Test and Evaluation of Land-Mobile Missile Systems

William R. Mentzer, Jr.

For almost 25 years, APL conducted a program for the test and evaluation of land-mobile nuclear missile systems deployed in Europe. In 1965, the Laboratory was asked to help design and conduct an operational test program for the Pershing system for the Joint Chiefs of Staff. To support that Pershing performance and subsequent survivability evaluation efforts—including the Operational Survivability Assessment Program for the Pershing II (PII), the Ground Launched Cruise Missile (GLCM), and the Lance systems—APL established its only foreign field office. During these evaluations, APL identified problem areas and made many contributions to improve the performance and survivability of these systems. Our contributions helped make the PII and GLCM the effective nuclear deterrents that brought the Soviet Union to the negotiating table for the Intermediate-range Nuclear Force Treaty. This program continued until the Pershing system was deactivated in 1990 as a result of the signing of that treaty.
(Keywords: GLCM, INF Treaty, Land-mobile missile systems, Pershing, Survivability testing.)

OVERVIEW

APL planned and carried out a test and evaluation program for U.S. nuclear land-mobile missile systems in Europe for almost 25 years. The effort began in late 1965 when the Army requested Laboratory assistance in establishing an operational test program (OTP) for the Pershing 1 (P1) weapon system that had just been deployed to West Germany as part of the North Atlantic Treaty Organization (NATO) theater nuclear forces.

The P1 missile, with a nominal range of 740 km, could reach only the western regions of the Warsaw Pact. The P1 system was intended to offset the growing imbalance of conventional Warsaw Pact forces by providing a theater nuclear deterrent. It was assigned a "quick reaction alert" (QRA) role (a rapid-response nuclear strike posture developed to counter a sudden Warsaw Pact/Soviet Union nuclear strike on NATO forces) and was included among other strategic ballistic missile system programs that were required by the Joint Chiefs of Staff (JCS) to provide an annual assessment of system performance capabilities.

Specifically, the Joint Chiefs had directed that the Commander-in-Chief (CINC) for each U.S. strategic ballistic missile system plan and conduct an OTP according to strict guidelines developed by the JCS's Weapon System Evaluation Group (WSEG). The OTPs for these critical strategic weapon systems were required to use deployed troops and equipment and to follow the WSEG guidelines for test sizing, evaluation, and reporting. The guidelines specified that the OTP evaluations were to rely on "demonstrated" performance data to the maximum extent possible.

To meet this challenging evaluation requirement for a foreign-deployed, mobile, manpower-intensive weapon system such as Pershing, APL concluded that a permanent, in-theater presence was needed to monitor the system on a daily basis. This decision led to the establishment of the Laboratory's only foreign field office, the European Field Office (EFO), in the spring of 1966 in Stuttgart, West Germany. By the fall of 1966, the EFO was operating in Heidelberg, West Germany (also the Headquarters of the U.S. Army, Europe), managing the OTP data collection effort and providing technical support to the Army's Pershing Operational Test Unit (POTU).

APL continued the performance assessment task as the improved Pershing 1a (P1a) system was fielded in 1970. This task expanded in the mid-1970s to include an evaluation of the vulnerability and survivability of the proposed Pershing II (PII) system through large-scale field testing using P1a equipment.

The success of the survivability evaluation for the planned PII system led to immediate efforts to improve survivability for the P1a system, then in the field. Eventually that work got the attention of the Defense Nuclear Agency (DNA). In 1981, DNA was starting to address the survivability of various nuclear activities in theater and saw the APL survivability evaluation approach based on controlled field experiments to be more valuable than the purely empirical studies DNA was planning. DNA first funded experiments to address survivability issues for the deployed P1a force. That work eventually resulted in an expanded survivability evaluation effort involving other theater land-mobile missile systems.

In 1983, the United States began fielding the longer-range theater-strategic PII and Ground Launched Cruise Missile (GLCM) systems, which could both reach targets in the Soviet Union. These deployments were the result of the 1979 NATO dual-track strategy to pursue arms negotiations with the Soviet Union while also countering Soviet missile deployments (especially the multiple-warhead SS-20 system) by upgrading the NATO theater nuclear forces. The PII and GLCM systems assumed QRA postures and were thus subject to the JCS test and evaluation requirements noted earlier. APL developed and helped implement the PII System Evaluation Program, which combined OTP and survivability evaluation requirements. We also supported the development and implementation of the corresponding GLCM System Evaluation Plan.

By 1986, the initial performance evaluations for PII and GLCM had been completed. At this point, DNA requested that APL plan and conduct a 5-year program to enhance the survivability of the theater nuclear forces, i.e., PII, GLCM, Lance, and a planned follow-on to Lance. The resultant APL-developed Operational Survivability Assessment Program (OSAP) examined potential survivability improvements by performing the same type of theater survivability field exercises in the tactical environment that the Laboratory first executed with Pershing. OSAP took advantage of the existing data collection infrastructure at EFO, supplemented by additional APL field test teams, to conduct and evaluate these survivability experiments.

In 1987, the Intermediate-range Nuclear Force (INF) Treaty eliminated an entire class of U.S. and Soviet short- and intermediate-range nuclear weapons including the Pershing variants (P1a, P1b, and PII), GLCM, and the Soviet SS-4, -X-4, -5, -12, -20, and -23 systems. There is widespread agreement that the successful deployment of the PII and GLCM as part of the NATO dual-track decision of 1979 was a crucial factor in getting the Soviet Union to the arms-negotiation table and in bringing about a peaceful end to the Cold War.[1]

The extended ranges of PII (1800 km) and GLCM (2500 km) had given NATO the flexibility to strike high-value targets deep within the Soviet Union with land-based assets (Fig. 1). The PII provided a short time-of-flight, highly accurate, terminally guided warhead with a selectable yield, suitable for use against individual hardened, high-value targets such as command and control centers. The slower, longer-range GLCM had a small radar signature, making it difficult to detect and counter.

The PII and GLCM were the premier theater-strategic deterrents for NATO. APL contributed to the successful deployment of these systems, in part, through realistic testing, both in highly visible European exercises and in U.S. test range flight tests that firmly established the credibility of these weapons to allies and adversaries alike. This credibility, plus the unflinching NATO commitment to deploy these systems in the face of massive demonstrations orchestrated by the Soviets, became the turning point of the Cold War.

Implementation of the INF Treaty caused a programmed phaseout of the APL land-mobile missile systems test and evaluation activities. On 27 May 1988, the United States ratified the INF Treaty, which established 1 June 1991 as the date for completion of system elimination. APL support was needed for PII during the drawdown period because PII retained some target coverage responsibility. The OSAP was refocused on Lance survivability assessments once the INF Treaty became a reality. APL supported this effort until all Pershing program responsibilities were terminated with the closing of the EFO on 30 September 1990.

Figure 1. European theater showing bases and coverage for the Pershing II (PII) and Ground Launched Cruise Missile (GLCM) systems. Numbers indicate GLCMs, except for Germany, which combines the count for PIIs (96) and GLCMs (108). The expanded view shows the locations of headquarters (squares), U.S. Army (triangles) and Air Force (circle) bases, and the APL field office in West Germany in 1987.

A comprehensive history of APL's land-mobile missile system test and evaluation program (see the boxed insert) would greatly exceed the space allotted here. As a result, this article attempts to give the reader a flavor for the depth and breadth of our effort by reviewing highlights of program activities. We

HIGHLIGHTS OF THE LAND-MOBILE MISSILE SYSTEM VI PROGRAM

7 Jan 1958	Pershing development approved by Secretary of Defense
25 Feb 1960	First P1 test flight conducted
Apr 1964	First P1 firing unit deployed
1 Mar–30 Apr 1965	Joint Environmental Test conducted
26 Nov 1965	Pershing Operational Test Program task accepted by APL
Dec 1965	Quick reaction alert (QRA) role assigned to 56th Artillery Group
23 Mar 1966	APL European Field Office (EFO) opened at Stuttgart
Oct 1966	EFO moved to Heidelberg
Aug 1969	First P1 Evaluation Report issued
Jul 1970	First P1a QRA status assumed
Aug 1971	First P1a Evaluation Report issued
Mar 1974	PII Survivability Study ordered by PII Defense Systems Acquisition Review Council
14 Sep 1976	Support to U.S. Army, Europe, Survivability Test Directorate starts
11–27 Oct 1977	Exercise Certain Thunder conducted
Oct 1979	NATO dual-track deployment decision made
5 May 1981	Defense Nuclear Agency (DNA) Pershing survivability task started
21 Jan 1983	First PII test flight success, Mission ED-10
15 Apr 1984	First PII QRA status assumed
Dec 1984	PII Preliminary Estimates Report and Ground Launched Cruise Missile Evaluation Report issued
Sep 1986	PII Early Assessment Report issued
Oct 1987	First PII Evaluation Report issued
8 Dec 1987	INF Treaty signed
Jun 1988	First PII firing unit deactivated
31 May 1990	APL Pershing Program Office disbanded
27 Jul 1990	PII data collection activities ended
30 Sep 1990	EFO closed
Oct 1990	Last DNA Lance Report issued

Note: APL activities indicated in blue.

begin with a discussion of how APL, a Navy-oriented facility, got involved with an Army missile system based overseas. Then we examine the Laboratory's approach to executing the original OTP, which we later built on to perform the survivability task. Finally, we discuss some of the major contributions APL made to the Pershing, GLCM, and Lance systems in the course of executing this program. The weapon systems that APL worked on over the years are shown in Fig. 2[2,3]; detailed characteristics are presented in Table 1.

PROGRAM TASKING

The P1 system deployed to West Germany as part of the 56th Artillery Group in 1964–1965 with 24 erector-launchers (ELs), carrying 1 missile each, in a support role to the U.S. Seventh Army. Secretary of Defense McNamara directed the Army to determine if the Pershing force could assume a QRA role to free up valuable, dual-capable air assets in Europe for their conventional use. The U.S. European Command conducted the Joint Environmental Test in 1965 to make this determination. Satisfactory completion of the test resulted in the 56th Artillery Group being assigned the QRA mission in December 1965.

The initial P1 QRA operational concept placed half the force on continuous alert at open sites as a visible deterrent, ready to prepare and launch their missiles as fast as possible (Fig. 3). In anticipation of P1 receiving the QRA mission, the Army prepared to help the Commander, U.S. European Command (the responsible CINC for Pershing) develop an OTP to meet the Joint Chiefs/WSEG evaluation requirement. JCS used the resulting system planning factors to prepare the annual targeting update for U.S. and NATO strategic forces.

To conduct this important evaluation for the P1, the Army wanted a technically qualified, independent organization. They were familiar with the test and evaluation task that APL was performing for the Navy's Polaris Fleet Ballistic Missile Strategic Weapon System. The Army requested Laboratory assistance in planning and executing the Pershing OTP in a 28 October 1965 letter from Leonard Sullivan, Jr., of the Office of the Director, Defense Research and Engineering. On 26 November 1965, APL formally accepted the Pershing task.

OPERATIONAL TEST PROGRAM IMPLEMENTATION

The Pershing evaluation effort was formed in the APL Polaris Division in 1965. The initial tasks included

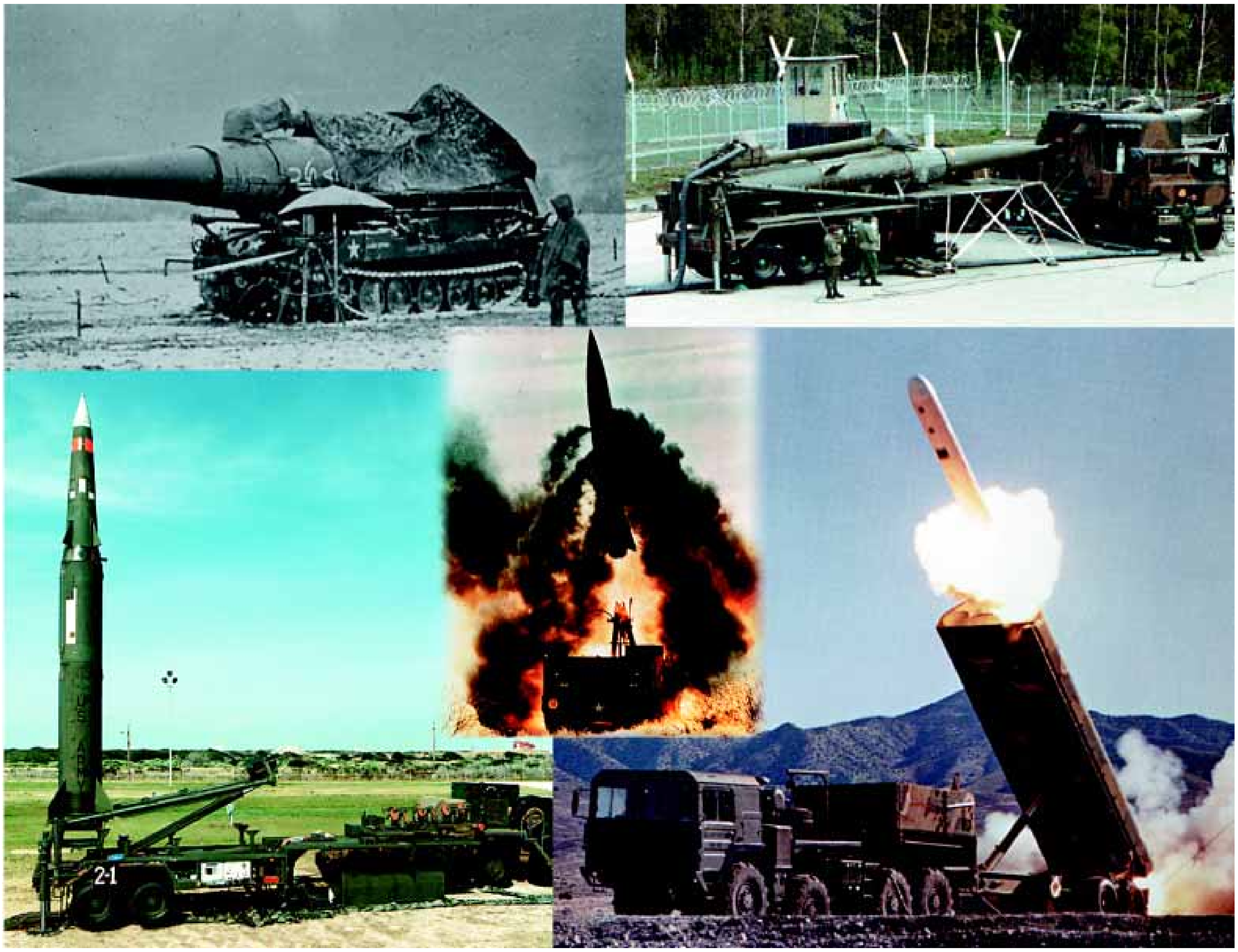


Figure 2. Weapon systems evaluated in this program: (clockwise from upper left corner) P1 missile on tracked erector-launcher at a field site, P1a missile on wheeled launcher at an open quick reaction alert site, PII missile at a U.S. firing range showing the fins on the maneuvering reentry vehicle, GLCM launch from a four-tube missile launcher, and (center) Lance launch from its tracked launcher.

development of the P1 OTP and production of the annual performance evaluation reports for submission to the JCS. As noted previously, APL determined that a presence in theater would be necessary to properly conduct such evaluations and to support the U.S. European Command. For the OTP, APL specified a two-part testing program, since all of the types of data needed for a rigorous system performance evaluation could not be obtained solely from missile test firing operations in the United States.

The two components of the OTP were: (1) no-notice countdown exercises for the portion of the force in theater on QRA status and (2) operational test missile firings at test ranges in the United States. The QRA exercise met the JCS objective, i.e., to rely on demonstrated performance data from the deployed force operating in the tactical environment to the maximum extent possible. The no-notice countdown exercises were initiated by nuclear weapon release messages (exercise versions of the tactical nuclear weapon release messages). These exercise release messages were transmitted over the same theater communications networks that would be used in wartime. This procedure made it possible to assess the reliability of the nuclear release communications process in theater. The QRA units responded to those messages, executing training countdowns with their alert missiles. Units were then able to provide representative launch reliability and reaction timeline data that reflected the effects of variations in the theater environment on personnel, communications, and equipment.

The annual OTP missile firings provided the data for missile flight performance and accuracy evaluations as well as data on those countdown functions that had to be simulated during the QRA exercise countdowns done in theater. These firings were conducted first at White Sands Missile Range, New Mexico, and later at the Eastern Test Range, Cape Canaveral, Florida, using troops, missiles, and associated ground support equipment selected from QRA status in theater.

The selection or "tapping" of QRA units to participate in OTP firing operations was random and

Table 1. Systems comparison.

Specifics	P1	P1a	PII	GLCM[a]	Lance
	Missile systems				
Missile type	MGM-31A, two-stage, solid-propellant, ballistic	MGM-31A[b] two-stage, solid-propellant, ballistic	MGM-31B, two-stage, solid-propellant, terminally guided	BGM-109-G, Tomahawk Cruise Missile, turbofan-powered/ solid-propellant, launch booster	MGM-52, one-stage, storable liquid-propellant, ballistic
Warhead	Nuclear	Nuclear (same as P1)	Nuclear, selectable yield	Nuclear, selectable yield	Nuclear/ conventional
Nominal range (km)	740	740	1800	2500	120
Ground support equipment	Tracked vehicles, analog computers, manual azimuth laying	Wheeled vehicles, digital computers, manual azimuth laying, ARS/SLA[c]	Wheeled vehicles, each erector-launcher was a self-contained firing unit	Wheeled vehicles	Tracked vehicles
Users	U.S. Army, West German Luftwaffe	U.S. Army, West German Luftwaffe	U.S. Army	U.S. Air Force at bases in Belgium, England, Italy, Netherlands, West Germany	U.S. Army and armies of Belgium, England, Italy, Netherlands, West Germany
U.S. Force size (loaded at any one time)	3 battalions of 4 batteries with 2 missiles each 24 missiles total	3 battalions of 4 batteries with 9 missiles each 108 missiles total	3 battalions of 4 batteries with 9 missiles each 108 missiles total	5 wings 3–10 flights 16 missiles each 464 missiles total[d]	6 battalions of 3 batteries with 4 missiles each 36 missiles total
APL involvement	1965–1970	1970–1984	1983–1990	1984–1990	1984–1990

[a]The GLCM system was designated “Gryphon” when deployed by the U.S. Air Forces in Europe, but INF Treaty documentation continued to use the term GLCM.
[b]Same as P1 until 1974 when digital guidance computer was upgraded.
[c]Automatic Reference System/Sequential Launch Adapter (added in 1976).
[d]Only 256 GLCMs had been deployed before the INF Treaty was signed and deactivation started.

Figure 3. Pershing 1a platoon at a full-criteria QRA site. Notice that although this site had a secure perimeter, the equipment was clearly visible as part of its role as a deterrent.

no-notice to ensure that the resulting performance was representative of the entire deployed force. Missiles from the tapped units were disassembled at the QRA site, and the missile sections were sealed in their shipping containers for return to the United States. Once returned, flight safety and instrumentation modifications were made, and the nuclear warhead components were replaced with inert test equipment. These operations were done under strict oversight by POTU with help from APL.

Over the years, the biggest change to this instrumentation process was to preselect the P1a OTP warhead sections from theater assets well before the QRA missile units were tapped. This step was initiated for P1a to reduce the costs of the warhead instrumentation effort. It was necessary to continue the warhead preselection process for PII firings because the PII reentry vehicle section required special machining as part of the instrumentation process. The instrumented missile sections were delivered to the firing units at the test range for reassembly in the same configuration and, as nearly as possible, the same condition as when selected in theater. All missile assembly, checkout, and firing operations were done by theater Pershing units with no outside assistance from contractor technical experts except for the handling of the associated instrumentation and range safety equipment.

Countdown operations were manpower-intensive for the P1 system, and no automated data collection system was available. APL had to rely on a manual data collection process to obtain the QRA data for the performance analysis. The Laboratory contracted for a permanent team of data collectors at each of the dispersed Pershing battalions and provided a set of data collection procedures to cover the QRA activities.

Since the QRA exercises could occur at any time, the data collectors were quartered with the Pershing alert crews near the missiles on alert. They were responsible for documenting all activities by the platoons they were monitoring. The addition of automated data recording equipment when the P1a system was fielded supplemented, but did not eliminate, the manual data collection requirement, since many relevant circumstances in countdown operations and maintenance could only be documented by an on-the-scene observer. It was this team of field data collectors, who were knowledgeable about both Pershing system operations and data collection requirements, that enabled APL to obtain the necessary data from both QRA sites and field exercises to successfully execute the Pershing OTP, the Pershing survivability operations, and the DNA-sponsored OSAP.

Although the principal output of the Pershing OTP was the annual CINC evaluation report for the Joint Chiefs, APL recognized that the QRA data collection and analysis process would also yield information valuable to the system user, the 56th Artillery Group (which later evolved to Brigade and then Command) and the materiel developer, the Army's Pershing Project Manager's Office (PPMO). For the user, we produced tailored reports on the countdown and maintenance activities of each QRA status period and compared these with cumulative weapon system statistics. The status of open maintenance actions was reported and corrective actions recommended. APL's EFO personnel reviewed these QRA reports with the leadership of the responsible firing batteries to ensure the accuracy of the interpretation of recorded data and analyses. For PPMO, and its supporting contractor community, the Laboratory provided copies of all raw data as well as the QRA status reports, regular compilations of performance and maintenance statistics, and recommendations for addressing equipment and procedural deficiencies. We also performed special studies for both communities upon request.

PROGRAM CONTRIBUTIONS

In executing performance and survivability programs for the theater land-mobile nuclear missile systems (Pershing, GLCM, and Lance), APL developed an in-depth understanding of all aspects of these systems: missiles, ground support equipment, communications systems and networks, targeting, command structure, operational concepts, and vulnerabilities. This detailed systems-perspective expertise provided a valuable asset to the military and enabled APL to make significant contributions to the systems covering a broad range of issues.

When system problems were uncovered in the course of analyzing QRA activities, missile firing operations, or survivability exercises, APL provided detailed analyses and recommended courses of action to resolve both equipment and procedural deficiencies. In addition, we often conducted special investigations to examine how new or improved capabilities could be implemented. APL also developed unique instrumentation to automatically record Pershing weapon system tests and to monitor and improve system survivability. The following sections describe some of APL's most significant contributions that emerged as a result of our participation in the OTP and survivability programs.

Operational Test Program Contributions

The focus of OTP efforts was the evaluation of weapon system performance. While conducting these evaluations over the years, APL was often able to identify performance problems and develop solutions that were then implemented either by PPMO or the Pershing force. These fixes resulted in improvements in weapon system reliability, reaction time, and accuracy.

P1a Accuracy Improvement

In 1972, when cumulated data from the P1a OTP missile flights at White Sands Missile Range confirmed the existence of a seasonally dependent accuracy bias, APL initiated a detailed investigation to identify the source of the problem. The study showed that the fire control computer was using incorrect firing table data to target the missile.

The tables had been created in the early 1960s using a 6-degree-of-freedom flight simulation implementing the best available atmospheric model (Atmosphere Research and Development Council-59). In that simulation, the atmosphere had been truncated at a 100,000-ft altitude, with constant values used for temperature, pressure, and density above that altitude. Because the P1a warhead section was released from its booster while still exiting the atmosphere, it was subject to atmospheric drag forces. Consequently, incorrect atmospheric modeling in the flight simulation above 100,000 ft caused erroneous drag calculations, resulting in faulty impact point predictions and incorrect firing table data.

When newer atmospheric models were examined during the course of this study, the existence of seasonal variations in the upper atmosphere was noted. This meant that the drag on a warhead section as it exited the atmosphere varied seasonally, causing the observed seasonal variations in the accuracy bias. Once APL identified the problem, the Army elected to field revised fire control software rather than regenerate the firing tables based on a better atmospheric model. The revised fire control software compensated for the expected variation in warhead drag by making adjustments to the warhead separation parameters.

P1a Performance Improvement

When the P1a system was fielded in 1970, the 56th Artillery Group became a Brigade, with the basic firing battery expanded from one 2-missile firing platoon to three 3-missile firing platoons, giving a total of 108 missiles deployed on ELs in Europe. In 1976, the P1a system ground support equipment was upgraded with the fielding of two new components, the Automatic Reference System (ARS) and the Sequential Launch Adapter (SLA), to simplify and speed up the missile launching process. These systems were developed as a result of APL's recommendations to the Army for improving system performance (based on identification of the need through analysis of QRA countdown performance and identification of solutions after researching the technologies to effect those improvements).

The ARS contained a north-seeking gyro coupled to a laser theodolite. One ARS was needed for each of the three ELs in a firing platoon. With the north-seeking gyro, a firing unit no longer required presurveyed launch points, which significantly expanded the choices of covert positions in the field for use as P1a launch sites. The laser theodolite replaced the crewman with a standard theodolite, thereby automating the missile aiming process. The SLA was a junction box connected to the fire control, power, and air systems of the P1a ground support equipment and to all three ELs at the same time. Because time was saved in not having to uncable, move, and recable the ground support equipment after each launch, the SLA significantly reduced the time required for a platoon to complete a three-missile launch sequence. The reduced cable handling also improved reliability by limiting the opportunity for cable and connector damage.

PII Targeting

The PII missile, although barely larger than the P1a, was much more sophisticated and had more than double its nominal range at 1800 km. It also featured a maneuvering, terminally guided reentry vehicle with a radar area correlator that resulted in significantly enhanced system accuracy (Fig. 4). The PII guidance system was also self-aligning, so there was no longer a constraint on the orientation of the ELs at launch sites.

A typical trajectory for a PII missile is shown in Fig. 5. Upon reentering the atmosphere, the PII reentry vehicle executed a pull-up/pull-down maneuver to reduce speed and orient itself so that the radar antenna in the nose could scan the target area. As the reentry vehicle descended, the radar determined the altitude and scanned the target area. The resultant data were compared (correlated) with the appropriate stored radar images of the target area for each altitude band. The set of four images for each target was produced from a Defense Mapping Agency digital mapping database, which included both terrain elevation and feature data. The radar scenes for an assigned target were loaded into the guidance computer in the PII

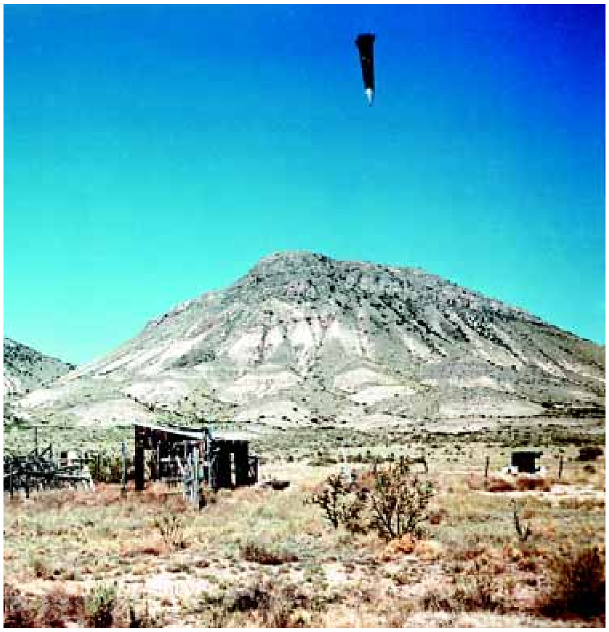


Figure 4. PII reentry vehicle nearing impact in a shot at White Sands Missile Range. The actual target was the corner of the building closest to the flight path of the reentry vehicle.

reentry vehicle during its launch countdown. During the terminal portion of flight, when guidance was in the terrain mapping mode, the positional differences between the scanned images and the stored images yielded steering corrections for the reentry vehicle. The quality of the resulting accuracy improvement was affected by the number of bands correlated as well as the quality of the correlations themselves.

The design of the PII terminal guidance process resulted in two situations that could significantly affect terminal accuracy. First, an error in specifying target coordinates would cause the reference scene to be centered on the wrong location, and the reentry vehicle would then "home in" on that wrong location. Thus, target location error translated almost completely into miss distance. Second, if sufficient terrain or feature information was lacking in the reference scene to provide a radar return, there would be no correlation, and the system would have only ballistic (inertial) accuracy.

APL evaluated this second problem by examining the satellite imagery and the corresponding digital mapping data for the complete pool of candidate PII targets. These targets were evaluated to determine whether sufficient information would be available in the tactically generated reference scenes to allow the terminal guidance system to perform a correlation and meet its accuracy criteria. Each potential PII target was then rated on the likelihood of achieving either full, partial, or no correlator accuracy. This rating information was provided to the JCS targeters to enable them to optimize the use of the PII system when they made the initial PII target assignments in 1984.

Instrumentation Systems

To meet its analysis needs for both the OTP and survivability tasks, APL found that we had to develop and build the necessary instrumentation. The most significant example involved the Pershing OTP. The P1a system featured only a limited automated data recording capability, a digital data recorder that mounted in the fire control van and received only the limited amount of countdown event information that the system designers had elected to record. For PII, the equivalent fire control function was done by a computer mounted on the side of each PII EL. APL recognized that if the instrumentation tap were in that computer, then access to all countdown sequence information would be possible, allowing us to specify the data elements required for the OTP evaluation. Also, as the system software evolved, the interface to the data would not be affected.

The Army adopted our recommended instrumentation approach, which resulted in tasking APL to develop a data recording device called the system data recorder (SDR). The SDR was designed to mount on the EL near the fire control computer (Fig. 6). Since it was exposed equipment on a tactical system, the SDR had to be operable in extreme environments. It also had to pass the same Army-specified production certification process as the tactical EL. Prototype units were subjected to thermal cycling, shock and vibration, and radio-frequency interference testing. They were even subjected to electromagnetic pulse exposure to validate that they met nuclear hardening standards and would not interfere with tactical system operation in a potential nuclear attack. APL then fabricated 30 SDRs; 27 units were sent to Europe and placed into service as the firing units completed their conversions from P1a to PII equipment. The Laboratory maintained and repaired the recorders in theater at a special APL instrumentation facility. Three SDRs were retained at APL and used to support PII OTP flight tests. The SDR supported PII OTP firings, QRA operations, and field exercises from 1983 until the OTP ended in 1990.

In addition to producing the recording instrumentation, APL also made significant contributions to the test range and blockhouse operations needed to conduct the OTP flight tests. The most significant effort was the development of the real-time display of countdown information at the project control facilities in the blockhouse at the Eastern Test Range. APL developed an optical interface to the P1a tactical system so that the instrumentation could receive weapon system data and pass it to external displays, while meeting

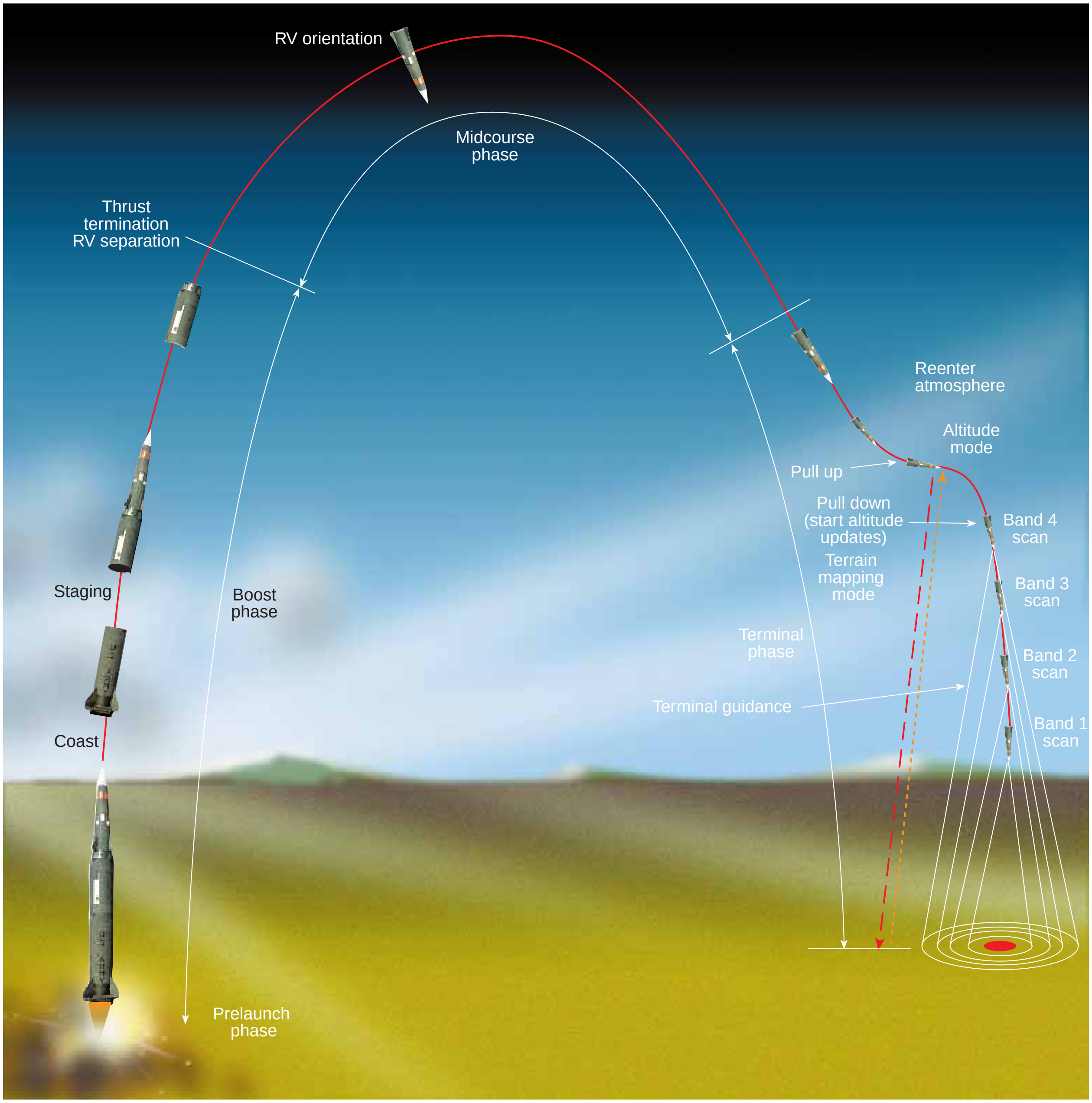


Figure 5. PII trajectory showing details of the terminal guidance process. The number of band scans that could be completed in the terrain mapping mode varied with the complexity of the target scene (RV = reentry vehicle).

strict requirements to ensure isolation from the tactical equipment. This display became an essential tool in the P1a project control flight test operations, and a similar systems approach was implemented in the SDR for the PII weapon system. APL also developed a comprehensive video system with recording capabilities to monitor and analyze firing platoon activities at the firing ranges. The real-time display and the video system helped meet the objective of minimizing nontactical interference with firing unit activities, yet allowing the project control personnel to maintain oversight of firing operations and ensure range safety.

Weapon System Evaluation Group Guidance Evolution

The WSEG military office personnel served as the JCS analysis staff, with civilian technical support from the Institute for Defense Analyses. The Joint Chiefs asked WSEG to take early (1963) JCS requirements for the test and evaluation of strategic ballistic missile systems, add the necessary data requirements, and standardize performance reporting across the military services. The WSEG version of the evaluation guidance contained the specific measures of performance

(a)

(b)

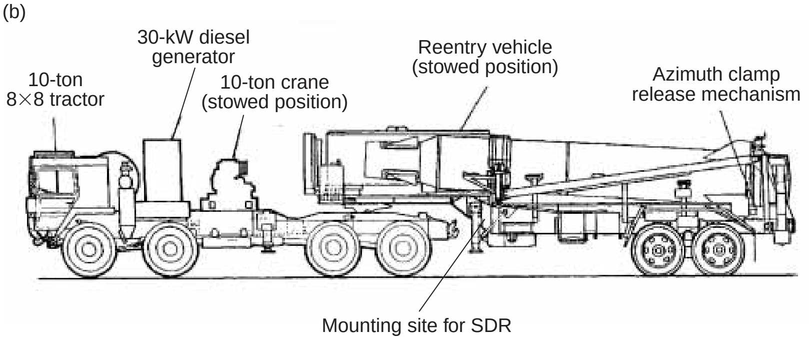


Figure 6. APL designed, built, and tested the system data recorder (SDR), which was to serve as the primary source of countdown data for the analysis of quick reaction alert performance. (a) PII SDR, dismounted, showing operator access and supporting equipment, and installed on the erector-launcher. (b) Erector-launcher in travel configuration showing where the SDR mounts.

to be evaluated; the statistical basis for those factors, which had the effect of sizing the operational test flight sample, thereby defining the required test-missile assets to be procured; general supporting data requirements necessary to show that the operational test sample was representative of the deployed force; and the reporting format.

The evaluation requirements developed by APL for the Polaris Fleet Ballistic Missile Program provided major contributions to the original WSEG evaluation guidelines. The WSEG guidance was updated periodically as new technologies (multiple independently targeted reentry vehicles) and new weapon systems (GLCM) were fielded. In this updating process, the APL Pershing staff contributed significant improvements including specifications for the use of Fisher's Exact Test as the statistical technique to determine if different flight test samples could be combined; use of the amount of change in in-flight reliability (at a specified level of confidence) between operational and follow-on operational test results as a criterion for sizing the follow-on operational test flight sample; and establishment of the requirement for reporting on the survivability of land-mobile missile systems.

APL Pershing staff also helped the Army develop new techniques that addressed the implementation of WSEG guidance with fewer flight test samples in response to DoD cost-saving efforts. Our study led to the use of Bayesian techniques to augment the reduced flight test sample with other data sources to meet the confidence limits stated in the WSEG guidelines. This methodology was reviewed and accepted by an independent board of statisticians, but the INF Treaty terminated the PII OTP before the APL approach could be implemented for Pershing; it was, however, eventually adopted by the Air Force for their annual JCS OTP evaluation of the Peacekeeper strategic weapon system.

Survivability Contributions

Most of our contributions to the several weapon systems examined in the survivability evaluation efforts were procedural in nature, i.e., they attempted to change the way the units operated in covert field positions to reduce their signatures. The major contribution in the equipment area involved an antenna for implementing high-frequency ground wave (HFGW) communications.

Pershing Survivability

The major Pershing Survivability Exercise, "Certain Thunder," was conducted in October 1977 using the deployed P1a force; however, its principal objective was to obtain data to validate the APL-developed Pershing Survivability Evaluation Model to provide a preliminary PII survivability estimate for PPMO. This survivability estimate was needed by PPMO to support a task from the PII Defense Systems Acquisition Review Council. Exercise Certain Thunder was the largest Pershing field exercise ever conducted in Europe. It involved the Brigade headquarters, two

Pershing battalions (each having 36 ELs with missiles), and associated support and security units operating simultaneously in their respective tactical operational areas.

A variety of U.S. and Allied forces were used to provide the surveillance and attack assets attempting to locate, identify, and target the Pershing units. The 56th Brigade conducted its planned wartime operational concept. They worked from covert sites in the woods, maintained coverage on assigned targets, and moved frequently to avoid detection. APL led the exercise planning effort by developing the exercise concept, coordinating the use of theater and national surveillance and attack assets, designing and executing the data collection process, and assisting in exercise control.

In wartime, a Pershing battalion would deploy and emplace three of its four batteries in a covert field location covering targets (Fig. 7), while the fourth battery would be moving to a new location. Once at its new site, that battery would emplace its missiles and assume coverage on a predetermined set of targets, freeing one of the other batteries to relinquish its coverage and move. This "leapfrog" pattern of movement was intended to make it difficult for the enemy to target the Pershing covert sites.

Figure 7. Pershing platoon in a covert position. This is a PII platoon in the QRA-87 posture responding to a QRA no-notice exercise. Note the difference between the exposure of the system in this exercise and the exercises done on the QRA site in Fig. 3.

One of APL's objectives in designing Exercise Certain Thunder was to examine the complete spectrum of Pershing battalion operations in the field without reliance on "simulated" Pershing batteries. The use of simulated batteries was necessary in typical field exercises because the battalion had to leave one battery on its real-world QRA mission. Consequently, the ability of a full four-battery battalion to execute the planned wartime movement concept had never been realistically tested.

A significant finding of the exercise involved the P1a battalion movement concept. When the battalions had to coordinate four real firing batteries in the field, as required in the exercise design, they could not leapfrog across their areas of operation at anywhere near the frequency expected and specified in their operational plans. In addition, the aural signature produced by the firing platoons while covering targets from their wooded positions presented a beacon to enemy special forces elements, allowing the special forces to easily locate and eliminate the Pershing units. The combined effect of these findings that were immediately applicable to the P1a force led to a major revision to the NATO operational concept for Pershing wartime employment. Target coverage requirements were relaxed, depending on the state of hostilities, allowing deployed Pershing firing platoons to remain better hidden by reducing or eliminating the critical noise signatures. Simultaneously, the 56th Brigade changed its operational concept, revising the movement frequency based on the difficulties encountered in orchestrating the leapfrog process. These changes resulted in major improvements to the survivability of the P1a force.

Following Exercise Certain Thunder, survivability testing of the P1a and then PII systems examined both proposed operational concept changes and postulated improvements in enemy threat capability. APL acquired existing military gear and also designed and tested special equipment to aid Pershing units in defending their perimeters against the special forces threat. The findings from these tests resulted in further refinements to the Pershing operational concept. APL was able to show that covert site perimeter security against the special forces threat at night could only be improved by employing sensing equipment such as night vision gear and seismic sensors.

GLCM Run Silent Concept

APL initially began working with the Air Force in Europe in 1984 to develop an OTP performance evaluation for the GLCM and later expanded its involvement to include survivability assessments as part of the OSAP. The Air Force had little experience with land-mobile missile systems when it started deploying the GLCM units to Europe in 1984. The GLCM operational concept called for the placement of tactical missile wings at existing NATO airfields. During peacetime, one missile flight with four transporter/erector launchers, carrying four missiles each, would be on QRA in a special security area on the base. The other two to six missile flights (not all tactical missile wings were to be the same size) would be in training or maintenance postures. In wartime, all missile flights would move out to covert field positions around the base and begin a leapfrog movement throughout the areas of operation, similar to Pershing, to minimize risk of detection. Those areas of operation for the GLCM missile wings were centered on their home air bases, which were to serve as their wartime maintenance sites.

Through OSAP field testing, APL demonstrated to the Air Force the importance of minimizing noise when operating at the covert field positions. As noted earlier in the section on Pershing survivability, generator noise was found to be a beacon that assisted enemy special forces searching for nuclear missile units operating from covert positions unless generator-quieting measures were taken. Pershing units had found that when trying to hide in covert sites while awaiting orders to launch their missiles, they could drastically minimize noise by operating equipment on battery power as much as possible and running generators only long enough to recharge those batteries. The Air Force initially planned to make great use of their generators when in covert sites. By structuring the GLCM OSAP exercises appropriately, APL was able to demonstrate this vulnerability and convince the units to revise their operational concept by adopting a "run silent" mode of operation at covert field sites.

Lance Survivability

APL was asked to examine survivability issues for the Lance battlefield nuclear weapon system as part of OSAP efforts starting in 1986. When the INF Treaty was ratified (1988) and the PII and GLCM systems were dropped from OSAP, DNA continued to support Lance survivability testing because the system still had a nuclear mission, and a planned follow-on-to-Lance system was under consideration. APL conducted 14 Lance survivability exercises in the period 1986–1990. Lance units from both the U.S. V Corps and VII Corps in Europe participated in those exercises. The same complement of threat assets was employed against the Lance units that had been used in the Pershing survivability testing: aerial reconnaissance with photographic, infrared, and radar assets; electronic warfare with both ground-based and airborne intercept and direction finding; unconventional warfare; and human intelligence.

The Laboratory developed annual survivability assessments and recommendations for improvements that were provided to both the DNA sponsor and the Lance units. In addition to the survivability assessments, we produced a Lance vulnerabilities compendium for DNA and a "Soldiers Guide to Concealment," which was distributed widely throughout the deployed Lance units.

High-Frequency Ground Wave Communications

An important APL contribution to OSAP was the development of a nuclear-survivable alternative communications method for land-mobile missile systems in Europe. In the event of a nuclear attack, existing communications systems could become unreliable because of ionospheric disturbances, which would disrupt high-frequency sky-wave links in the affected area. The Pershing weapon system, because of the importance of its theater-strategic mission, had identified a need for a reliable, nuclear-survivable method to communicate among its widely dispersed command elements in the field.

APL proposed using HFGW in the 20- to 30-MHz band to meet this need. HFGW propagation would not be significantly affected by a nuclear event. In addition, it offered improved beyond-line-of-sight communications using existing military radios connected to an antenna that was resonant at these frequencies. To be useful to Pershing, intelligible voice communications links of at least 40 km had to be achievable in mountainous terrain; significantly greater distances were undesirable because of the possibility of intercept and exploitation by hostile forces immediately outside the areas of operation. HFGW in the 20- to 30-MHz band uniquely satisfied these constraints.

Also, the antenna had to be reasonably small and easily assembled to be useful to these highly mobile units. A system optimization study resulted in the selection of a 4-m-high, portable, broadband discone antenna capable of operating in the 20- to 30-MHz HF band. Prototype antennas were fabricated at APL and extensively tested in the Pershing operational areas of West Germany. Reliable, nonfading, beyond-line-of-sight voice and digital data communications were demonstrated around-the-clock in mountainous regions at ranges of up to 100 km.[4] Automated HF monitoring stations were established in Spain and the United Kingdom to determine the extent to which sky-wave components from an HFGW reference antenna broadcasting in West Germany could be detected and exploited from long range.

Additional interest in HFGW expressed by the U.S. Marine Corps and the Southern European Task Force, among others, led to further demonstration tests in the Norwegian fjords, Italian Alps, and several sites in the United States. The Laboratory built a special lightweight (7-lb), collapsible version of the discone antenna to simplify its transportation, employment, and repositioning. This backpack-portable unit was satisfactorily tested in Europe and was eventually licensed for production. APL's HFGW expertise accumulated within this project has been applied to solve an important communications deficiency for another APL sponsor.

PROGRAM TERMINATION

Once the INF Treaty was ratified, the planning for the retrograde of PII and GLCM assets from Europe began. POTU was assigned the additional task of assisting PPMO and U.S. Army, Europe, in planning the withdrawal or in-theater elimination of PII components as well as assisting in treaty-required site inspections. APL helped POTU plan the required INF Treaty implementation. Since the treaty prescribed a 3-year period to complete removal of the equipment from theater, the Pershing force retained its QRA responsibility during the drawdown interval. As the drawdown got under way in earnest in early 1990, emphasis was placed on identifying the older or problematic equipment for early removal, ensuring that the best equipment was retained for tactical use until the end of the program. The APL maintenance database aided this effort. In preparation for the end of the program in Europe, the Laboratory developed a plan for phasing out data collection contractor support, reflecting the combined needs of the Pershing alert units, the deactivation activity, and continuing OSAP testing with Lance. The last Lance survivability exercise was conducted in April 1990. EFO closed on 30 September 1990, culminating over 24 years of support to the military in Europe.

CONCLUSION

The APL land-mobile missile system test and evaluation effort addressed the performance and survivability of the theater nuclear missile systems deployed in Europe from 1965 until the end of the Cold War. The APL effort was built initially on the Pershing missile system OTP development and implementation and later expanded into survivability field testing. The performance and survivability evaluations were uniquely challenging tasks for APL because it was initially necessary to establish a presence in Europe to plan the OTP, collect the QRA data, and maintain liaison with the Pershing forces and their higher-level commands. It was this presence in theater that enabled APL to implement the survivability work, which emphasized evaluating defensive operations rather than offensive operations, the normal task of this department. APL was able to contribute effectively to the development and employment of the Pershing missile system and later the GLCM and Lance missile systems because of the "systems perspective" we took in establishing the initial OTP effort.

APL staff became intimately familiar with all aspects of the Pershing system, not just the technical features needed to develop the OTP evaluation methodology, but also the logistical support, training, command and control systems, targeting, and, as the survivability involvement developed, the threats, vulnerabilities, and war plans. In this way, we established a broad insight into the capabilities of the Pershing system, making it possible to respond to a broad spectrum of weapon system problems as they arose. Further, this expertise was transferred effectively to benefit the needs of the GLCM and Lance weapon systems. It should also be noted that it was the capabilities and dedication of the team of civilian data collectors that played a significant part in making it possible to implement the APL approach for conducting the survivability field exercises.

The contributions of the government, military, and contractor personnel to the development, operations, support, and evaluation communities were all important in maintaining the PII and GLCM systems as the credible deterrents that produced the INF Treaty and helped the United States and NATO end the Cold War. The treaty brought an end to the APL land-mobile missile systems work because the two QRA systems being evaluated, PII and GLCM, were destroyed in accordance with the treaty. The third missile system, Lance, never received a QRA tasking before it was retired. The significance of APL's contributions was recognized in a 13 July 1990 letter of appreciation from the then Deputy CINC, U.S. Army, Europe (later Chairman, JCS), LTG John M. Shalikashvili, which said, in part:

> [APL] has provided this headquarters with vital assistance in the areas of operational analysis, performance testing and system survivability as part of the Pershing Operational Test Program. . . .Your organization did much to make the Pershing missile system a viable part of NATO's nuclear deterrence. The success of the Pershing program in Europe is due in no small measure to the quality of analysis and testing performed by the EFO; this success was instrumental in bringing about the Intermediate-range Nuclear Forces Treaty. . . . Congratulations on a job well done.

REFERENCES

[1] Dewar, H., "NATO Commander Galvin Defends INF Treaty, Disputes Predecessor," *The Washington Post* (3 Feb 1988).

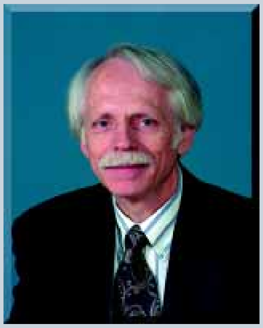
[2] Lennox, D., and Loasby, D. (eds.), *Jane's Strategic Weapon Systems*, Issue 24, Jane's Information Group Ltd., Surrey, UK (May 1997).

[3] Lennox, D., and Loasby, D. (eds.), *Jane's Strategic Weapon Systems*, Issue 26, Jane's Information Group Ltd., Surrey, UK (Jan 1998).

[4] Champion, J. R., "An Empirical Investigation of High-Frequency Ground Wave Propagation," *Johns Hopkins APL Tech. Dig.* **13**(4), 515–525 (1992).

ACKNOWLEDGMENTS: The author wishes to thank the many former members of the Pershing Program Office—including, Gary R. Bartnick, Judson C. Brown, David J. Carter, James R. Champion, John K. Hildabolt, John F. Lyons, Carlton L. Ragland, Charles C. Rodeffer, Edward J. Scheick, and John M. Watson—now scattered across APL, for their help in compiling the information included herein and reviewing the many drafts that led to this final version.

THE AUTHOR



WILLIAM R. MENTZER, JR., received B.S.M.E. and M.S.M.E. degrees from the University of Maryland in 1961 and 1966, respectively, and is a member of the APL Principal Professional Staff. He worked at NASA's Goddard Space Flight Center, Vitro, and Bowles Fluidics Corp. before coming to the Laboratory in 1970. Mr. Mentzer started with the Pershing Program Office and remained with it until it was disbanded. For the survivability effort, he was the lead analyst for human intelligence threat work and electronic warfare threat work. He served a tour as Supervisor of the European Field Office (1974–1977) and was the Assistant Pershing Program Manager (1988–1990). After the Pershing Program was disbanded, he served as the Tactical Systems Evaluation Program Manager for SSD (1990–1995). Presently, Mr. Mentzer is one of the APL residents at the POET facility in Crystal City, supporting the Ballistic Missile Defense Organization. His e-mail address is william.r.mentzer@jhuapl.edu.