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EXTRACTED VERSION

OPERATION HARDTACK

PROJECT 9.3A

Operation of Missile Carrier for Very-High-Altitude Nuclear Detonations

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NOTICE:
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This project moved all personnel and equipment to Site How, Bikini, in anticipation of the first firing. The project was instructed to relocate to Johnston Island in view of anticipated effects, particularly the possibility of retinal damage to natives on atolls within several hundred miles of Bikini.

The missile-pod scheme of delivering a nuclear device to extreme altitude, as well as close-in positioning of instrumentation has been demonstrated as highly successful. The accurate positioning of all pods with respect to the burst on both firings, with the exception of Pod 4 or Shot Orange, met the stated requirement. The integration of pod-ejection commands into the guidance-and-control system of the missile enabled this accurate positioning despite unpredicted missile behavior.

Reliance upon demonstrated ballistic characteristics of free flight projectiles is considered far preferable to a combination of devices controlled from ground stations.

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FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

OPERATION HARDTACK—PROJECT 9.3a

OPERATION of MISSILE CARRIER for VERY-HIGH-ALTITUDE NUCLEAR DETONATIONS

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FOREWORD

This report presents the results of one of the projects participating in the military-effect programs of Operation Hardtack. Overall information about this and the other military-effect projects can be obtained from WT-1660, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

Project 9.3a with personnel from the U.S. Army Ballistic Missile Agency, Redstone Arsenal, Alabama; Picatinny Arsenal, Dover, New Jersey; Fort Belvoir, Virginia; and Fort Sill, Oklahoma; participated in Operation Hardtack by firing two Redstone missiles

The project physically occupied Site How, Bikini, and erected and checked out Missile 50 in early April; however, the project was instructed to relocate to Johnston Island, based upon a decision of the Commander, Joint Task Force Seven, to launch from that location. The first firing, Shot Teak, took place from Johnston Island on 31 July 1958, with a burst altitude of approximately 76 km. The second firing, Shot Orange, took place on 11 August 1958, with a burst altitude of approximately 43 km.

In addition to providing the missile system for these detonations, the U.S. Army Ballistic Missile Agency designed, mounted on the missile, and positioned in space, four instrument carriers (pods), which were mounted on the thrust unit and expelled explosively from it during the powered phase of the trajectory.

Certain indications of missile performance were provided the Missile Flight Safety Officer (who was not a member of this project, but a staff officer of JTF-7), as well as means of taking corrective action in the event of malfunction. These were command destruction of the fuel tanks and command cutoff. In the case of Shot Orange, a means of preventing warhead arm was also provided for the Missile Flight Safety Officer.

CONTENTS

TABLES

OPERATION of MISSILE CARRIER for VERY-HIGH-ALTITUDE NUCLEAR DETONATIONS

The project moved all personnel and equipment to Site How, Bikini, in anticipation of a ready date of 23 April 1958 for the first firing. The project was instructed to relocate to Johnston Island, in view of anticipated effects, particularly the possibility of retinal damage to natives on atolls within several hundred miles of Bikini.

MISSION ASSIGNED

Missile Trajectories. Project 9.3a participated in Operation Hardtack by firing two Redstone missiles detonating Shot Teak at approximately 76 km altitude and Shot Orange at approximately 43 km altitude (Figure 1). The project was responsible for reporting the actual location of the bursts after the fact, based upon telemeter and DOVAP records. Surface zero for Shot Teak was planned at a horizontal distance of approximately 5.4 naut mi from the launcher. Surface zero for Shot Orange was planned at a horizontal distance of approximately 21 naut mi from the launcher. Both firings took place from a launching site on Johnston Island on an azimuth of 180 degrees true. A third Redstone missile was available for repetition of Shots Teak or Orange, but such repetition was not required.

Instrument Carriers. Four instrument carriers, or pods, carried externally on each missile, were ejected during the powered portion of the flight (Figure 2). Project 9.3a was responsible for providing and positioning these pods and reporting the actual location after the fact, based upon telemeter and DOVAP records. Scientific instrumentation in the pods was provided by other participating agencies.

Safety. Project 9.3a was responsible for providing data on missile location and performance for the benefit of the Missile Flight Safety Officer (MFSO), a member of CJTF-7's staff. The primary source of flight-safety information was an instantaneous presentation of doppler tracking in a system known as Beat-Beat. Certain additional aids were provided from missile telemetry, including a teletrack presentation of the pitch program. Although the MFSO could not see the missile from his blockhouse position, visual contact was provided by a closed-loop television system. The television camera tracked the missile from takeoff to provide a visual indication of cutoff and burst.

The MFSO had the capability, by activating a radio frequency transmitter, of terminating rocket engine thrust or of destroying the fuel tanks on board the missile to prevent an unsafe impact. In addition, for Shot Orange, he was provided the ability to prevent arming in the event programming failed and the missile followed a vertical or near-vertical trajectory. Complete redundancy was provided in this command-destruct system by two completely independent receivers on the missile, and two transmitters in the bunker.

Overall safety aspects of both Shots Teak and Orange were considered in detail by a Safety Working Group, which reported to the Chairman of the Eniwetok Proving Ground Planning

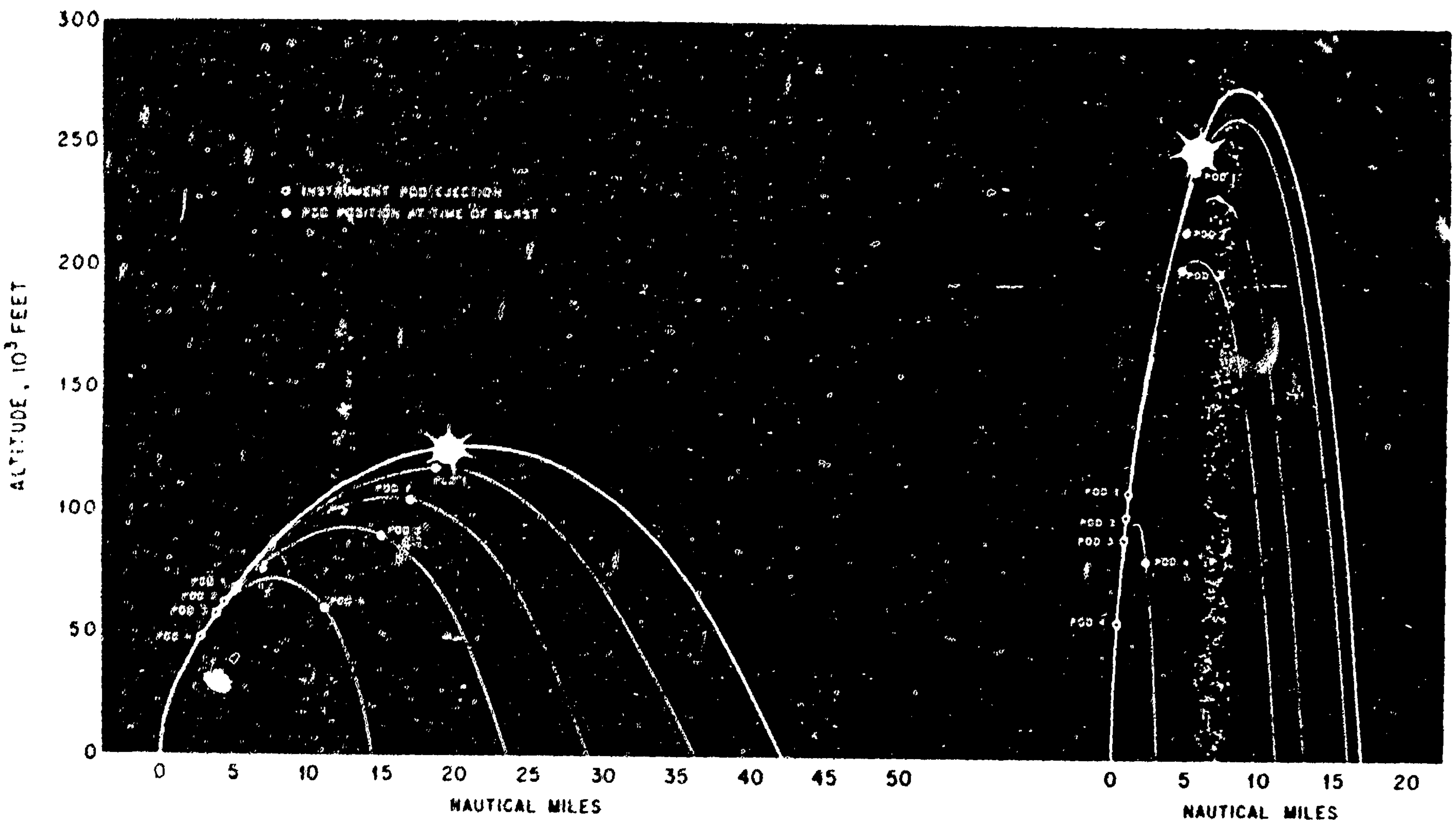

Figure 1 Planned trajectories, Operation Hardtack.

Board (Reference 1).

Provision of Signals. Project 9.3a provided a signal at liftoff of the missile, which was used as zero time for the Edgerton, Germeshausen and Grier (EG&G) master timing system. Additional signals were provided as required by participating projects, including an indicat... in the event of safety action taken by the MFSO.

DEVELOPMENT EFFORT

Development effort on behalf of the project fell into three general areas: missile sy...em; adaption kit; and pods.

Missile System. The lateral accelerometer was used during Operation Hardtack as in the tactical missile, i.e., to sense accelerations perpendicular to the plane of th... alculated trajectory. A second accelerometer, which, in the tactical configuration senses .n range, was rotated to sense variations in the vertical direction. This modification was made to provide increased accuracy in the altitude of the burst point. The warhead-arming limits of the guidance system were widened to permit a detonation, even though the missile did not follow closely the prescribed trajectory. This was requested by Field Command AFSWP and did not degrade safety due to the large size of the prescribed danger area. The normal limits and the Hardtack limits are given for comparison purposes in Table 1.

Tactical tolerances are referenced to cutoff conditions, whereas in the Hardtack application they are referenced to conditions at ejection of Pod 3. Hence, Hardtack tolerances, particularly those for vertical velocity, vary about a value noticeably greater than zero.

TABLE 1 WARHEAD-ARMING LIMITS

Tactical Redstone		
Range Velocity	− 40 m/sec to + 50 m/sec	
Range Displacement	− 6 km to + 4 km	
Lateral Velocity	± 8 m/sec	
Operation Hardtack	**Shot Teak**	**Shot Orange**
Vertical Velocity	+ 165 m/sec to + 285 m/sec	+ 85 m/sec to 205 m/sec
Vertical Displacement	− 4 km to + 8 km	− 4 km to + 8 km
Lateral Velocity	± 20 m/sec	± 20 m/sec

Adaption Kit. Reliability of the system after launch was increased by incorporation of a multiple fuzing circuit. In this arrangement, operation of any three out of five timing devices was sufficient to provide arming and firing signals which were permitted to reach the warhead by the two safing and arming devices in parallel (Reference 2).

The adaption kit used on the tactical Redstone required modification, inasmuch as its radar fuze would not be effective at the required detonation altitudes. The radar fuze, which would have had no reference plane, was replaced by a mechanical timer system designed to operate in conjunction with onboard missile functions.

Additional preflight safety devices were installed, including two jumper cables, which physically interrupted the arming circuitry when detached. These added precautions were instituted to insure minimum probability of an unsafe nuclear burst.

Missile 41 was fired 30 October 1957. Test results were inconclusive, due to missile malfunction.

Two malfunctions occurred in the adaption kit of Missile 42, which was fired 10 December 1957. They were attributed to a premature operation of a portion of the safing and arming (S&A) device which caused a dud of the warhead system, and to a burned out pulse transformer used in the backup fire circuit. That portion of the S&A device which safed prematurely was determined to be unreliable, and its function was deleted to eliminate the possibility of a recurrence of this malfunction. The preflight test procedure was changed to obtain maximum assurance of the reliability of the pulse transformer, and a certain check of its condition was included in the final preflight checks.

The adaption kit tested on Missile 46, fired 11 February 1958, was partially successful in that the two S&A mechanisms, the power supplies, and the electrical networks operated properly. The arming and fuzing device failed to operate, due to loss of an electrical ground return. Corrective action was made by chassis-grounding all affected components.

Through the adaption kit is believed to have operated normally during the test on Missile 43 on February 1958, telemetered indications of warhead functions provided the basis for a final modification to the adaption kit. This was the interchange of the primary and backup fire signals to give first priority to that signal which had indicated higher reliability of the complete adaption-kit-and-warhead system.

Pods. Both missiles launched carried four pods externally mounted between the fins of the thrust unit (Figure 2). These pods were approximately 6 feet long and 10 inches in diameter and weighed approximately 150 pounds each. During the developmental period, experiments were conducted on the use of canted fins on the pods, with the theory that an induced spin might assist in stabilization. This was found not to be the case. On the contrary, a distorted conical precession, in combination with the Magnus force, increased the angle of attack to the point where tumbling became likely. Therefore, pods were equipped with straight fins. Three of the pods, instrumented by Project 2.6 (Naval Material Laboratory), had the configuration shown in Figure 2. The fourth pod, instrumented by Project 8.6 (Wright Air Development Center), had a blunt face with a false nose cone, which was explosively detached prior to burst. Due to the configuration of the Wright Air Development Center (WADC) instruments which had to "see" the burst, it was found unfeasible to incorporate these instruments into a conical nose.

Four pods were flight tested on Missile 45, fired from Air Force Missile Test Center (AFMTC) 14 January 1958, to verify considerations of pod design and to check trajectory calculations. In a night firing, flashes along all trajectories were recorded on photographic plates, which, in conjunction with certain telemetered data, allowed a comparison of actual location with previously computed locations. The test was highly successful, both in terms of missile performance and in terms of test data obtained.

PROCEDURE

Special Requirements. A tactical Redstone missile firing used mobile air-transportable equipment. In the case of Operation Hardtack, this equipment was supplemented due to the increased instrumentation requirements and the safety considerations not normally involved in a tactical firing (Figures 3 and 4).

Whereas a tactical missile would be checked out horizontally, the large amount of telemetry equipment located in the aft unit, the requirement for late arming of the warhead, and the requirement for installation and checking of pods after installation, necessitated a mobile vertical service structure This structure was located on the 36-by-36-foot concrete firing pad, and was moved back to an auxiliary pad approximately 150 feet from the missile shortly before launch.

A bunker located 300 feet from the launcher housed the fire-control equipment, the instru-

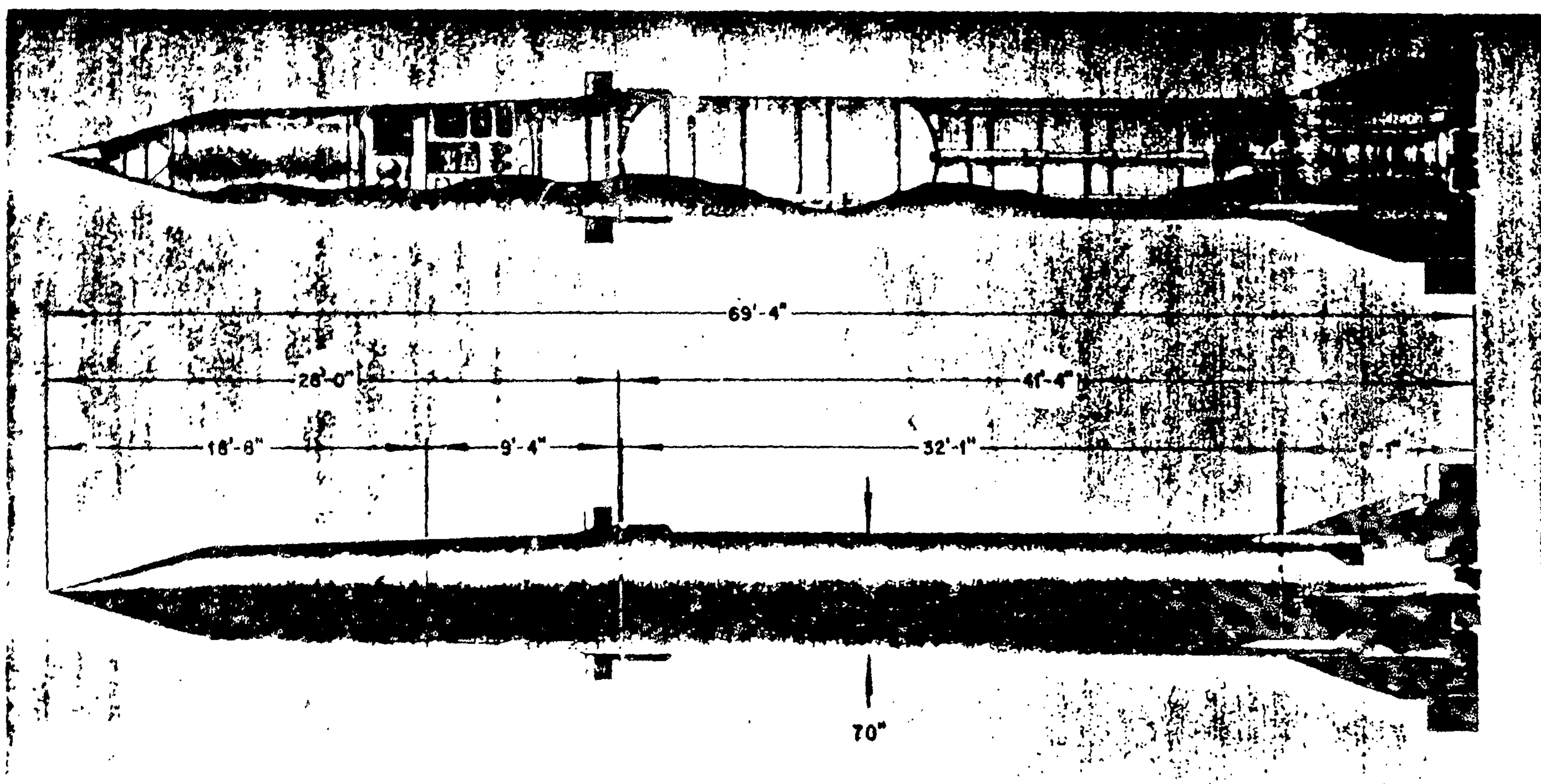

Figure 2 Redstone missile.

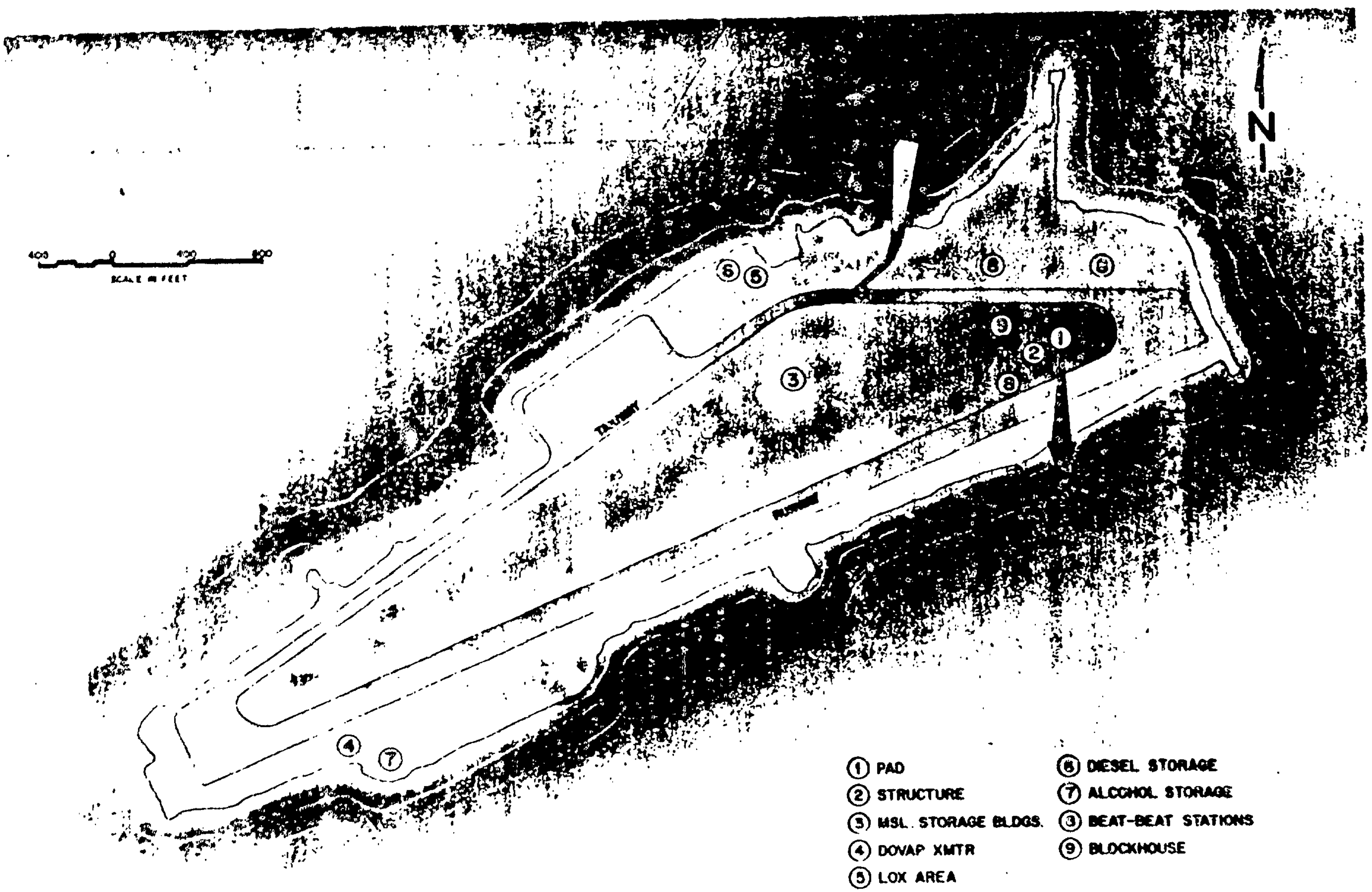

Figure 3 Johnston Island laycut.

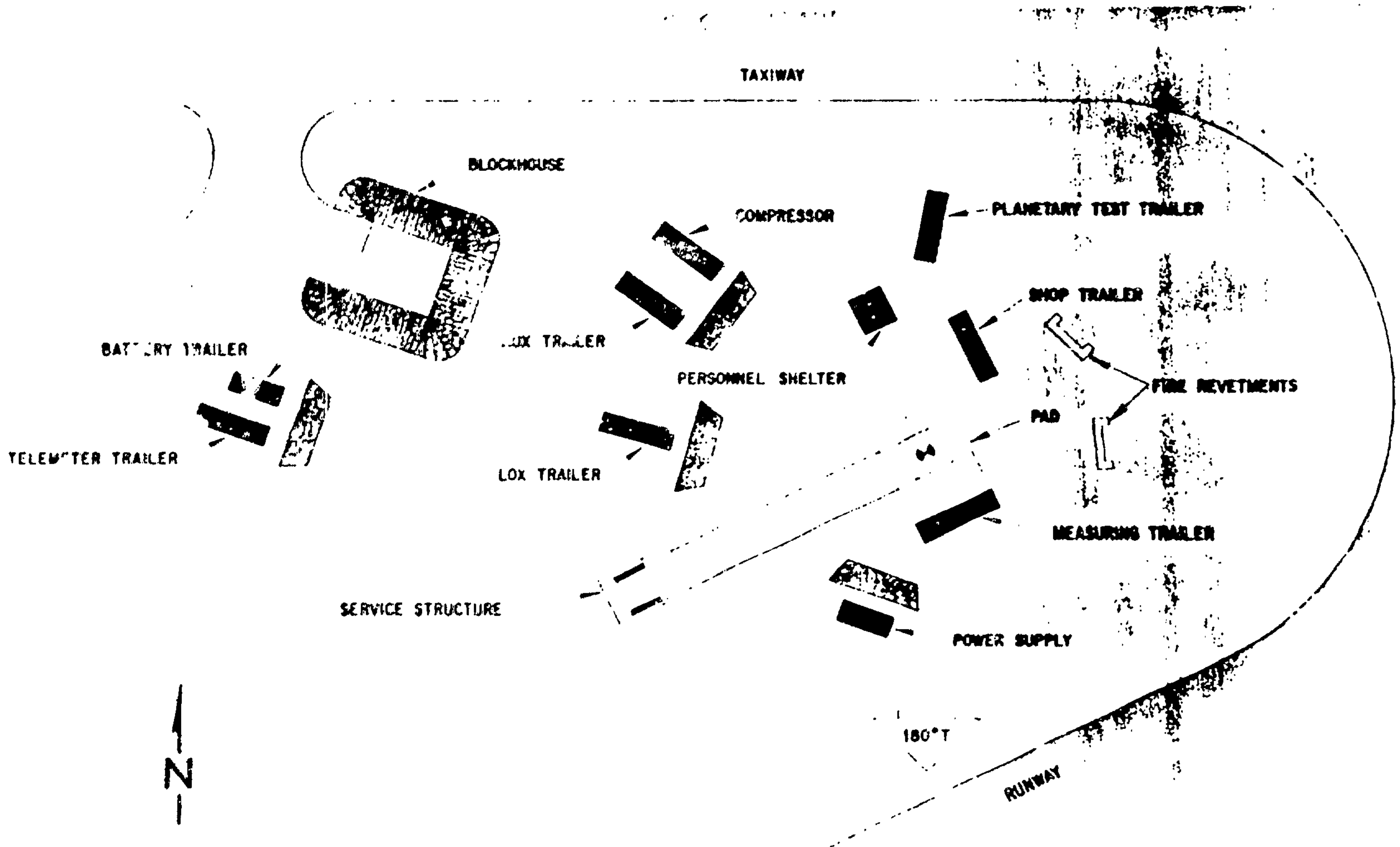

Figure 4 Bunker and launching pad, Johnston Island.

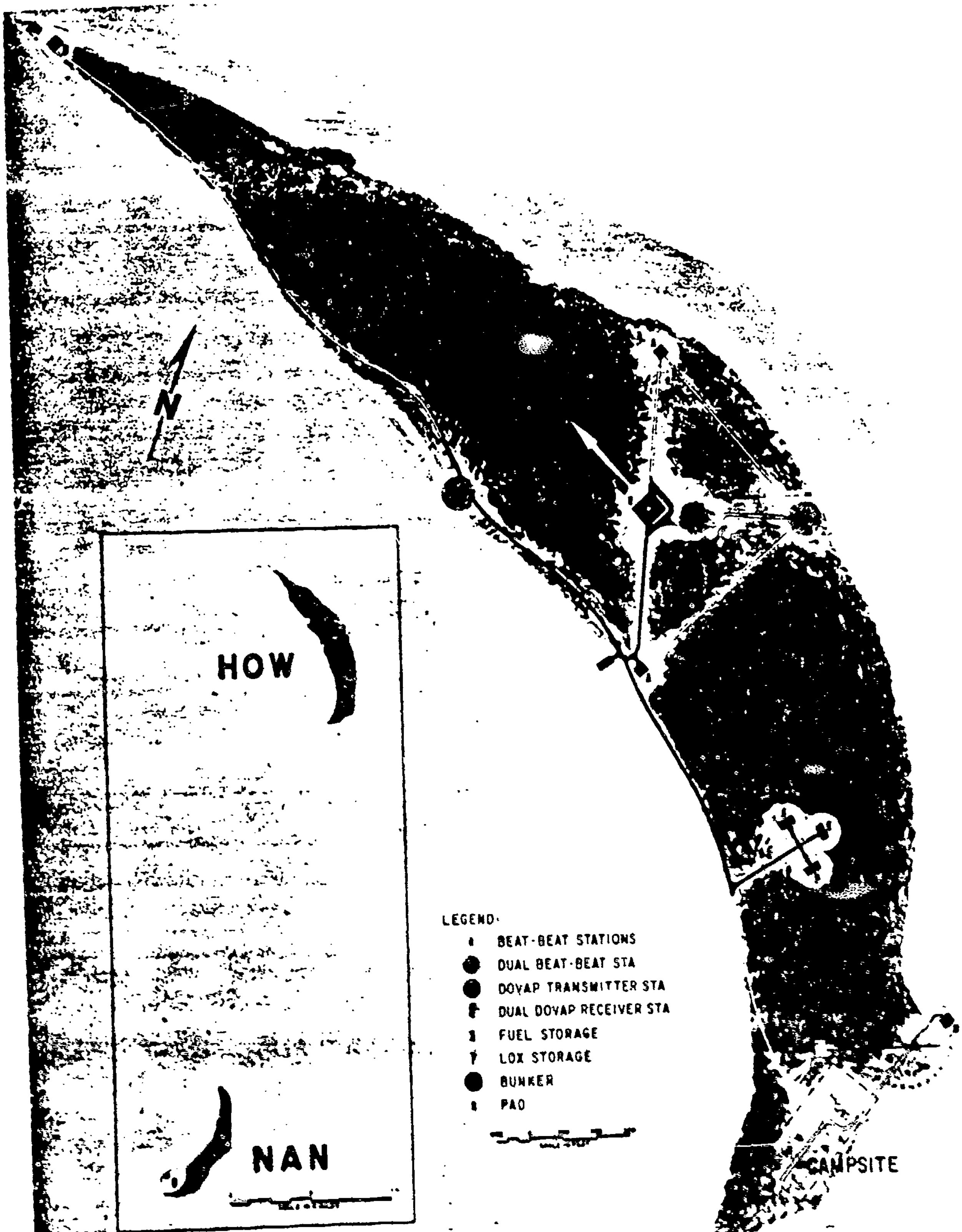

Figure 5 How Island layout.

mentation systems, radio-control flight safety and communication equipment. This bunker also gave protection to project and TG 7.1 command personnel who were required in the immediate vicinity of the launch pad.

Several hundred feet away from the launching pad were three Beat-Beat receiver stations. The DOVAP transmitter station was located near the southwestern end of Johnston Island and two DOVAP receiver stations were located in the firing bunker. The liquid oxygen (LOX) generation and storage area was located on the north side of the island.

The Redstone missile required certain logistical support that is provided for in the tactical organization. In the Hardtack operation, the number of personnel and amount of equipment was reduced to a safe minimum to permit firing of Shots Teak and Orange. This resulted in placing requirements on the Task Force for certain peculiar items. Solidified carbon dioxide (dry ice) is required for the missile cooling system. This was obtained in Honolulu and flown to the site in 1,500-pound containers to meet the checkout and firing schedules. Deionized water is required for fuel mixing and for the hydrogen peroxide system. This was obtained from the local water distillation plant by taking the normal output of the plant and rerunning it until desired purity was reached.

Liquid oxygen was obtained by transporting to the site two 5-ton/day LOX plants of the Redstone tactical system. A 35-ton tactical storage tank plus four 9-ton storage and transporting trailers were filled to meet the launching requirements a total of 75 tons was generated on Bikini and 161 tons on Johnston, with the plants averaging a little better than 5 tons/day per plant when in operation.

Other items required for the system were common to other users in the proving ground. All support requirements were met on time.

Pre-Operational Schedule. Shots Teak and Orange were originally planned to be accomplished from a launch point at Site How. All required facilities were completed there as shown in Figures 5 and 6. All equipment and personnel necessary for Shot Teak were present at that site by 8 April 1958. Marriages of the Shots Teak and Orange warheads were accomplished on Site Elmer, and Teak was transported to Site How on 5 and 6 April by LSD, erected the evening of 6 April, and a ready date of 23 April was planned. On 9 April a decision was made to move to Johnston Island with ready dates of approximately 1 August for Shot Teak and 11 August for Shot Orange. The warheads were removed from the nose cones and the missile sections were placed on the trailer transporters and held at Eniwetok for air shipment to the new site. The nose cone and aft unit of the spare missile (CC 53) never reached the Eniwetok Proving Ground (EPG) but were off-loaded and stored at Hickam Air Force Base when the decision to move to Johnston was made. The thrust unit of Number 53 was flown from Eniwetok to Hickam and stored with the other two sections.

During the period from 11 to 14 June, the components of Missiles 50 and 51 were flown via C-124 to Johnston Island, and on 10 July the two nose cones were flown to Hawaii for warhead mating, which was accomplished on 12 and 13 July. The remaining cargo was shipped by surface vessels from Eniwetok to Johnston, arriving during the period from 27 to 28 May. No major difficulties were experienced during this move.

A total of 127 personnel of Project 9.3a participated in the operation at one or both of the launching sites. This number included 45 military personnel, 79 civil-service employees, and 3 contractor personnel. Project personnel who had arrived at Bikini returned to their home stations for other duties after rollup requirements at Bikini were met. The maximum number on site at one time was 91. The Project Office consisted of three personnel and functioned as the coordinating agency for the planning, implementation and rollup phases of the operation. The firing team was provided by the Missile Firing Laboratory of the Development Operations Division, U.S. Army Ballistic Missile Agency (ABMA), augmented by seventeen personnel from other divisions of ABMA, and six artillery enlisted specialists from Fort Sill, Oklahoma. The firing team installed the necessary equipment in the trailers and firing bunker; received, prepared, checked out and fired the two missiles; and obtained the required after-the-fact information as to trajectory and burst location. Data were reduced by Aeroballistics and Computation Laboratories, ABMA, and Chrysler Corporation. A team of four warhead-adaption-kit specialists from Picatinny Arsenal, augmented by one contract civilian, installed and checked out the warhead adaption kit for the missile system. A detachment of sixteen U.S. Army Engineers from Fort

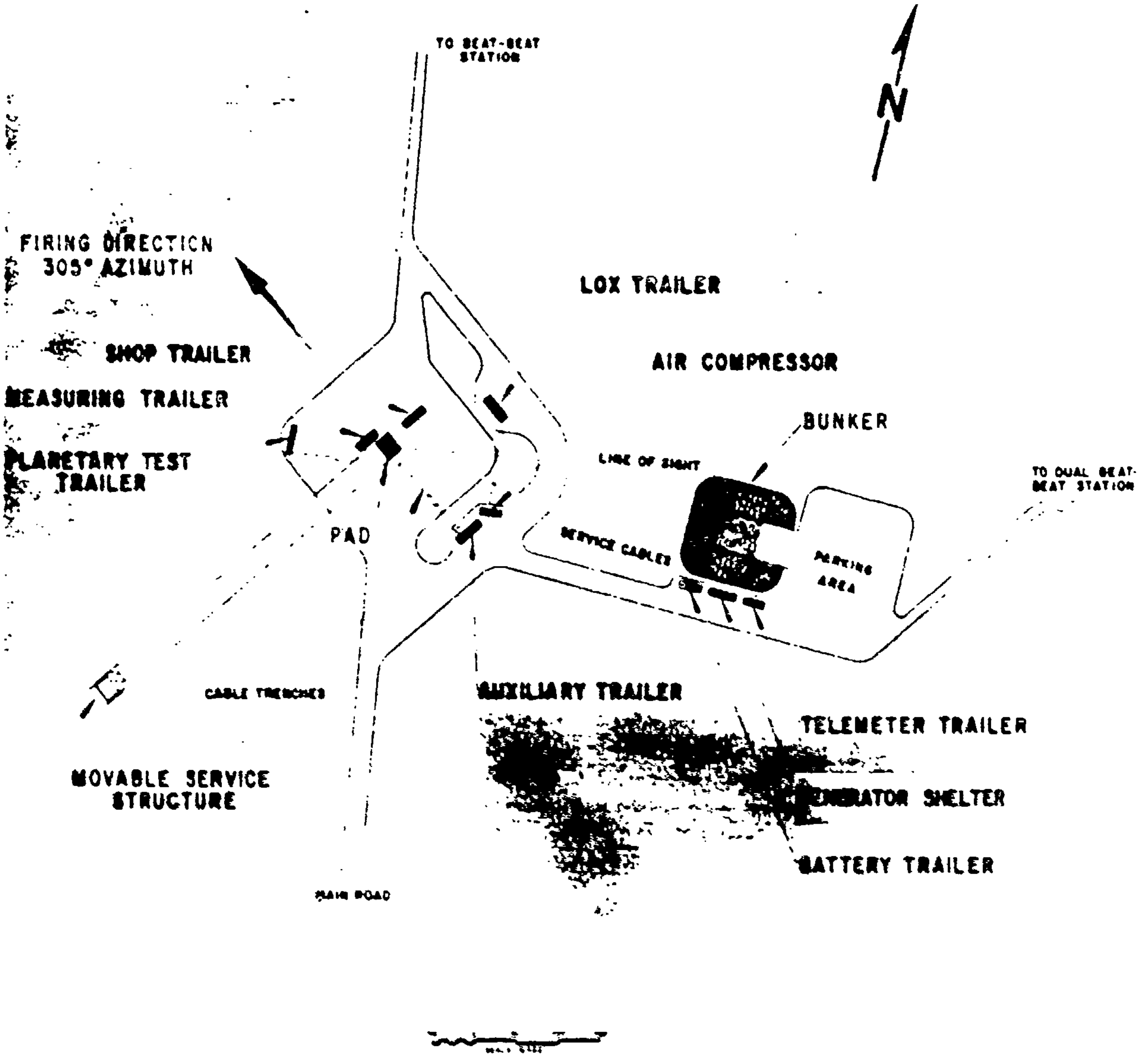

Figure 6 Bunker and launching pad, Bikini.

Belvoir, Virginia, augmented by a civilian contractor representative, operated the liquid-oxygen plants and provided maintenance assistance on the tactical engineer equipment. Figure 7 reflects the intended personnel schedule for Bikini, and Figure 8 is the actual schedule for the Johnston Island phase.

The first significant group of project personnel arrived at Johnston Island in mid-June. The

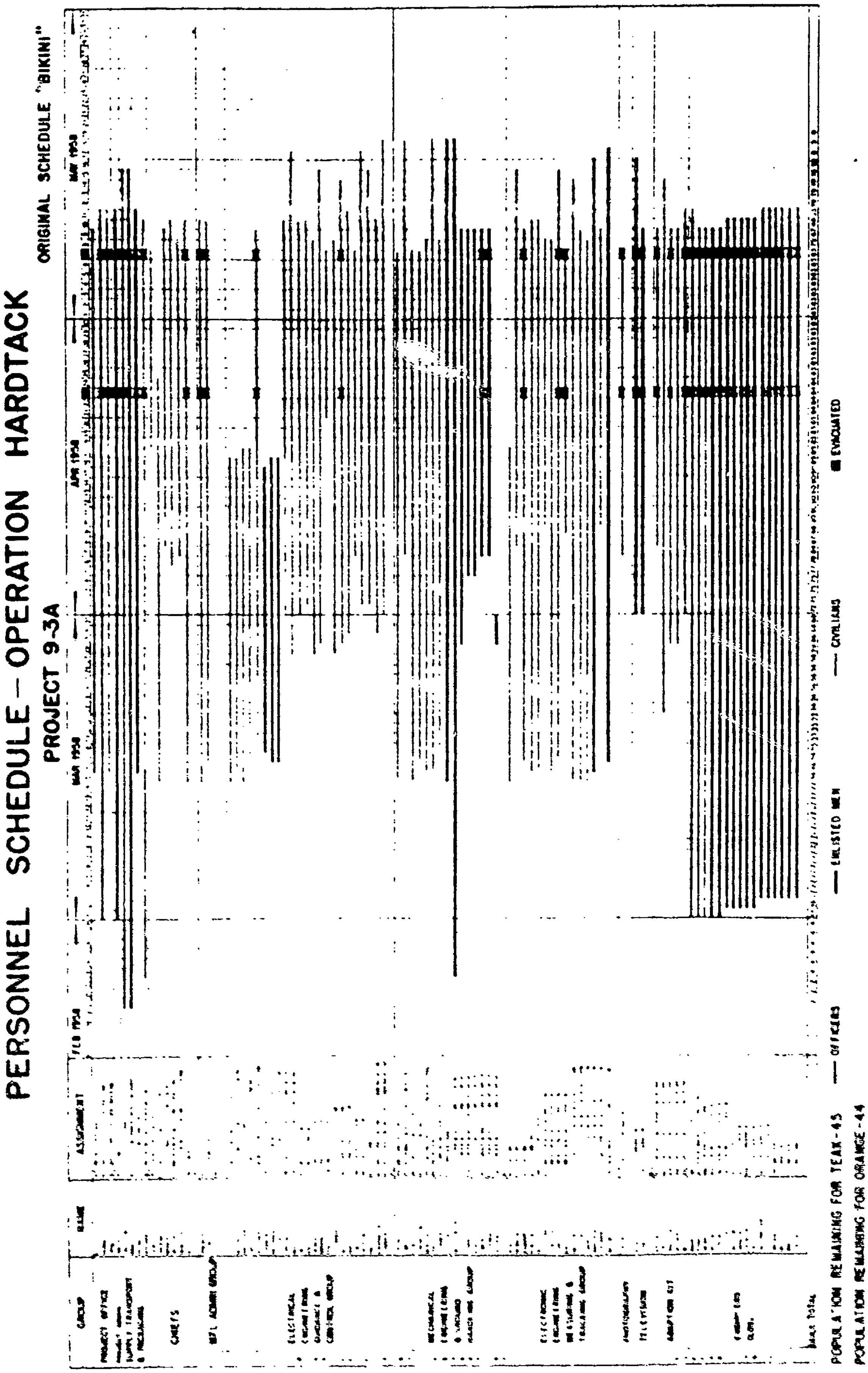

Figure 7 Personnel chart, Bikini.

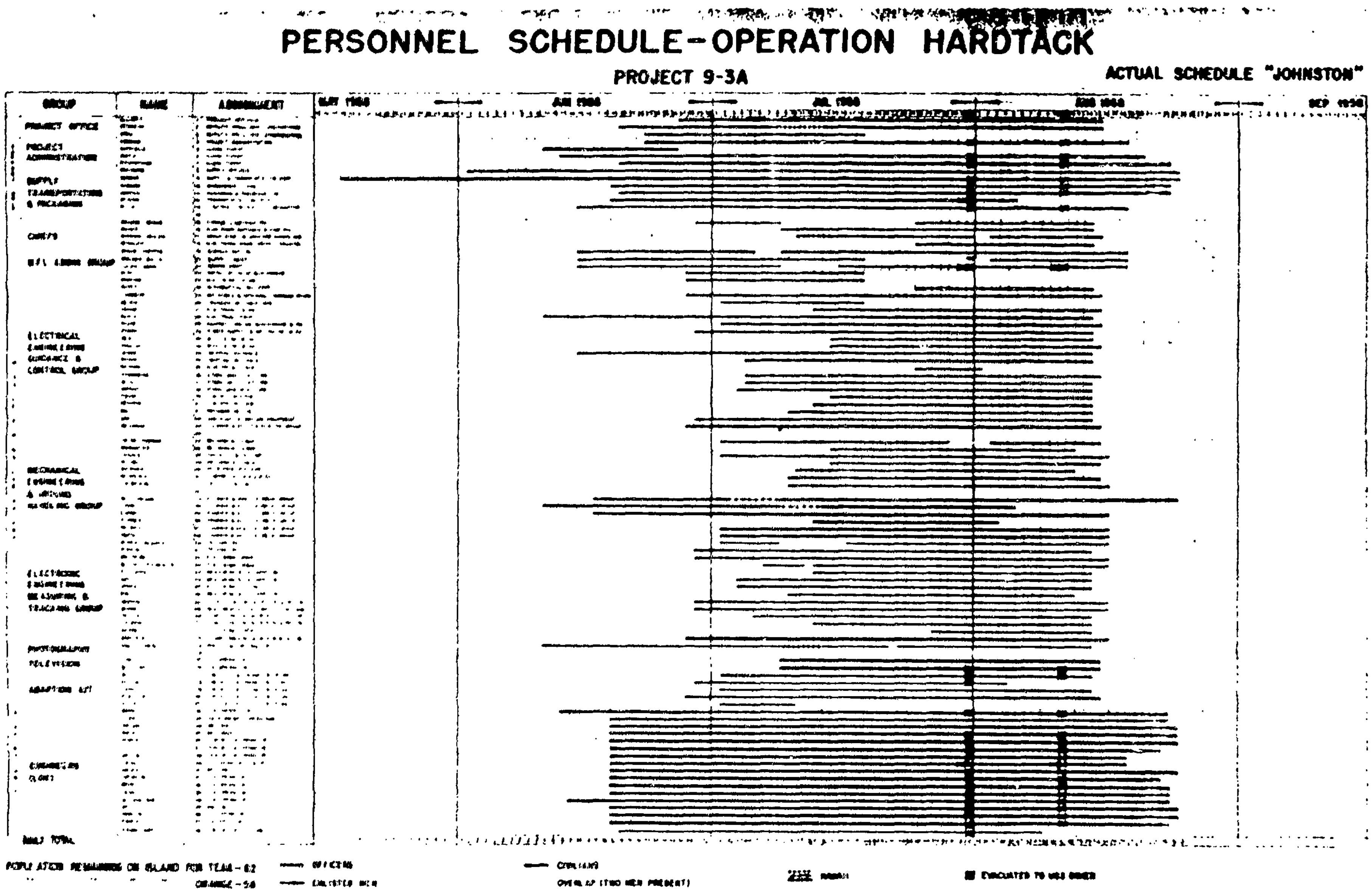

Figure 8 Personnel chart, Johnston Island.

time until 14 July was required for setting up launching equipment, telemetry and tracking stations, installation of a communication system for internal project use, interconnection of internal and external communication systems, connection of all instrumentation trailers to power lines, checkout of air compressor, LOX plant, fire-fighting equipment, and tests of the stabilized platforms.

Operational Schedule. Missile 50 was designated for Shot Teak, Missile 51 for Shot Orange, and Missile 53 was a spare for either.

The nose unit of Missile 53 was not married at this time but was held in readiness at Waikele for a marriage in either configuration. Firing preparations started with the arrival of the nose unit of Missile 50 on Johnston Island on 12 July, and ran through 31 July 1958, the firing day for Shot Teak. During this period all portions of Missile 51 were on Johnston Island, so it would be readily available to be erected after a successful Teak. If a decision had been made to repeat Teak, a crew would have been flown to Hawaii for the marriage of Missile 53. Missile 51 was erected on 2 August, checked out, and launched on 11 August as scheduled. Missile 53 was erected on 13 August, less nose cone, but was taken down on 14 August when word was received that the firing phase was concluded. Missile 53 was returned to ABMA via C-124. Table 2 shows the day-by-day schedule for Shot Orange.

RESULTS

Determination of Locations. The location of Missile 50, used for Shot Teak, was calculated from lateral and program Beat-Beat data, resulting in an estimated accuracy of 1 part in 2,500 in the coordinates, with no consideration having been given to systematic recording [illegible]

The location of Missile 51, used for Shot Orange, was calculated from lateral Beat-B[illegible] teletrack data, with approximately the same accuracy as above.

In order to obtain initial points for the pod-free flight trajectories, the position data were fitted to a third-degree polynomial by a least-square procedure. It was assumed that the pods were ejected perpendicular to the missile axis with a velocity of 6.7 m/sec. The ejection velocities were resolved into component velocities and added to the missile velocities at the times of ejection, as read from telemetry records. Computations of the free-flight trajectories were made using the same aerodynamic coefficients that were used in the theoretical pod trajectories.

Location of Bursts and Pods. The results of Shots Teak and Orange appear in Tables 3 and 4, respectively. The X, Y, and Z Cortesian coordinate system was centered at the DOVAP transponder with the missile in the launch position. Geographical coordinates of this location were 16 degrees 44 minutes 3.697 seconds north and 169 degrees 31 minutes 35.512 seconds west. The transponder was assumed to be 15 meters above the Clarke Spheroid of 1866. The coordinate system was oriented with the X axis on an azimuth of 180 degrees, the Z axis 270 degrees east of north, and the Y axis perpendicular to the XZ plane.

Pods for each shot were numbered consecutively according to increasing distance from the burst. Pod 1 was closest, Pod 2 next closest, and so on. Ejection times were in reverse order, with Pod 4 being ejected earliest during the powered phase of the missile trajectory.

DISCUSSION

Shot Teak. Teak detonated approximately 11.2 km north and 800 meters east of the intended point. Altitude deviation was negligible, calculated at approximately 50 meters low. Due to a malfunction in the tilt program system, the control system did not receive tilt commands. Inasmuch as the platform performed properly in prelaunch checks, and there was no indication of any tilt pulses whatever during the flight, the possibility of electronic failure in the tilting mechanism seems most likely. Another possibility, even though very remote, is that there may have been a mechanical malfunction. However, there is not enough evidence on hand to deter-

TABLE 2 DAY-BY-DAY SCHEDULE, SHOT ORANGE, AUGUST 1958

1 August:
1. Clean and paint table
2. Prepare pad for erection
3. Check pad cabling

2 August:
1. Assembly of missile
2. Erection
3. Vertical and azimuth alignment (rough)
4. Enclose missile in structure
5. Electrical and pneumatic connection
6. Install ST-80 and make fine vertical and azimuth alignment
7. Apply dc power
8. Instrument compartment pressure test

3 August:
1. Apply dc power to missile and make initial network checks
2. Connect measuring trailer and begin measuring calibration
3. Begin power plant checks
4. NRL pod-check cable
5. Begin detailed radio frequency check

Night:
1. Changes in tilt program circuits

4 August:
1. Continue power plant checks
2. Begin control test
3. Measuring calibrations
4. Radio-frequency checks

5 August:
1. Pressurization test
2. Overall Test No. 1
3. Overall Test No. 2
4. Overall Test No. 3
5. Measuring calibration
6. Complete guidance-gyro-control tests
7. Measuring calibration
8. ST-80 cooling test
9. Instrument compartment cooling test
10. Mounting and aligning Pod 1
11. Radio-frequency checks of Pod 1, WADC
12. Remove pod after completion of work

6 August:
1. G and C overall test with telemeter, Sandia, Picatinny and WADC
2. Tail plug overall test
3. Examine telemetry records from overall test
4. Mounting and aligning Pods 1, 2, 3, and 4
5. Prepare ABMA radio-frequency equipment for range rehearsal test

7 August:
1. Remove Pods 1, 2, 3, and 4
2. Final preparations for simulated flight test
3. Safety wiring
4. Check remaining system faults
5. Mix alcohol

8 August:
1. Simulated flight test
2. Examine telemetry records

9 August:
1. General checkout

Night:
1. Rehearsal

10 August:
1. D – 1 day work

11 August:
1. Launch countdown
2. Fire during night

mine the precise cause of malfunction.

Shot Orange. Orange detonated approximately 4 km south and 50 meters west of the intended point. It was 4.7 km higher than intended.

A malfunction occurred in the guidance system at approximately 68 seconds. This malfunction resulted in late solving of the cutoff equation, which in turn resulted in ejection of Pods 3, 2, and 1 and engine cutoff occurring later than predicted. The malfunction, or combination

TABLE 3 RESULTS OF SHOT TEAK, REDSTONE MISSILE 50

1. Launched at 23:47:14.99 Johnston Island time; 31 July 1958
2. Burst occurred at 23:50:5.597 Johnston Island time; 31 July 1958
3. Burst location with respect to launcher

	X_e	Y_e	Z_e
	km	km	km
Actual	−0.987	76.311	0.688
Predicted	10.225	76.382	1.494
Error (A-P)	−11.192	−0.051	−0.806

4. Pod locations at burst with respect to launcher

Number		X_e	Y_e	Z_e
		km	km	km
1	Actual	−0.714	69.838	0.684
	Predicted	9.795	70.075	1.050
2	Actual	−1.270	66.419	1.250
	Predicted	8.856	66.980	1.473
3	Actual	−0.613	60.582	1.187
	Predicted	8.783	60.927	1.106
4	Actual	−0.958	22.607	0.338
	Predicted	4.450	24.084	0.340

5. Pod locations at burst relative to the missile. A negative sign indicates that the missile is ahead of the pod.

Number		X_e	Y_e	Z_e	Slant Range from Burst
		km	km	km	km
1	Actual	−0.253	−6.473	−0.004	6.478
	Predicted	−0.430	−6.287	−0.444	6.318
2	Actual	0.303	−9.882	0.562	9.903
	Predicted	−1.369	−9.382	−0.021	9.481
3	Actual	−0.354	−15.729	0.499	15.741
	Predicted	−1.443	−15.435	−0.388	15.507
4	Actual	−0.009	−53.704	−0.350	53.705
	Predicted	−5.775	−52.278	−1.254	52.611

TABLE 4 RESULTS OF SHOT ORANGE, REDSTONE MISSILE 51

1. Launched at 23:27:34.498 Johnston Island time; 11 August 1958
2. Burst occurred at 23:30:8.607 Johnston Island time; 11 August 1958
3. Burst location with respect to launcher

	X_e	Y_e	Z_e
	km	km	km
Actual	41.690	42.973	0.933
Predicted	37.665	38.257	0.885
Error (A-P)	+4.025	+4.716	+0.048

4. Pod locations at burst with respect to launcher

Number		X_e	Y_e	Z_e
		km	km	km
1	Actual	39.793	40.727	0.687
	Predicted	35.773	35.861	0.696
2	Actual	35.298	35.751	0.952
	Predicted	31.278	30.971	0.629
3	Actual	32.553	31.369	0.883
	Predicted	28.997	26.324	0.560
4	Actual	23.270	20.006	0.249
	Predicted	22.097	18.119	0.389

5. Pod locations at burst relative to the missile. A negative sign indicates that the missile is ahead of the pod.

Number		X_e	Y_e	Z_e	Slant Range from Burst
		km	km	km	km
1	Actual	−1.897	−2.246	−0.265	2.952
	Predicted	−1.892	−2.396	−0.189	3.059
2	Actual	−6.392	−7.222	+0.019	9.644
	Predicted	−6.387	−7.286	−0.256	9.693
3	Actual	−9.137	−11.604	−0.050	14.770
	Predicted	−8.768	−11.733	−0.325	14.651
4	Actual	−19.324	−22.967	−0.684	30.023
	Predicted	−15.560	−20.183	−0.496	25.489

of malfunctions, has been neither duplicated in the laboratory nor explained independently to date.

CONCLUSIONS

Missile-Pod Method for Very-High-Altitude Tests. The missile-pod scheme of delivering a nuclear device to extreme altitude, as well as close-in positioning of instrumentation has been demonstrated as highly successful. The accurate positioning of all pods with respect to the burst on both firings, with the exception of Pod 4 on Shot Orange, met the stated requirement. The integration of pod-ejection commands into the guidance-and-control system of the missile enabled this accurate positioning despite unpredicted missile behavior.

Reliance upon demonstrated ballistic characteristics of free-flight projectiles is considered far preferable to a combination of devices controlled from ground stations. For example, the self-correction described above would not have been possible if the pods had been guided or had their own propulsion systems. The complication introduced into the program by incorporation of independently controlled devices would be inordinate in comparison with reliance upon proven physical phenomena.

Safety. The dangerous aspects of any mission are determined as much by the state of training of personnel as by the conditions under which they work. The safety aspects of this operation were adequate and no additional precaution or devices are recommended.

Adequacy of Tracking and Position Data. Position data for Shot Teak were determined mainly on the basis of Beat-Beat information. Position data for Shot Orange were determined mainly on the basis of teletrack information. Teletrack differs from Beat-Beat mainly in that the raw data for teletrack was recorded as the difference in frequencies observed by a pair of receivers rather than as an angular displacement.

While accuracy of both systems' data was not optimum, due to limitations in base-leg distances, data obtained were adequate for the missions assigned.

APPENDIX: TACTICAL REDSTONE MISSILE SYSTEM

At separation, the Redstone missile divides into two parts, the body unit and the thrust unit.

Body Unit. The body unit consists of a nose cone, which contains the payload, and the aft unit, which houses the guidance and control components. Four pairs of spatial air jets permit correction of the attitude of the body after separation from the thrust unit, and four evenly spaced air vanes are located on the outer surface of a circular skirt section to control the body after re-entry into the atmosphere (not a requirement for Operation Hardtack).

Thrust Unit. The long cylinder-shaped center section of the thrust unit contains two large propellant tanks, one for an alcohol-water mixture and the other one for liquid oxygen. The rocket engine is attached by means of a braced thrust structure to the lower end of the center section. A tail section encloses the rocket engine and supports the missile when it is erected on its launcher. Four large air rudders, carried on fixed fins of the tail, operate in conjunction with carbon jet vanes, which project into the rocket engine exhaust stream, to provide both path and attitude control.

Missile Flight. The characteristics of the missile in powered flight are shown in Figure 9. The rocket engine, developing a thrust of 78,000 pounds, lifts the missile from its table-like

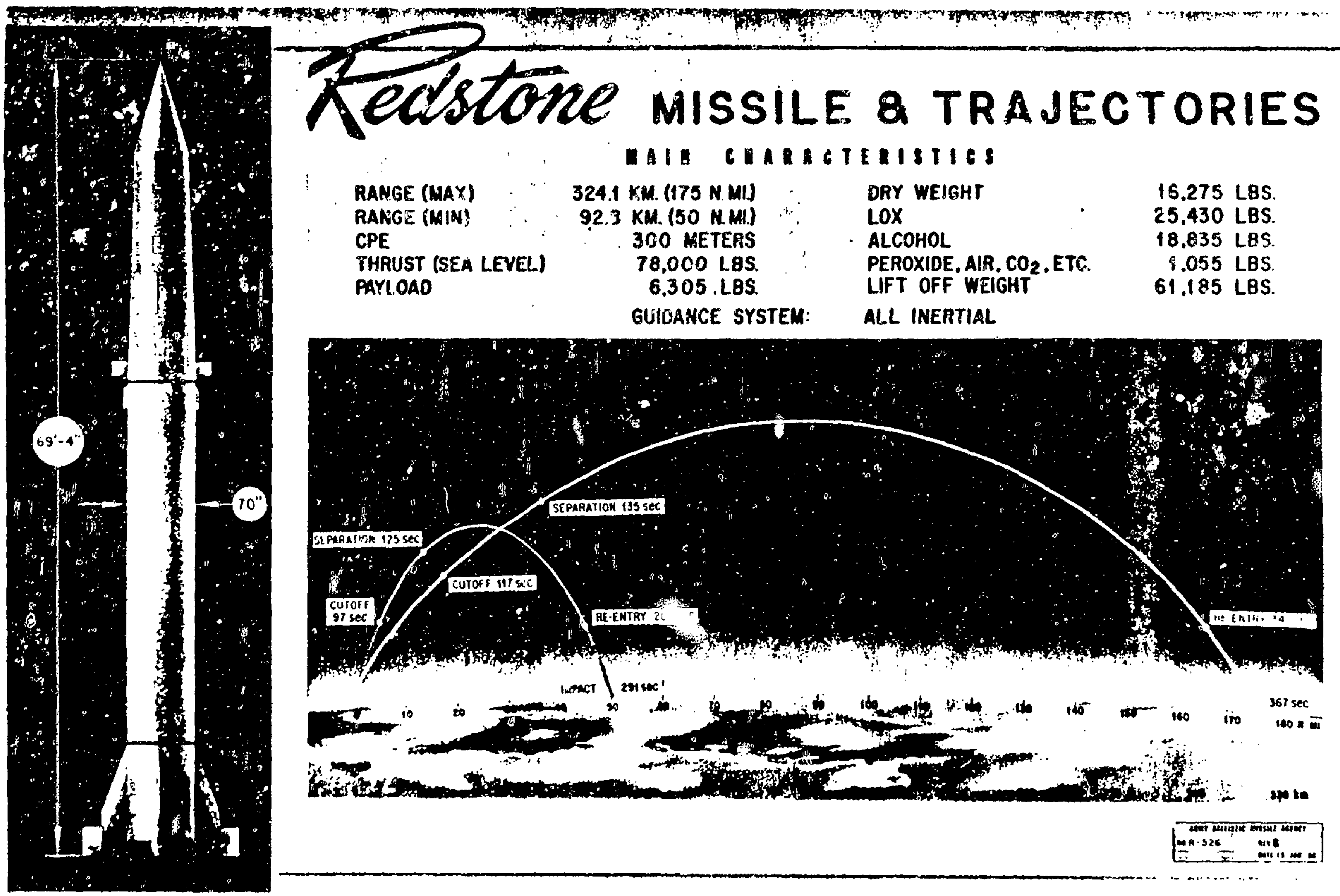

Figure 9 Redstone missile and trajectories.

launcher and accelerates it for approximately 2 minutes of flight. Onboard guidance serves mainly to ensure an accurate cutoff velocity and location. Shortly after the rocket engine cuts off, the body unit separates from the thrust unit. The body unit then continues in free flight on a ballistic trajectory until burst.

Guidance and Control Systems. The guidance system generates continuous information on the position of missile relative to its theoretical trajectory. The control system provides for attitude control and also utilizes tape-recorded information to provide missile time programming functions, one of which is the tilt program which aims the missile toward the target.

Two guidance measuring directions are incorporated in tactical Redstone missiles. One accelerometer is mounted with its measuring axis in the lateral direction. The second detects deviations in the range direction. These accelerometers are connected to computers that determine the velocity and distance by which the missile deviates from the theoretical trajectory. The computers not only generate appropriate corrective commands in the event of such deviation, but also determine when cutoff will occur, taking into account variations in missile thrust and weight.

Computer indications are supplied to the missile arming system. Since an instantaneous check of this system would not be indicative of the missile's continuing to follow the theoretical trajectory, the adaption kit monitors this indication for a number of seconds between cutoff and separation. This method prevents arming if there are indications that the missile deviates to a certain degree from the proper trajectory, or if the computer is not giving correct values.

REFERENCES

1. "Report on a Study of the Safety Aspects of UHA and VHA for Operation Hardtack" (U); 21 October 1957; Field Command, AFSWP; Secret Restricted Data.

2. "Feasibility and Reliability Study of Redstone Missile Adaption Kit for Operation Hardtack" (U); 30 April 1957; Picatinny Arsenal; Secret Restricted Data.