System

Early in 1963, studies were in progress on the requirements for the NIKE-X Data Processing System. What was clear from the start was the need for high-speed calculations (up to 30 million per second) that could be provided in modular equipment giving stepped capability for future growth. Equally important was the need for equipment having reliability an order of magnitude better than any commercial computer then available or planned. In reviewing the status of computing equipment designs with manufacturers, it became clear that the NIKE-X data processing requirements dictated a challenging new design approach.

Bell Laboratories enlisted the help of UNIVAC and formed a joint team in the spring of 1963 to establish design requirements and specifications for the NIKE-X Data Processing System. Studies were made in the areas of basic hardware and logic, computer organization, switching and control, displays, recording, programming, and fault location. Out of these studies came the decision that performance capability in a stepped-module structure and high system reliability could only be met by a multiprocessor design. Also, the basic logic integrated-circuit package had to meet reliability goals of 8 fits (8 failures in a billion hours). The Bell Laboratories Device Organization accepted the challenge of providing the integrated circuit to meet this reliability. More detailed discussion of the data processing equipment is given in Chapter 11 on the SAFEGUARD Data Processing Hardware.

Many experts during the late 1960's, including a special committee of the American Academy of Science, reported to the Army that, in their opinion,

a multiprocessor could not be made to meet the expected calculations per second (MIPS) predicted by Bell Laboratories. In final test measurements on SAFEGUARD, MIPS were plotted versus processors in parallel. The curve followed an essentially linear line through eight processors and met or exceeded the performance predicted early in the design. The integrated-circuit package developed for NIKE-X, and manufactured by Western Electric and three subcontractors for the SAFEGUARD program, has now accumulated many millions of device hours and shows results of reliability approaching the 8-fit goal.

REENTRY MEASUREMENTS PROGRAM

In the earlier discussion of discrimination, reference was made to the initial studies and laboratory work that included initial radar and optical observations at Ascension Island carried out during the early ZEUS program. By 1962, the ZEUS radar sensors were now deployed and operational at Ascension, WSMR, and Kwajalein, and an organized reentry measurements program was established (referred to as RMP A, B, and C) as part of NIKE-X R&D to cover the period from 1962 to 1970. The objectives of the program were to develop general discriminants for conical reentry vehicles based on radar observable characteristics as a function of vehicle size, shape, and ablator material. Optical and infrared sensors were also provided as part of these measurements.

The Measurements Program at WSMR starting in 1963 included the use of the ZEUS elements, ZAR, TTR, and DR, as well as an infrared radio-meter installed on a HERCULES mount. By June 1964, the WSMR was taking data on the first successful Athena test missile fired from Utah into WSMR. The major portion of the RMP tests was comprised of full-scale reentry flights principally into the Kwajalein Test Range. Special unique targets were provided by the NIKE-X Program, with other targets furnished

by the Air Force, Advanced Ballistic Reentry Systems (ABRES), Strategic Air Command (SAC) Evaluation Missions, and the Navy Polaris Program.

The NIKE sensors, TTR and DR, went through major modifications at the end of the ZEUS System Tests at Kwajalein to adapt them to the sensor data-gathering requirements of RMP. For example, TTR No. 4 was changed from a 22- to a 40-foot antenna dish and a wide-band 60-MHz coherent system. (See Figure I-35.) In addition, an X-band receiver system was added to provide telemetry reception from NIKE-X supported RVs equipped with special on-board instrumentation. Similarly, the DR at Kwajalein was modified to include a Coherent Signal Processing System (CSPS) developed at General Electric as well as wideband recording equipment.

In January 1964, a reentry physics panel was organized at Bell Laboratories with specialists in electromagnetic theory, plasma physics, gas chemistry, aerodynamics, and hydrodynamic stability to help guide the reentry field-measurements program and represent Bell Laboratories in contacts with outside organizations having related interests. Further information on the RMP work is covered in Chapter 2 on NIKE-X.

Nth COUNTRY THREAT

In February 1965, at the request of the Army, an intensive investigation was started on possible modifications of the NIKE-X System and hardware concept to reflect the heightened national concern about the "Nth country" threat. Special emphasis was to be given to the evaluation of alternate techniques for achieving effective high-altitude defense against relatively unsophisticated attacks with deployment growth to meet sophisticated threats. In particular, other options were to be considered leading to a lower cost MAR-II. As part of this system study, the usefulness of

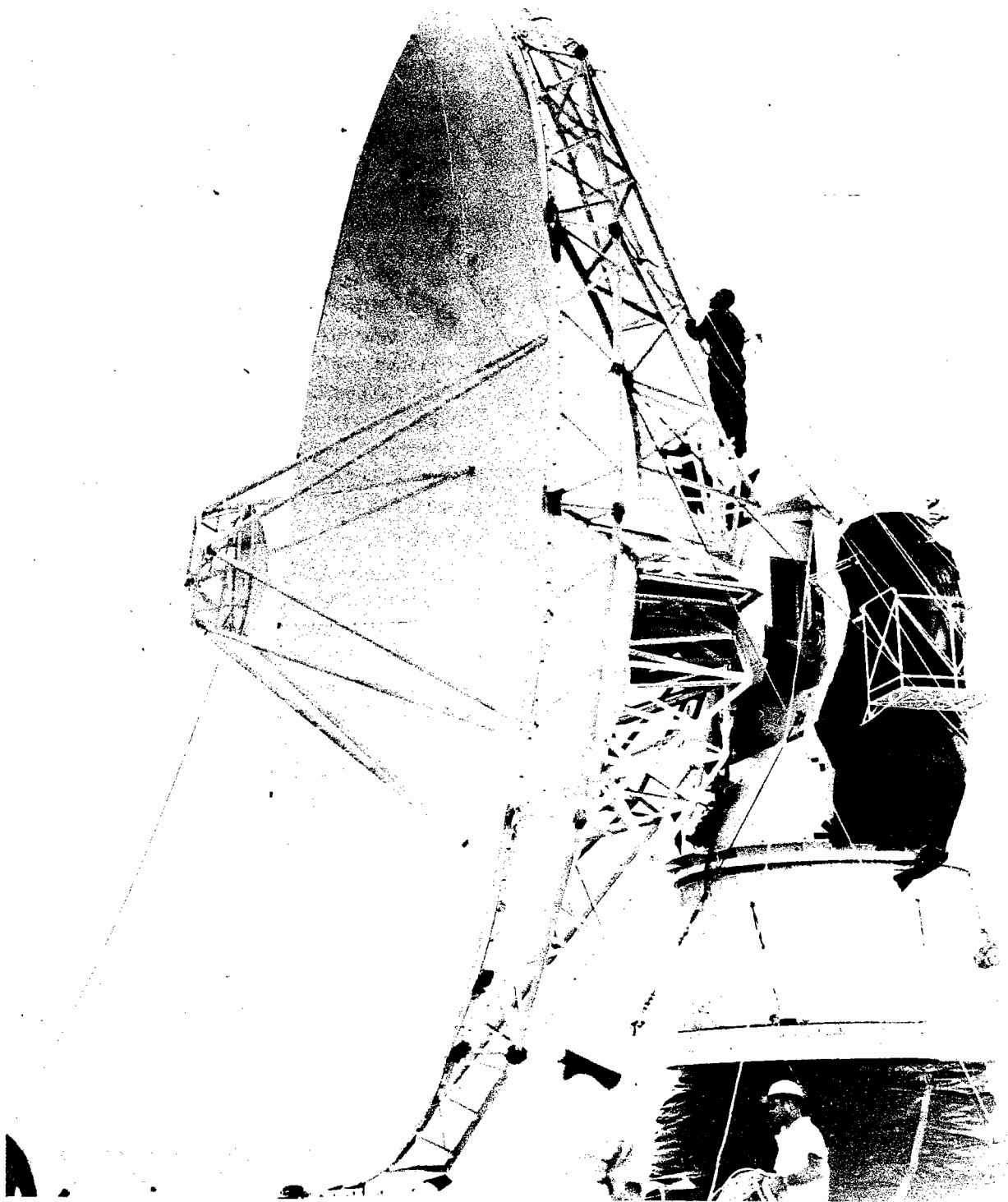


Figure I-35. TTR 4 Antenna, showing 40-foot reflector with subreflector being readied for use in RMP B

VHF radars as supplementary sensors for acquisition, discrimination, or designation in defense against light, unsophisticated attacks, was investigated at Bell Laboratories. Included in this study was the blackout problem in the VHF band.

On April 23, 1965, the major conclusions of this study were orally presented to Dr. Harold Brown, Assistant Secretary of Defense for R&D. A variety of radar design approaches was summarized in terms of performance, cost, and growth potential. The radars proposed were a MINI-MAR — a lower cost, reduced-performance array radar with potential for growth to a full-sized MAR — supplemented by a companion radar at VHF for long-range detection of sneak attacks that could be met by the ZEUS missile. The MSR was the choice for missile guidance, although S-band missile tracking radars of lower cost could be used. For close-in defense, SPRINT and MSR remained the choices. In May 1965, following this presentation, Bell Laboratories was authorized to reorient the NIKE-X System requirements to include certain modifications aimed at providing a more cost-effective defense against a possible Nth country threat, in addition to the more sophisticated Soviet-type threats on which past NIKE-X design had been based.

This was in line with Secretary of Defense McNamara's rising concern early in 1965 over the nation's vulnerability to the kind of attack that some less advanced country might launch. For this reason, it was urgent to determine whether NIKE-X was the most cost-effective way to provide an early defense against such a threat, or if there were less expensive ways.

As a result of these studies, the NIKE-X concept was expanded to provide capability for a broad general defense of the whole continental United States against the full threat spectrum. This change was made possible by increased confidence that large nuclear warheads borne by two or more modified (for greater payload and range) ZEUS missiles in a barrage mode could

provide large volume kill capability — leading to the possible concept of an umbrella coverage of the entire country. (Only as threat sophistication increased to extremely hard, i.e., radiation-resistant warheads and RVs, would the short-range terminal defense be required.) As visualized at that time by the Director of Defense Research and Engineering (DDR&E), the VHF radar would be a straightforward development (essentially off the shelf), and thus actual development effort would not have to begin until production was authorized.

In October 1965, in response to a request from DDR&E, a quick examination of minimum NIKE-X hardware was made to assess a defense against simple first-generation Nth country ICBMs. This hardware consisted of 4 VHF radars and 12 MSR sites, with 20 modified ZEUS missiles at each site. Although good coverage against this particular threat was demonstrated in principle, the many limitations of such a defense concept were pointed out by Bell Laboratories.

In November 1965, a new study of active defense for hardened sites was initiated by DDR&E. Three teams — Air Force, Advanced Research Projects Agency (ARPA), and NIKE-X Project — were to study defense systems to meet the threats and defense objectives defined by DDR&E. This initial study and many more that followed associated with Hardsite Defense are covered in Chapter 2 on NIKE-X. It is sufficient to note here, that while studies were going on directed to light area Nth country defense, Bell Laboratories was being asked to carry out studies of high-traffic terminal defense of our offensive weapons. It was during these studies that the concept of pitch-and-catch for the missile-launch phase was seriously considered. Up to this time, in all of our NIKE System developments, the requirement to be completely locked on the missile prior to launch was considered inviolate. However, with the MSR inertialess tracking beam, it was found that SPRINT could be acquired after launch with separations of up to 20 nautical miles.

To provide a suitable missile element for the Nth country barrage-type defense, authorization was received in January 1966 to start development work at McDonnell-Douglas on a modified ZEUS DM-15C missile for this role. The missile payload would be increased to 2900 pounds for the high-yield nuclear warhead, necessitating larger first- and second-stage motors. The decision was made to use the modified DM-15C booster design for both the 5-second first stage and the 19-second second stage. The new three-stage ZEUS missile was expected to have a peak velocity of 9000 ft/sec and a range of about 300 nautical miles. The first firing was scheduled for Kwajalein Island in March 1968. For a discussion of the evolution of this missile into its successor, SPARTAN, refer to Chapter 10 on the SPARTAN Missile Subsystem.

As mentioned earlier, a VHF radar was being studied as a complementary long-range search and acquisition radar for Nth country defense. In December 1966, General Electric at Syracuse, New York was selected to start Phase I study work on this radar under contract to Bell Laboratories. Called the Perimeter Acquisition Radar (PAR), this new development presented the General Electric and Bell Laboratories team with the initial important system consideration of deciding on the operating frequency, VHF or UHF. A schedule for completing design definition by July 1, 1967 was established.

An important consideration in this study was whether a UHF design matching the VHF performance could be realized without a substantial increase in cost. Cost comparisons were made for a UHF radar that matched the VHF performance, -3 dB down and -6 dB down. Bell Laboratories had agreed with an Institute of Defense Analysis (IDA) summer study in 1966 that the radar blackout from offensive and defensive warhead burst would seriously degrade a VHF radar; thus UHF was recommended. By April 1967, Bell Laboratories and General Electric had completed a cost comparison of VHF and UHF for presentation to the Army and DOD. The

decision was made to proceed with the planning for a PAR operating at UHF, but arranged so that initial deployment would be -6 dB down to minimize initial cost. However, the design should permit later growth to 0 dB performance for smaller future targets. This next phase, called Phase 1B, was limited to defining the system and developing critical components until such time as a deployment was authorized. A full story of the PAR as finally developed and deployed for SAFEGUARD is given in Chapter 8.

I-67 STUDIES LEADING TO SENTINEL SYSTEM

In December 1966, the Army AMC-NIKE-X Project Office and DOD asked Western Electric and Bell Laboratories to study a deployment model for NIKE-X designed to combine area defense with hardsite defense capabilities. This model, approved by DOD for production planning purposes, was officially designated as "Plan I-67 Area/Hardsite Defense." The major objectives of the deployment were defense against a deliberate Chinese People's Republic (CPR) industrial/urban attack (countervalue) and defense against a deliberate high-level ICBM attack from the USSR (counterforce) aimed at U. S. strategic forces. In making this request, Secretary of Defense McNamara invited top executives of the Bell System to Washington on December 9, 1966 to ask their support and experience in finding ways to minimize the cost of an ABM deployment, while providing a system of high reliability. This meeting was followed by another on December 13, 1966 involving executives of Western Electric and Bell Laboratories and Dr. John S. Foster, Deputy Director for Research and Engineering (R&E) with his staff in the Pentagon, together with General A. W. Betts and members of his Army staff. This meeting again emphasized that cost was a most important parameter in making the I-67 study.

As a result of this request, Bell Laboratories and Western Electric initiated a six-month study

on January 16, 1967 to evaluate the "I-67" plan. The most important aspect of this study was to optimize system elements with the objective of selecting the option with the greatest cost-effectiveness. A three-month status report of this study was presented by Bell Laboratories to Generals I. Drewry and A. W. Betts on March 2, 1967, and again on March 4, 1967 to Dr. John S. Foster, Deputy Director for R&E, DOD. A status report at the end of the six-month study of the I-67 deployment model was presented to Secretary of Defense McNamara on July 5, 1967 at the Pentagon. Bell Laboratories made the primary presentation while AMC-NXPO presented possible growth options for the I-67 deployment model. Secretary McNamara was pleased with results of the study but asked for further investigation of specific questions dealing with growth aspects of the CPR threat and corresponding growth of the I-67 deployment model. A total report of the Bell Laboratories study was issued on July 5, 1967.

The results of the study were strongly influenced by three conditions: (1) specific design threat, (2) total investment cost not to exceed 5 billion dollars, and (3) initial operating capability (IOC) within 54 months of a deployment decision, thereby limiting choice of equipment to NIKE-X elements. The deployment recommended in the I-67 study consisted of 6 PARs, one of which would be in Alaska, 17 MSRs, including one in Alaska and one on Hawaii, 480 SPARTAN (the new name for a modified ZEUS DM-15C with large payload) interceptors, and 455 SPRINT interceptors of which 325 would be for defense of Minuteman sites. Other studies, directed by the Secretary of Defense, were carried out by the Office of Director of Defense Research and Engineering (ODDR&E) and the NIKE-X Systems Office with threats and constraints changed from the Bell Laboratories study.

On August 1 and 2, 1967 at Los Angeles, California, Mr. D. P. Ling of Bell Laboratories made a presentation on the I-67 deployment to the Defense Science Board of DOD.

On September 18, 1967, Secretary of Defense McNamara announced that production of a "light defense" NIKE-X System would begin before the end of 1967. The "light defense" deployment was to include PAR, MSR, SPRINT, and SPARTAN. This modified system, derived from the I-67 study, was limited in its initial role to a complete area defense against a CPR industrial/urban attack on CONUS, with a growth option for defense of certain U. S. ICBM bases against a USSR attack. With this decision, plans were set for completing the deferred development effort (referred to as objective budget) required to support the I-67 type deployment. This development work included design and manufacture of the PAR prototype, tactical test equipment, a tactical software control center, tactical ground support equipment for SPRINT and SPARTAN, and completion of design documentation.

On November 1, 1967, the Department of Defense announced the locations of the first ten SENTINEL sites, which included Boston, Chicago, Grand Forks and other cities as shown in Figure 3-1 of Chapter 3. Initial SENTINEL deployment was to consist of 6 PARs, 17 MSRs, 480 SPARTANS, and 220 SPRINTs. This deployment could later grow to provide Minuteman defense by the addition of 208 SPRINTs, and modification of the hardware and software located near the Minuteman bases. For further details on the I-67 Study and the SENTINEL System refer to Chapter 3.

SAFEGUARD SYSTEM

Construction contracts were awarded by the Army Corps of Engineers and construction started for the first SENTINEL Site (PAR) at Boston late in 1968. Strong opposition developed, however, over the construction of such sites, and against the deployment of missiles with nuclear warheads for ABM defense. The old question faced with earlier NIKE deployments was now present to a much greater extent; that is, "put it in someone else's back yard." In view of this strong opposition, the acquisition and construction of other sites

were suspended on February 6, 1969, pending a review of the SENTINEL System by President Nixon. On March 14, 1969, President Nixon announced that the SENTINEL System would be "substantially modified" in the form of a new deployment called SAFEGUARD with the following new defense objectives:

- First priority would be protection of our land-based retaliatory forces against a direct attack by the USSR; the complement of equipment was to be modified in accordance with this initial objective.
- A growth option to provide defense of the U. S. against the kind of attack the CPR would likely be capable of launching within the decade.
- Protection against the possibility of accidental attacks from any source.

The SAFEGUARD deployment plan reduced the number of sites to 12, as shown in Figure I-36, and deleted most large city sites. The initial deployment was to proceed in two phases, the first to protect part of the Minuteman force,

and the second to complete the coverage of Minuteman sites and cope with more sophisticated threats.

Between the start of SAFEGUARD in March 1969, and the signing of the Strategic Arms Limitation Treaty (SALT I) with the USSR in May 1972, the authorized deployment went through a series of changes. In 1970, approval was given to start work on two Phase I sites, one near Grand Forks AFB, North Dakota, and one near Malmstrom AFB, Montana. Advanced preparation of five additional sites (Phase II) was also authorized; this was later reduced to advanced preparation at only two of these sites, for a total of four sites. The four-site plan was the one authorized through most of this period until the signing of the SALT I Agreement.

The SALT I Agreement permitted the deployment of one ABM defense site for offensive forces and one for the National Command

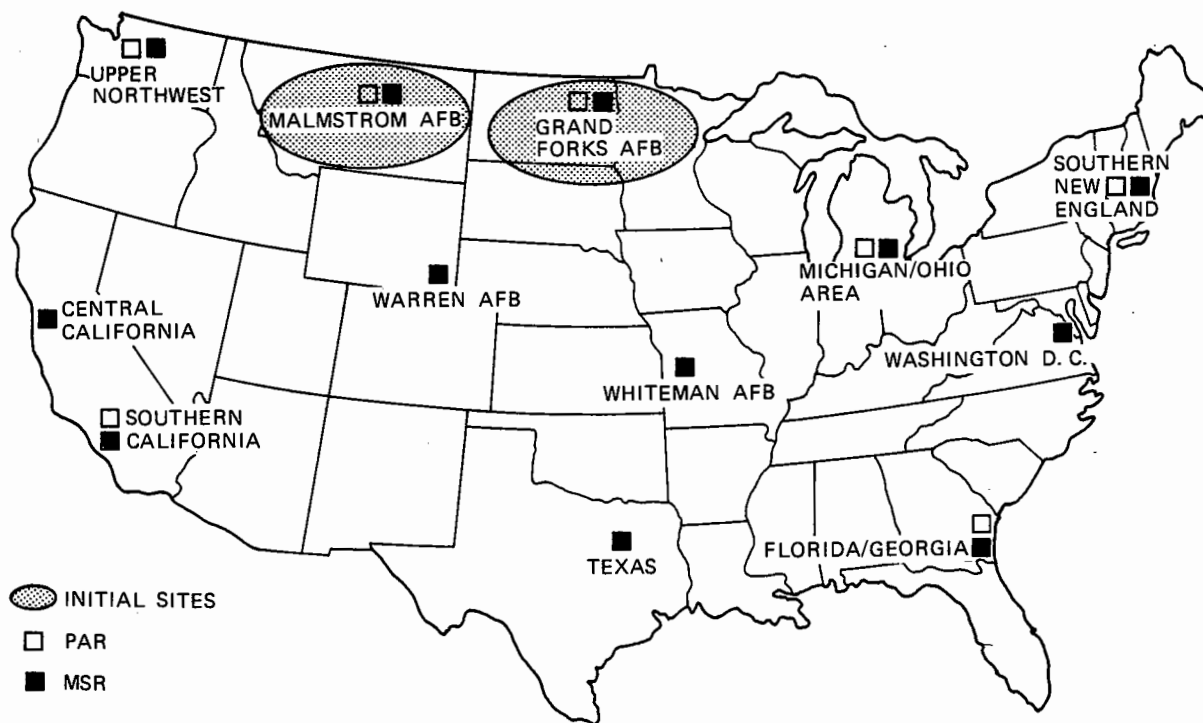


Figure I-36. SAFEGUARD Deployment Plan, March 1969

Authority around Washington, D. C. With this agreement, the second Minuteman site at Malmstrom AFB in Montana, then under full construction, had to be terminated leaving only the site near Grand Forks to continue. Later, the government decided not to proceed with the SAFEGUARD defense of Washington, D. C.

In accordance with the terms of SALT I in May 1972, and the subsequent Congressional decision not to authorize the deployment around Washington, D. C., the SAFEGUARD System consisted of the PAR and a Missile Direction Center (MDC), which included the MSR together with local and remote missile launch farms in the Grand Forks, North Dakota area. The system was under control of the Ballistic Missile Defense Center (BMDC) in Colorado. Under the SALT I Agreement, only 100 defensive missiles were permitted. Both SPARTAN and SPRINT missiles were collocated with the MDC, while additional SPRINT missiles were located at four remote missile farms. See Chapter 4 for more information on the SAFEGUARD System.

Fortunately, the changes in deployment objectives in going from SENTINEL to SAFEGUARD did not require major changes in the test plans for Meck Island. Most important was the proving in of the prototype MSR with its associated software as an operational phased-array radar. Continued development firings were also required for the SPRINT and SPARTAN missiles. Finally, to integrate these elements, a full series of system tests was carried out to progressively stress system capability against live ICBM and IRBM targets. Software packages, which were built up in complexity to match the system test objectives (called the M-test series), were introduced until the final software package (the part to be tested through live ICBM tracking or intercepts) matched the tactical software installed in the Grand Forks tactical system. The field testing at Meck complemented the more exhaustive testing of SAFEGUARD software at the Bell Laboratories Tactical Software Control Site (TSCS) in Madison, N. J. Here, threat inputs

were introduced to match the design threat levels not attainable in field testing. Actual tracking data from the Meck tests were used in forming the test input tapes for the TSCS evaluations. Full details of the field tests at Meck and those carried out at the TSCS are given in Chapter 5 on SAFEGUARD System Evaluation.

During the SENTINEL and SAFEGUARD period, much thought was given to the installation of a PAR prototype on Kwajalein or Meck. Time schedules (with PAR development awaiting a production decision) and costs, dictated that the PAR prototype should be evaluated at the first tactical site and then turned over for tactical use after completion of R&D tests. Technically, a much more complete evaluation of the system could have been achieved with an installation on Kwajalein. However, it was also technically true that better evaluation of the PAR from a radar standpoint could be obtained from an installation in the northern hemisphere, where aurora effects, ground clutter with abnormal propagation, and low-angle atmospheric tracking errors could be determined. In discussions with the Army and DOD, it was agreed that simulation of PAR outputs for the Kwajalein system tests would be acceptable, although a larger deployment of SAFEGUARD would certainly have dictated a PAR installation on Kwajalein later in the program.

Some of the key dates in the Kwajalein/Meck buildup of testing are given below:

- Mar. 2, 1968 — First SPARTAN development firing at Kwajalein.
- May 18, 1968 — Power-on achieved for Meck MSR.
- Oct. 8, 1968 — First software data transfer accomplished on satellite data link between Whippany and Meck.
- Apr. 18, 1969 — Multiprocessor system demonstrated in Whippany SAFEGUARD Data Processing Laboratory in support of Meck tests.
- Dec. 11, 1969 — First MSR track of ICBM.

Apr. 14, 1970 — M-1 Test Series starts at Meck.
 Aug. 28, 1970 — First successful intercept of ICBM with SPARTAN.
 Dec. 23, 1970 — First live target intercept by SPRINT.
 Jan. 11, 1971 — First SPARTAN Salvo.
 Mar. 17, 1971 — First SPRINT Salvo.
 Aug. 27, 1971 — First M-2 mission.
 Mar. 16, 1972 — First remote launch of SPRINT from Illeginni (about 20 miles from Meck) to test "toss and catch."
 May 1973 — Revision 19 of software delivered to Meck for final M-2 Series Tests.
 Aug. 1974 — Final M-2 System Tests.
 Apr. 1975 — Final warhead and production missiles fired from Meck — 2 SPARTANs and 1 SPRINT.

A capsule summary of the M Series of system tests is given below. The M-1 Series was to prove in the basic concept of the system elements working together, while the M-2 series evaluated the system against increasingly stringent target and system conditions.

	<u>M-1 — Concept Verification</u>	<u>M-2 — Final System Evaluation</u>
Success	12	46
Failure	5 (includes one due to target)	7 (includes three due to target)

The TSCS test facility at Bell Laboratories in Madison, N. J. contained the full PAR and MDC data processing equipment and all portions of the analog hardware that interfaced with the missiles and radars at site. This facility accurately reproduced the software in its tactical operational environment and was indispensable in developing software relatively free of errors when introduced at site. A system exerciser for tests at TSCS and at site provided the means of introducing sufficient traffic capability and related attack parameters to test the tactical hardware and software at the required SAFEGUARD design threat level. These evaluation tests, carried out during 1974 and up to

April 1975 at the TSCS, supplemented by the M-2 live-target tests at Meck, provided full verification that the SAFEGUARD System deployed at Grand Forks met its performance requirements.

The Equipment Readiness Data (ERD) for the Grand Forks site was met several days before October 1, 1974 — the scheduled date set almost four years earlier. Initial Operational Capability (IOC) was achieved shortly after the April 1, 1975 scheduled date, with operational missiles installed in their cells and full system operation underway, 24 hours a day and 7 days a week.

ABM R&D SUMMARY

The major development milestones in the 20-year evolution of ABM defense, beginning with the early studies in March 1955 and leading to a tactical SAFEGUARD System near Grand Forks, North Dakota, are shown in Figure I-37. These developments trace the history of the step-by-step advance in technology that kept the United States well in the forefront of ABM defense and led eventually to the SALT I Agreement with the USSR. From the initial NIKE-ZEUS System, which extended earlier air defense technology (designed to protect against the bomber) to meet the extreme ICBM threat of very high speed and small radar size, to the more advanced systems designed later to protect against highly sophisticated threats, a large number of truly innovative developments were required. These began with the ZEUS System, whose Acquisition Radar with Luneberg lens and three-dimensional automatic detection and tracking, together with a high-performance missile combining aerodynamic and jet control, made possible the first successful intercept of an ICBM in 1962 at Kwajalein, after earlier testing at Ascension, WSMR, and Pt. Mugu.

With the decision not to deploy the NIKE-ZEUS System, a period of four years followed from January 1963 to September 1967 (referred to as NIKE-X) in which major steps forward were made in ballistic missile defense technology

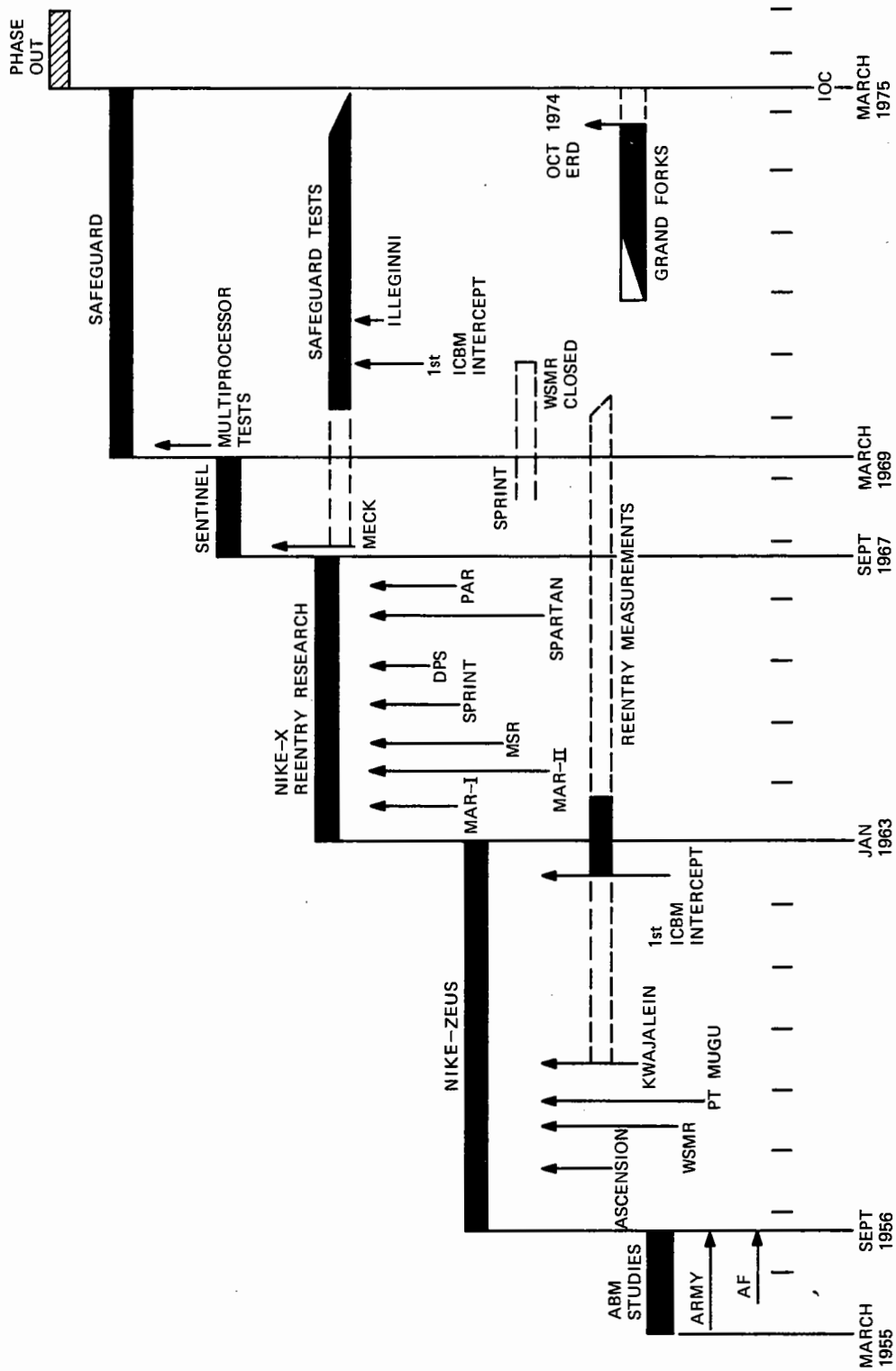


Figure I-37. Summary of Major ABM Developments, 1955 through 1975

to counter the increasing complexity of the ICBM threat. An exhaustive program of reentry research was carried out using the ZEUS radars at the three test sites as sensors for data gathering. Electronic phased-array radars, which compared to the ZEUS mechanically-steered radars had inertialess antenna beams, were developed for multifunction applications in the MAR I, MAR II, and MSR Subsystems. These radars were the major step required to successfully meet the high-traffic threat.

A super-accelerating missile called SPRINT was developed to permit delayed, low-altitude discrimination for close-in terminal defense. This missile represented another major step in technology, since it required high-impulse, short-burning motors and the ability to handle skin temperatures about three times those of the ZEUS missile. The requirements for data processing meant yet another major advance in computing technology to meet the need for high-speed calculations (up to 30 million per second), multiprocessor organization, and an order-of-magnitude improvement in reliability of the basic logic circuits. Closely related to these advances in hardware technology and work on discrimination was a continuing systems engineering activity to determine the optimum subsystem arrangements and deployments to meet various defense objectives of the Army and the Department of Defense.

The new technologies and systems approaches carried out in the NIKE-X period between 1963 and 1967 were "on the shoulders" of the R&D ABM advances made during NIKE-ZEUS System development. When the Secretary of Defense made the decision in September 1967 to deploy an ABM system called SENTINEL, the major elements required were available from NIKE-X development, except for the Perimeter Acquisition Radar (PAR), which was then under study. Later, in March 1969, when this deployment was changed to provide Minuteman defense

under the SAFEGUARD Program, these same elements — then under test at WSMR and Meck Island — again met the defense requirements.

One of the major contributions in the last seven years of the R&D program was the successful development of one of the most complicated real-time software systems ever conceived. Critics of ABM defense in the late 1960's concentrated on the software problem as being too complex to provide the reliability needed. However, the high reliability currently attained with the tactical system at the Grand Forks site, 24 hours a day, 7 days a week, is a convincing answer to such critics. Furthermore, the software R&D effort on SAFEGUARD produced a solid background of experience and knowledge that will be helpful in building new defense systems in the future.

Another major contribution of the ABM R&D effort, extending from the first installation of a ZEUS track radar on Ascension Island in 1968 to the present time, has been support of offensive weapons programs. During this period of time, hundreds of data packages obtained from reentry missions have been supplied to the Air Force and other DOD agencies as a byproduct of having the most versatile and accurate radars available at the test ranges. For example, during the last three years of operation of the MSR Subsystem on Meck Island, some sixty data packages were supplied to other agencies concerned with offensive technology. Thus, the ABM program not only advanced its own defense technology, but made important contributions to offensive technology as well.

Each of these developments throughout the 20-year history of ABM activity contributed valuable experience and brought new insights to the challenge of meeting an increasingly sophisticated threat. The details of each of these programs and the lessons learned are discussed in the remainder of this report.