HISTORY

of the U.S. Army Research Laboratory

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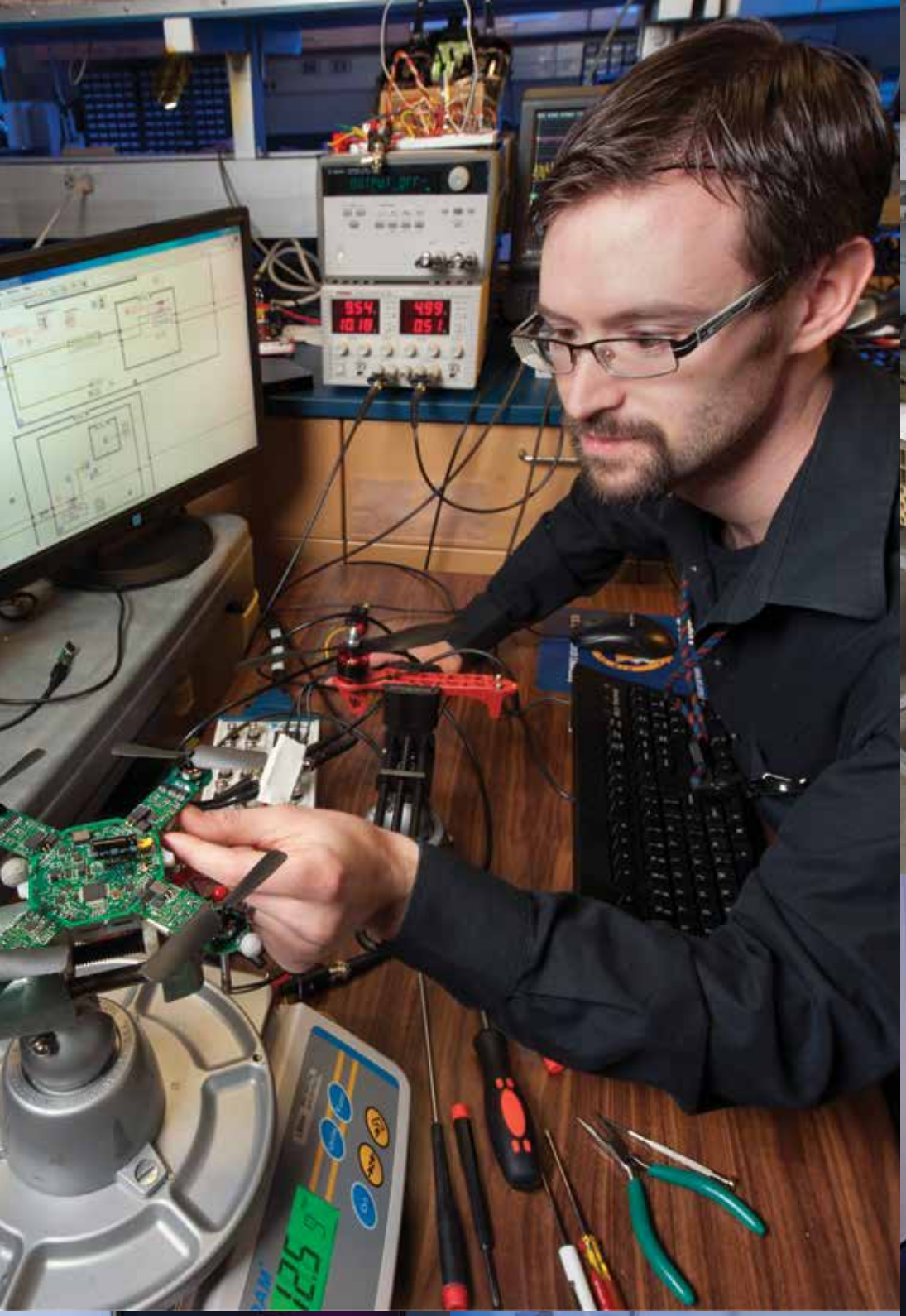

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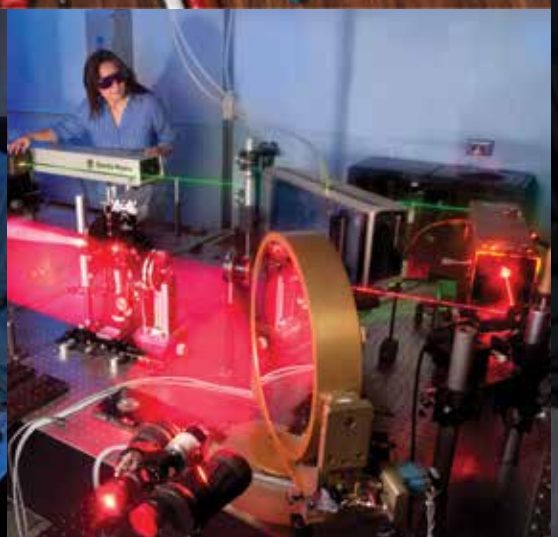

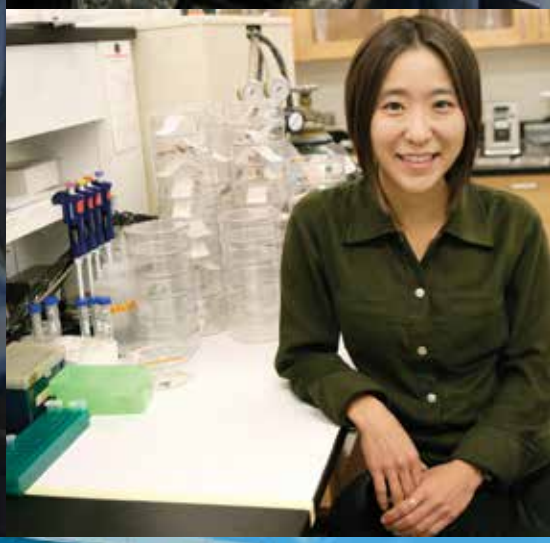

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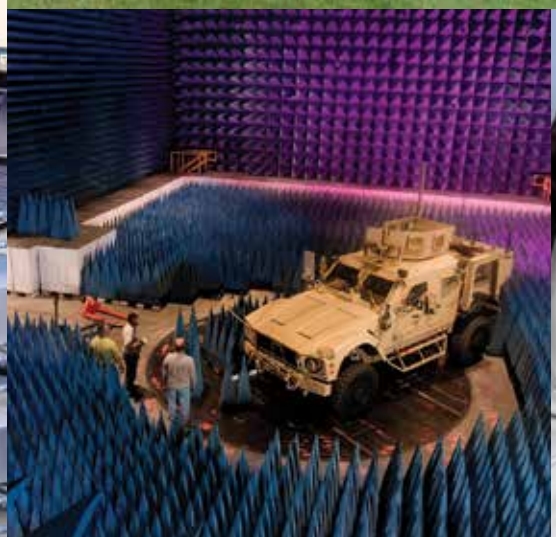

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Photograph of President Truman standing in front of the ENIAC.
—U.S. Army Photo from the archives of ARL/SLAD/BVLD,
preserved by Mike Danish and Beth Ward.

Message from the Director

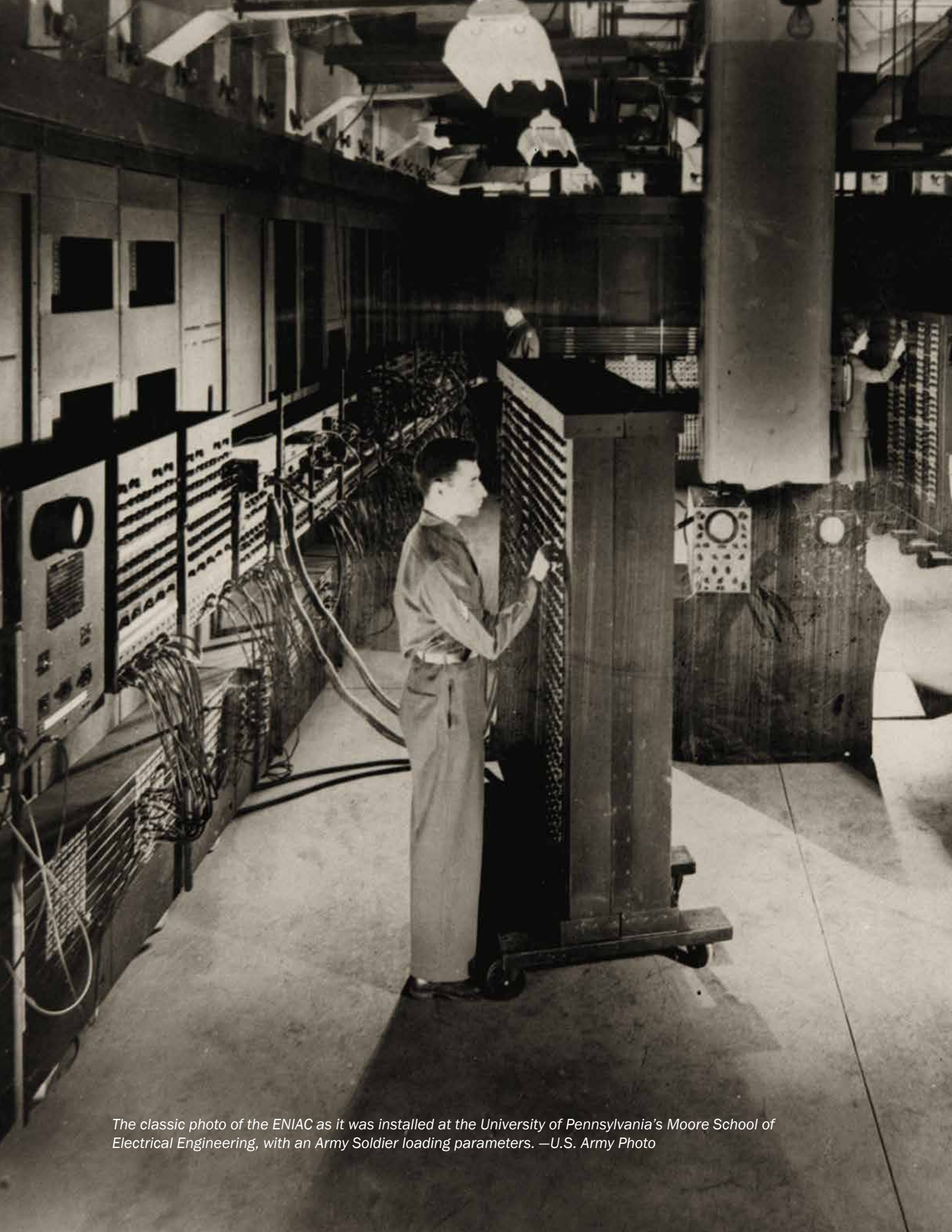
This history book produced by the U.S. Army Research Laboratory (ARL) is a celebration of 25 years of service to the Soldiers of the United States Army. It tells an amazing story of discovery and innovation that you, the reader, will soon experience for yourself. It is also a unique tribute to the thousands of scientists and engineers who have performed foundational research at ARL that has led to significantly better capabilities for the American Soldier since ARL's founding in October 1992.

Over the past 25 years, ARL has grown from eight separate laboratories into a single premier Department of Defense laboratory for ground forces with a mission to discover and innovate and then transition knowledge to our research partners in government, academia and industry to ensure continued land dominance in the decades to come. And although you will gain a wealth of knowledge on ARL's first 25 years, you will not gain an appreciation for the future direction the laboratory is taking including ARL's new business model called "Open Campus," our strategic approach to research supporting the Army of 2050 and beyond or how we've grown as a laboratory providing new workforce flexibilities that will allow us to compete for the nation's best and brightest scientists and engineers.

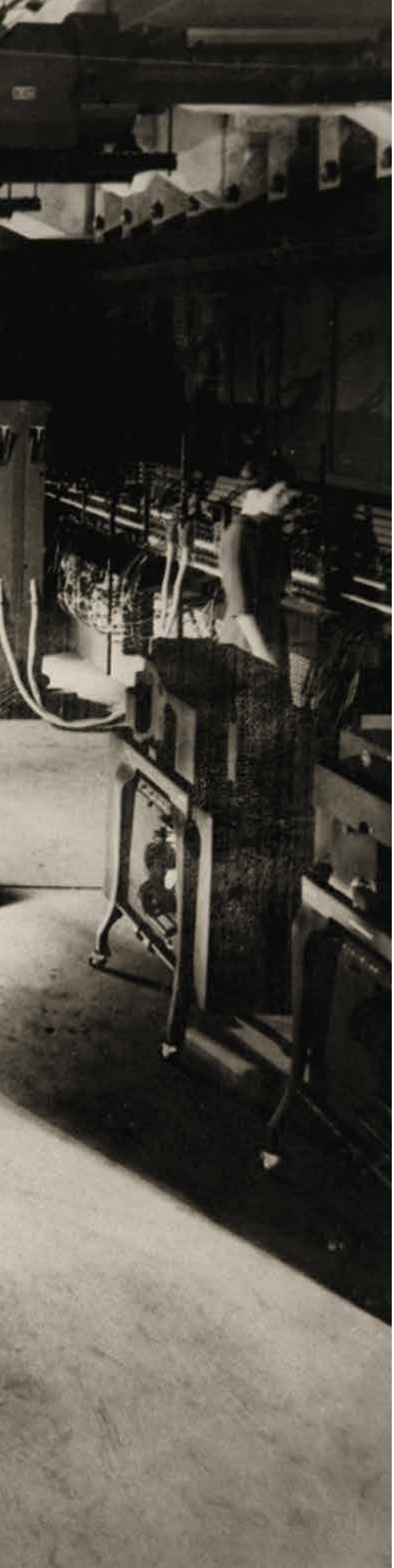
The work we do today is focused on a complex world where global competitiveness has encroached on our technological superiority. Rest assured that we are focusing on essential research areas that will provide new capabilities in order to maintain our technological overmatch. In the future, we will see novel tools and methods that enable Soldiers to learn in ways that maximize value of each individual's unique qualities and autonomous intelligent systems that understand the intent of Soldiers, learn and adapt as situation evolves, and act as members of a unified human-machine team in all domains—physical and cyber. Our future Army will have at its disposal materials for armor and projectiles that rapidly change their properties as needed to defeat the adversary action and enhanced capabilities to manufacture repair parts and munitions, and generate energy in tactical environments from a variety of local materials and sources.

At ARL, we believe that we can shape the future battlespace by exploring how science can bridge the gap between the known and unknown. Throughout the lab, we are living tomorrow's history today!

Philip Perconti
Director
U.S. Army Research Laboratory



The classic photo of the ENIAC as it was installed at the University of Pennsylvania's Moore School of Electrical Engineering, with an Army Soldier loading parameters. —U.S. Army Photo



Prelude:

Before ARL

Today's U.S. military laboratory system has deep roots, going back to the early years of the 19th century when America first found its footing on the international stage. Military research began in the United States with ordnance supply and Army medical research.

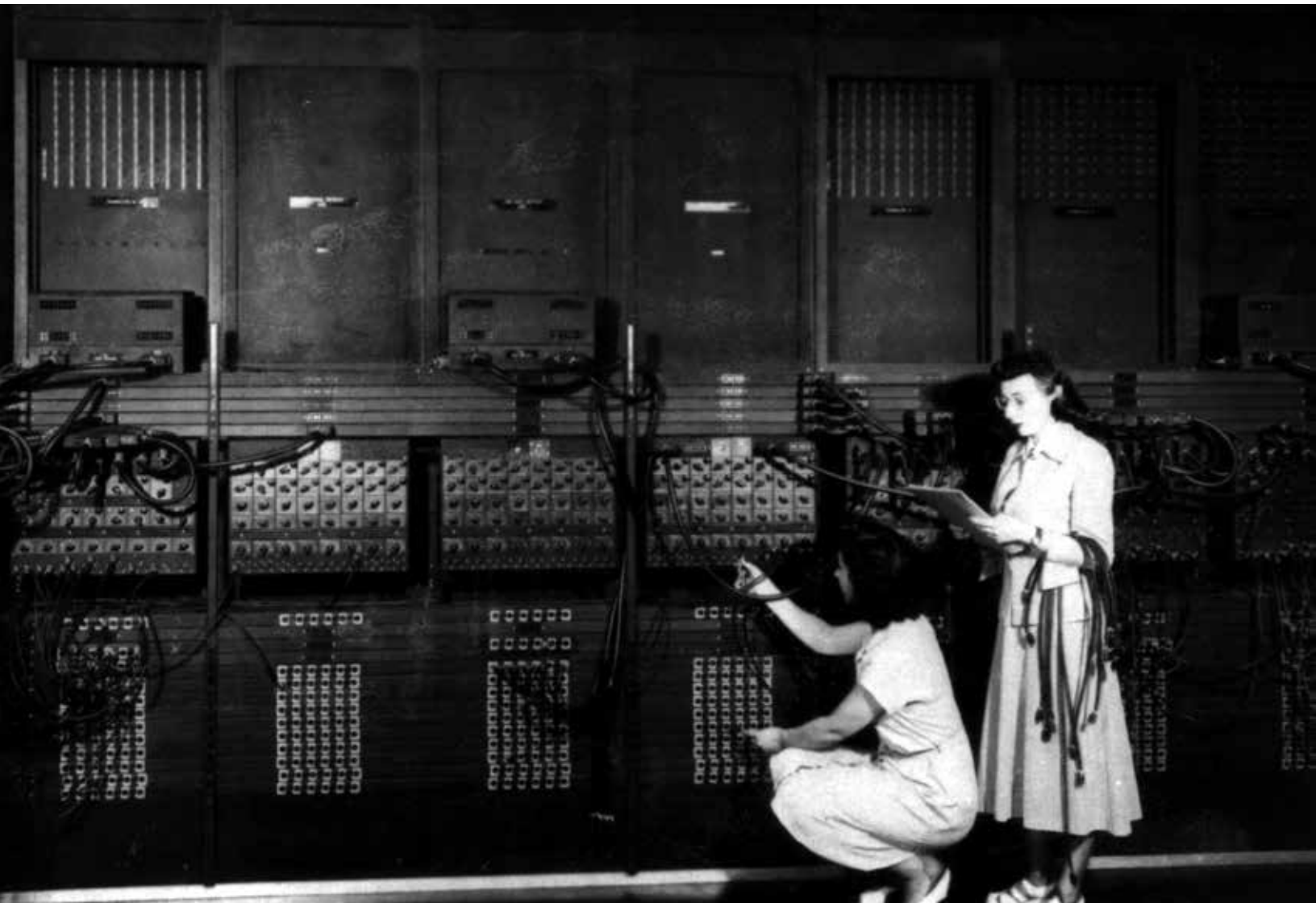
More than 100 years later, in 1945, the Army published its first official policy on research and development (R&D), formally recognizing the need for civilian scientific assistance in military planning and weapons production. The Research and Development Division of the War Department General Staff was established on June 11, 1946, marking the first time R&D was recognized as a separate military effort. The initiative, however, didn't last.

In 1947, the R&D Division was abolished as a separate unit and designated a group in the Service, Supply and Procurement Division of the General Staff. Civilian scientists, though, campaigned for recognition. Opposition to establishment of a separate R&D command or element came from Army staff and technical-service chiefs who opposed dismantling the traditional technical-service structure.

The scientists eventually got their wish. The Office of the Chief of Research and Development emerged as an independent General Staff agency in 1955. At about the same time, the civilian position of director of R&D was established at the Army assistant-secretary level. This action reflected the influence of the Army Scientific Advisory Panel, a group of civilian scientists and industrialists.

General reorganization of the Army in 1962 heavily impacted R&D alignment, and the Army Materiel Command (AMC) inherited the procurement and development functions for weapons and munitions. From the beginning, AMC encountered problems in balancing its two basic missions: systems acquisition and readiness. In 1966, AMC's commanding general appointed a Deputy for Research and Laboratories to exercise direct line authority over the nine AMC central laboratories and over the technical quality of research conducted in the laboratories of AMC's major subordinate commands (MSCs). In 1969, AMC established two deputy commanding generals: one for materiel acquisition and one for logistics support.

Two women wiring the right side of the ENIAC with a new program, in the "pre-von Neumann" days. Standing: Marlyn Wescoff—Crouching: Ruth Lichterman —U.S. Army Photo from the archives of the ARL Technical Library.



Mr. W.J. McMahon using counting equipment in Isotope Lab at Watertown Arsenal Laboratory, May 1953.

AMARC (1973) to ERADCOM (1978–1985)

In 1973 the Secretary of the Army established the Army Materiel Acquisition Review Committee (AMARC), an ad hoc group consisting primarily of civilians from outside the government with a charter to analyze the entire materiel-acquisition process and to recommend improvements. The committee noted the progress achieved over the previous ten years but found a number of weaknesses in the scientific development and technology areas.

To address some of these deficiencies, AMARC proposed separating the management of new weapons systems and major product improvements

Materials Technology Laboratory

The Materials Technology Laboratory (MTL) traces its roots back to 1800 with the establishment of an arsenal at Charlestown, Mass., on Boston harbor. Following the War of 1812, the Ordnance Department purchased land at Watertown, Mass., constructed buildings and transferred activities to Watertown from Charlestown.

At its peak, the Watertown Arsenal encompassed an area of approximately 130 acres and employed 10,000 people. Originally established as a depot for the storage, cleaning, repair, and issue of small arms and ordnance supplies, its activities were expanded to include the manufacture of field, siege, and coastal guns and carriages. In 1881, it assumed functions as a test and experiment unit.

Following extensive activity during World War I, the Arsenal made several important technical contributions, including developments in radiography, qualitative spectrum analysis, and molybdenum high-speed tool steel. The Arsenal won five Army–Navy "E" awards for excellence in equipment production during World War II. During the 1950s, the arsenal developed the 75-mm "Skysweeper" anti-aircraft gun, as well as the first 280-mm atomic cannon. In 1960, it dedicated the Army's first research nuclear reactor.

Until the Army reorganization of 1962, Watertown was part of the Ordnance Department. Then, the Army assigned responsibility for conventional weapons work to the Rock Island Arsenal, and Watertown took a supporting role in the Missile Command. At the same time, combining the Ordnance Materials Research Office and the Watertown Arsenal Laboratory created the Army Materials Research Agency (AMRA).

In 1964, the Secretary of Defense announced that Watertown Arsenal would be declared excess and phased out, while AMRA would continue in place. Following considerable public discussion, the Arsenal was closed in 1967. AMC consolidated structural materials R&D at AMRA and renamed it the Army Materials and Mechanics Research Center (AMMRC). In transition to the U.S. Army Laboratory Command (LABCOM) in 1985, AMMRC was renamed the Materials Technology Laboratory to highlight its intensified focus on the development of new materials.

As a result of the Base Realignment and Closure of 1991, most of MTL moved to Aberdeen Proving Ground, Md. as part of today's Weapons and Materials Research Directorate (WMRD). The structures element transferred to NASA–Langley as part of the Vehicle Technology Directorate (VTD).

Console of BRLESC-I computer, front view. —U.S. Army Photo from K. Kempf's historical monograph "Electronic Computers Within the Ordnance Corps."

The Ballistic Research Laboratory (BRL) began during World War I to meet increased demands for firing tables and other ballistic data. By that time, practically all of the test and experimental work was conducted at Aberdeen Proving Ground, Md., which had been established in 1917 to replace inadequate facilities and space at the Sandy Hook Proving Ground, N.J. Thanks to careful planning, BRL expanded in a rapid but orderly manner to meet wartime demands. In 1943, the Ordnance Department designated BRL its principal research organization.

In the postwar period, BRL pioneered development of high-speed computers and electronic devices, which greatly enhanced its ability to analyze weapons systems. This expanded scope was reflected in new construction, such as the wing that housed ENIAC (Electronic Numerical Integrator and Computer)—the Army's first computer. BRL served as home to the Army's first two supercomputers.

Significantly, appropriations after World War II continued at levels even higher than those reached in wartime budgets. During the Army reorganization in 1962, BRL was transferred into AMC and reported directly to Headquarters as a corporate laboratory. Over the next 20 years, BRL was attached to the Aberdeen Research and Development Center, and then later to the Armaments R&D Center. But in 1984, BRL was reassigned directly to AMC headquarters, again as a corporate laboratory. One year later it became part of LABCOM.

BRL formed the core of ARL's Weapons and Materials Research Directorate, with computer technology elements migrating to the Computational and Information Sciences Directorate and vulnerability analysis efforts moving into the Survivability/Lethality Analysis Directorate.

Console of BRLESC-I computer, rear view (during the recording of a television program for OGMS-TV). —U.S. Army Photo from the archives of the ARL Technical Library.

from logistics management. In implementing this organizational concept, AMC discontinued its commodity commands and established parallel R&D and readiness commands. AMC decided against establishing a Combat Support Center, moving instead to study the formation of a Harry Diamond Development Center (HDDC)—named for the pioneering electronics engineer who helped develop the proximity fuze in WWII. It would be based on an enhanced Harry Diamond Laboratories (HDL). The Department of the Army (DA) evaluation favored establishing HDDC under AMC.

In 1977, the Deputy Secretary of Defense and the Secretary of the Army announced a modified plan for the organization of the Electronics Research and Development Command (ERADCOM) with headquarters to be collocated with HDL at Adelphi, Md. On Jan. 3, 1978, ERADCOM was formally activated. Thus, for the first time, the Army had a single command responsible for its combat electronics materiel.

ERADCOM to LABCOM

The incorporation of ERADCOM into the U.S. Army Laboratory Command (LABCOM) represented the Army's recognition of the importance of R&D and its continual attempt to properly balance materiel development with logistics. LABCOM was also the final realignment to result from reconsideration of AMARC recommendations.

The following were incorporated into LABCOM: Ballistic Research Laboratory (BRL) and Human Engineering Laboratory (HEL), Aberdeen Proving Ground (APG), Md.; Harry Diamond Laboratories (HDL), Adelphi, Md.; Materials Technology Laboratory (MTL), Watertown, Mass.; Electronics Technology and Devices Laboratory (ETDL), Fort Monmouth, N.J.; Vulnerability Assessment Laboratory (VAL) and Atmospheric Sciences Laboratory (ASL), both at White Sands Missile Range (WSMR), N.M.; and Army Research Office (ARO), Research Triangle Park, N.C.

LABCOM was activated in 1985 as AMC's newest MSC; its business was research with a mission to put scientific findings to maximum use on the battlefield. While threat capabilities were constantly changing and increasing, and revolutionary scientific discoveries promised exciting new capabilities, these circumstances also meant that even the most advanced equipment might be obsolete as soon as it was fielded. The key was to harness advanced technology to the Army's advantage. However, translating the foundational discoveries of the laboratory to the real world of weapons and equipment was a critical challenge. It required increasing the impact of the Army's scientific research by accelerating the implementation of the technological breakthroughs.

LABCOM managed the AMC corporate laboratories as

Electronics Technology and Devices Laboratory

The Electronics Technology and Devices Laboratory (ETDL) traced its origins to the Signal Corps Laboratories at Fort Monmouth, N.J. During the 1920s, Fort Monmouth emerged as the Army's center for communications training and research. In the 1950s, the Electronics Components Research Laboratory, as ETDL was then known, moved into expanded facilities at the new Hexagon Building in the Camp Wood Area, Monmouth County, N.J. With emergence of the semiconductor industry setting the stage for major displacement of conventional tubes and electronic devices by transistors and miniature parts, the laboratory established a new Solid State Division to support the solid circuit or integrated circuit concepts.

With the Army reorganization of 1962, the renamed U.S. Army Electronics Research and Development Laboratory joined AMC as an element of Electronics Command (ECOM). In a 1965 restructuring, ECOM organized seven separate R&D activities along functional lines, among them the Electronic Components Laboratory and the Institute for Exploratory Research. In 1971, these two activities were consolidated to form ETDL. In 1978, ETDL was placed in ERADCOM, subsequently becoming part of LABCOM in 1985.

For LABCOM, ETDL advanced the technology base in electronic devices and materials. It managed the Army program in very high-speed integrated circuits (VHSIC), with the primary objective of accelerating the introduction of advanced integrated circuit technology into weapons systems. ETDL also operated and managed the Army's new Pulse Power Center at Fort Monmouth that provided the defense establishment with expanded capability for development, test, and evaluation of high-energy/high-power components, which were important elements in the Strategic Defense Initiative.

With the realignment into ARL, ETDL provided most of the Electronics and Power Sources Directorate. In 1995, the major portion became the Physical Sciences Directorate (PSD); most of PSD later migrated into the Sensors and Electron Devices Directorate.

The history of the Harry Diamond Laboratories (HDL) dates back to 1940. Prompted by increasing warfare abroad, the National Defense Research Committee organized a group of scientists and engineers into the Ordnance Development Division of the National Bureau of Standards (NBS) to develop fuzes for nonrotating (e.g., fin-stabilized) munitions such as bombs, rockets, and mortar shells. Harry Diamond, a pioneer radio engineer, was given technical direction of the program, a position he held until his death in 1948. Proximity fuzes were first used in combat in January 1943, and the War Department later described the proximity fuze as "one of the outstanding scientific developments of World War II ... second only to the atomic bomb" in military importance.

In 1953, the Ordnance Development Division was transferred to the Army as an R&D installation and named the Diamond Ordnance Fuze Laboratories (DOFL) in honor of the early leader. DOFL made significant contributions to fuze technology in areas such as printed circuits, casting resins, flow and temperature measurement, reserve power supplies, high-resolution radar, air navigation systems, and nuclear-effects studies.

During the 1962 Army reorganization, DOFL was assigned directly to AMC as a corporate laboratory, and the next year its name was officially changed to Harry Diamond Laboratories to reflect broadened, Army-wide missions. AMC later studied the possibility of establishing a Harry Diamond Development Center that would consolidate and integrate work in radar, lasers, electro-optics, signal intelligence, and electronic warfare. Instead, AMC established ERADCOM as the overall command with HDL as a major element. HDL later became a critical component of LABCOM. At the time, HDL occupied a modern research facility located on 137 acres in Adelphi, Md. It also controlled two other sites: a test range at Blossom Point, Md., and research facilities at Woodbridge, Va.

As the Army's lead laboratory in nuclear survivability studies and under sponsorship of the Defense Nuclear Agency, HDL operated Aurora, the world's largest full-threat gamma radiation simulator. HDL was also responsible for the technology base in battlefield surveillance radars and antiradiation missile countermeasures. During the ARL organization, most of HDL transitioned into the Signatures, Sensors, Signal and Information Processing (S3I) Directorate. The nuclear-weapons-effects activities were separated, with the technology base research functions migrating to the Weapons and Materials Technology Directorate and the analytical functions moving to the Survivability/Lethality Analysis Directorate. In 1996, the S3I Directorate was split, with various parts going into the Computational and Information Sciences Directorate and Sensors and Electron Devices Directorate.

well as specific technology-related programs that cut across the MSCs and mission-area lines. In addition, the corporate laboratories provided independent technical advice and R&D assessments to the Army.

Managing AMC's Technology Base

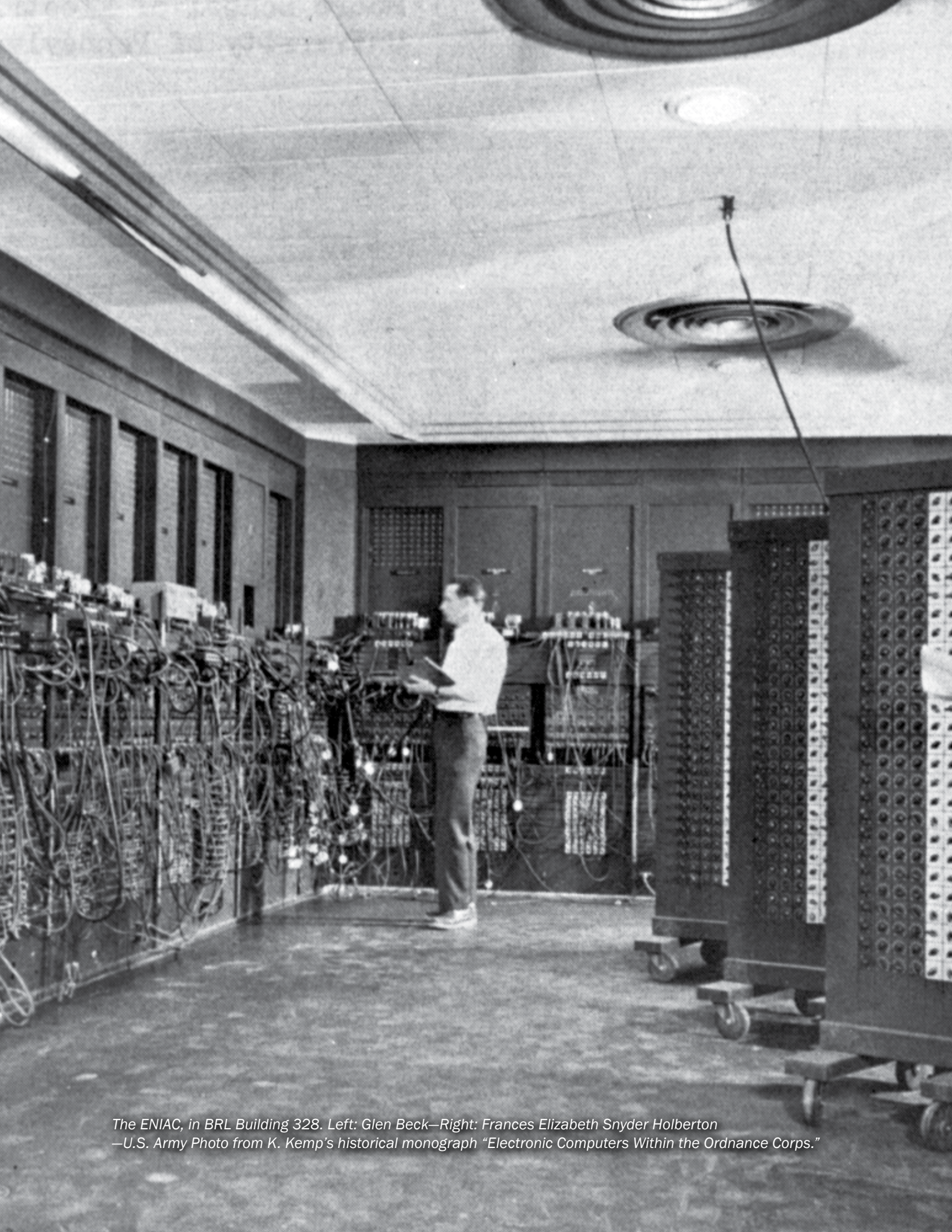
Establishing LABCOM brought together under one MSC the AMC research laboratories that generated technologies and advanced concepts to carry the Army into the future. The corporate laboratories' programs were reoriented to concentrate on critical technology barriers related to the development and production of new Army systems, especially high-risk–high-payoff concepts that could significantly increase battlefield effectiveness. The strategic long-range plan called for identifying areas of common interest and focusing efforts on multi-laboratory, cooperative ventures. Four specific initiatives were in smart weapons, enhancements to autonomous machines, active protection, and vulnerability expert systems.

The technology-integration effort, designed to exploit the work being done by others, allowed the Army to capitalize on advances made by other research communities and, perhaps more importantly, to focus its resources on Army-critical issues while satisfying many of its needs from more generic R&D conducted in other sectors. Through the integration

efforts, LABCOM forged close ties with private industry, other government agencies, academia, and technology programs of foreign allies.

Technology developed by LABCOM's laboratories soon paid off in battle. In 1990, America went to war against Iraq, marking the Nation's first major combat involvement since the end of the Vietnam War. American ground forces deployed to Saudi Arabia were equipped with systems that the AMC's R&D activities had developed. For the first time in modern warfare, advanced technological battlefield capabilities took center stage, greatly assisting American Soldiers in battle and paving the way to a sweeping victory in the deserts of the Middle East.

U.S. Army Spc. Eric Leon stands security watch with an M240B machine gun during a cordon-and-search operation with Iraqi army soldiers in Diwaniyah, Iraq, Sept. 16, 2006. DoD photo by Tech. Sgt. Dawn M. Price, U.S. Air Force. (Released)



The ENIAC, in BRL Building 328. Left: Glen Beck—Right: Frances Elizabeth Snyder Holberton —U.S. Army Photo from K. Kemp's historical monograph "Electronic Computers Within the Ordnance Corps."

History in the Making:

Founding of ARL

At approximately 4 p.m., on Feb. 26, 1991, at the navigational line referred to as "73 Easting" by the U.S. military, a group of coalition tanks advanced on well-fortified Iraqi Republican Guard positions in southeastern Iraq. The Desert Storm ground war had begun only two days earlier, on Feb. 24, and coalition forces were hoping to push the Iraqis back and retake northern Kuwait. While resistance to the first 48 hours of U.S. ground attacks had been light, the looming battle at 73 Easting promised to be much different. Iraqi forces were attempting to stop an advance on Basrah, a port city just north of Kuwait and 50 miles inland from the Persian Gulf. Capturing the city would have effectively cut off most of the Iraqi forces from Kuwait. The Iraqis knew this and defended heavily all routes to the port, utilizing a large force of tanks, armored personnel carriers, and trucks. In addition to superior numbers, the Iraqi forces had other factors on their side: They were defending familiar territory; their positions were well-entrenched and in some cases well-hidden by a sandstorm; and they were fighting coalition forces with little combat experience. In contrast, many of the Iraqi commanders had been battle hardened by the recently concluded Iran–Iraq War. Essentially, the Iraqi forces had significant advantages in numbers, experience, and terrain.

Yet only 23 minutes into the battle, the Iraqi mechanized force had been utterly destroyed. A total of 28 Iraqi tanks, 16 personnel carriers, and 39 trucks were either destroyed or immobilized. As the once-proud Iraqi Republican Guard forces lay in smoking ruins on the windswept desert plain, coalition forces rounded up more than 1,300 prisoners. Even more surprising, not a single U.S. serviceman was killed in the battle. The lopsided victory was best described by an Iraqi commander, who noted that "On January 17, I started with 39 tanks. After 38 days of aerial attacks, I had 32, but in less than 20 minutes with the M1A1 (U.S. tank), I had zero." (Reported by Col. Don Holder, Commander, 2nd Armored Cavalry Regiment.)

How had the coalition forces overcome numerous disadvantages to turn the battle of 73 Easting into a complete rout? Certainly, the command decisions of Army leadership, along with the training and courage of American troops, were significant factors in the battle. But just as important was the technological superiority of the M1A1 Abrams tanks American Soldiers brought into battle with them. LABCOM had been significantly involved in fitting the tank, which featured M1A1 armor resistant to some Iraqi shells, the M829A2 armor-penetrating round, and significantly better weapons range. Quite simply, the U.S.

tanks could see their enemy better, fire first in virtually every engagement, reload before many of the Iraqi gunners could get them in range, and withstand enemy fire at an unusual level. The U.S. tanks could overwhelmingly outrun them and outgun them.

Without a doubt the United States' technological superiority had contributed significantly to overcoming the disadvantageous factors in the battle. While it was certainly not the first time in modern warfare that the more technologically advanced force defeated its opponent, it was significant given the strength of both the Iraqi position and numbers. Throughout history, advances in technology had supported U.S. Soldiers in battle. Now, it could be argued that technology had vaulted itself onto center stage. With the Cold War at an end, the United States proved in the Persian Gulf War that it was significantly more advanced than the rest of the world in development and deployment of military technology. The destruction of the Iraqi tank forces at 73 Easting had decisively demonstrated that. During the Gulf War the technological superiority of the U.S. military was shown on TV screens around the world. Steps had already been taken to ensure future research efforts would preserve the U.S. military's position at the forefront of technological development. The swift defeat of Saddam Hussein's forces and restoration

Atmospheric Sciences Laboratory

Located in the historic Tularosa Basin at White Sands Missile Range (WSMR), N.M., the Atmospheric Sciences Laboratory (ASL) was founded shortly before World War II. Meteorological research for the Army began in the 1920s when scientists began evaluating meteorological phenomena related to artillery. By 1956, there were 15 meteorological support teams located at test facilities throughout the United States. Headquarters were located at Fort Huachuca, Ariz., under the direction of the Signal Corps at Fort Monmouth, N.J.

During the 1962 Army reorganization, responsibility for meteorological R&D was assigned to the U.S. Army Electronics Command (ECOM), which later established ASL at Fort Monmouth. In June 1969, as a step to correct some of the geographical and organizational fragmentation, ECOM consolidated meteorological efforts by transferring the headquarters of ASL from Fort Monmouth to WSMR. Shortly thereafter, the meteorological activities at Fort Huachuca were also moved to WSMR.

With the establishment of LABCOM in 1985, ASL became part of the new command, but only after some discussion. AMC considered abolishing ASL but concluded that ASL's work was valuable to the Army. ASL gave the Army expertise in the atmospheric sciences, providing developers with assessments of atmospheric effects on proposed weapons and concepts. ASL also provided atmospheric and meteorological technology, sensors, and systems to support artillery, chemical, aviation, armor, and intelligence activities. Linking these sensors and systems provided weather intelligence for combat operations.

When ARL was established in 1992, ASL transitioned into the Battlefield Environment Directorate (BED). In 1995, the BED Atmospheric Analysis and Assessment team moved to the Survivability/ Lethality Analysis Directorate (SLAD), expanding SLAD's threat-effects analysis mission. In 1996, the remaining bulk of BED was folded into the Computational and Information Sciences Directorate.

of peace to Kuwait with minimal U.S. casualties—not one M1 Abrams hull was penetrated by enemy fire, for example—would not have been possible without the significant efforts of Army scientists and engineers over the previous decade.

It was in this atmosphere, in which the importance of technology was growing almost daily, that the U.S. Army Research Laboratory (ARL) was formed. Its mission was to conduct basic and applied research and analysis to ensure supremacy in future land warfare, in turn protecting both America and its Soldiers.

ARL's Formation

The impetus for ARL grew out of efforts to realign the Army's technology base following the collapse of communism in Eastern Europe and the end of the Cold War. In December 1988, the Defense Secretary's Commission on Base Realignment and Closure (BRAC) identified the MTL at Watertown for closure primarily because the MTL facilities needed major renovation or replacement. Missions and functions would be dispersed and the property sold, with transfers of functions scheduled for 1994 and all realignments completed by Sept. 30, 1995. However, there were still questions as to where LABCOM fit into these realignment efforts.

LABCOM had been established as AMC's MSC, responsible for research laboratories that produced generic technologies and advanced concepts to carry the Army into the future. It was also recognized as the Corporate Technology Center that provided technical support and services to other MSCs and program executive officers. The LABCOM commander served as AMC's deputy chief of staff for technology planning and management (DCSTPM), coordinating approximately 75 percent of the Army's technology base effort. Combat systems supported by LABCOM included the Abrams (M1A1) main battle tank, the Bradley fighting vehicle, the Patriot point-defense antimissile system, the Multiple Launch Rocket System (MLRS), the High Mobility, Multipurpose Wheeled Vehicle (HMMWV)—which already had been deployed in Panama—and the Army Tactical Missile System (ATACMS).

On Jan. 6, 1989, the LABCOM Commander signed a memorandum stating the command's dedication to "accomplish the Army's materials research, development, and consultation requirements." In the ensuing months, LABCOM

ARL researchers explain a hardware design issue to a service member. This collaboration brings the radio's system designers and developers to the customer—the Warfighter.

developed a proposal to move the core of materials research to one location as part of a concept for integrating the corporate laboratories into a single physical entity, which would eventually become ARL.

In the same month President George H.W. Bush was inaugurated, the Defense Management Review (DMR) was launched, resulting in formation of the Army Management Review Task Force as a component of the DMR. The initial concept of a centralized Army "corporate" laboratory arose from this task force, and in the fall of 1989 the "LAB 21" study was chartered to develop this idea. The ARL or Combat Materiel Research Laboratory (CMRL) construction continued to evolve during fiscal year (FY) '90, emerging as the centerpiece of the Army's LAB 21 effort. Implementation of the LAB 21 scheme was delayed, however, while another laboratory-consolidation study was performed. Congress initiated another round of base closure and realignment activity, passing legislation (Public Law 101-510) establishing BRAC 91, with members nominated in January 1991. Then, in April 1991, the Department of Defense (DoD) published its recommendations to BRAC 91, adopting the consolidation proposal to realign Army laboratories and create ARL. Under the scheme, the labs would be consolidated primarily at Adelphi and APG, and the BRAC 88 mandate would be revised, with most of MTL relocated to APG.

In its report to the President, released in July 1991, BRAC 91 endorsed the LAB 21 plan for laboratory restructuring but directed DoD to delay implementation until January 1992 to consider guidance from the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories. Also established under Public Law 101-510, the Federal Advisory Commission was charged with recommending various means to improve the operation of the laboratories, including 1) conversion of some or all to government-owned, contractor-operated (GOCO) labs, 2) mission and/or function modification at some or all, and 3) consolidation or closure of some or all. The advisory commission's September 1991 report stated that "fixing the problem organically is preferable" to converting to GOCO organizations and suggested a number of steps to improve the effectiveness of the labs as "dedicated organizations free from commercial pressure." In the main, the advisory commission also accepted the creation of ARL, stating that proposed consolidations and realignments should begin in January 1992.

The leadership of the early organization was also in a transitional phase at this time. Maj. Gen. Jerry C. Harrison, the commander of Laboratory Command, had coordinated with AMC Headquarters and the Corps of Engineers to initiate

Mr. Richard Vitali

construction projects to meet the requirements established by BRAC 91. After his transfer to serve as Army's chief of legislative liaison, Harrison was succeeded in January 1992 by Maj. Gen. Patrick J. Kelly, who facilitated coordination of Harrison's plans. However, Kelly retired later that year; on Oct. 1, 1992, Mr. Richard Vitali, the former LABCOM director of corporate laboratories (DCL), became the acting director of ARL.

The change of leadership was significant because it represented an exception to the implementation plan submitted to the Assistant Secretary of the Army for Research, Development and Acquisition (ASA [RDA]) in a March 13, 1992, memorandum and approved in the December

1992 implementation plan. The plan authorized a major general as commander, along with a civilian technical director, with the commander reporting directly to the AMC Commanding General. However, the Assistant Secretary stipulated that the new organization would have a civilian director as its chief executive and a general officer as deputy. The revised implementation plan of July 1992 provided the impetus for the selection of a chief executive no later than Oct. 1, 1992. Therefore, ARL was activated with a civilian acting director and a colonel as deputy. Orders provisionally establishing ARL, dated July 23, 1992, provided operational control of LABCOM, the seven corporate laboratories, the LABCOM Installation Support Activity, and the Special Technology Offices, as well as those elements transferring into the new laboratory. The activation ceremony was held at Adelphi on Oct. 2, 1992, and permanent orders organizing ARL were published on Nov. 2, 1992.

With activation in October 1992, Mr. Richard Vitali officially became the acting director of ARL, a position he held for almost one year. His mission was twofold: facilitate the organizational transition from LABCOM into ARL, and provide an atmosphere where scientists could continue their research efforts initiated at LABCOM. Vitali had a wealth of experience in LABCOM's predecessor organization, having served as its technical director and eventually having been named its director of corporate laboratories in 1988. He had also been instrumental in forming LABCOM's organizational structure, and came to ARL with the reputation of being able to nurture his subordinates by preparing them gradually for their eventual levels of responsibility. Essentially, Vitali's strength was his reputation as a mentor who could provide the organization and guidance to current and potential employees being groomed for future leadership positions. These skills served Vitali and ARL well, as his tenure was a success in several areas.

Creation of the ARL Fellows

In fact it was Vitali who years earlier, along with the LABCOM Commander Brigadier General Malcolm R. O'Neill, helped conceive the idea of an advisory body of senior scientists and engineers, drawn from throughout the command. Both men saw the LABCOM fellowship as a semi-independent, peer-elected, self-perpetuating consultative asset to the Commander. The first LABCOM fellows, selected by Vitali and the Technical Directors, proved a success. The fellowship drafted its charter, which provided a mechanism for electing new members. When Vitali became acting ARL director he asked the LABCOM fellows to form the nucleus of an ARL fellowship. By institutionalizing the Fellows as a brain trust of individuals with world-class expertise in their fields, LABCOM, then ARL gained a valuable asset of senior advisors who at first acted as screening panels for technical competitions such as the Army Science Conference and the Army R&D Achievement Awards. Later, the Fellows' roles and numbers would expand.

Initially, Vitali saw his primary task as helping to facilitate an atmosphere where former LABCOM and other scientists could transition their work into ARL's new mission. The new organization encompassed research in a variety of fields, including information distribution and management technologies; human cognitive and sensory capabilities; simulation and virtual reality; nanotechnology; composites and ceramics; ultra wide-band radar; and lightweight, rechargeable power sources. The challenge was to continue these efforts while establishing ARL's structure and facilities. Among these was construction at Adelphi, which would accommodate personnel relocating from Fort Belvoir, Va., Fort Monmouth, and WSMR. In addition, new facilities at APG would house the Materials Directorate, moving from Watertown.

Vitali was also responsible for overseeing the formation of ARL's Board of Directors. The Board of Directors' mission was to enable contacts between ARL and Research, Development, and Engineering Centers (RDECs) and AMC command, to ensure that the laboratory was fulfilling the needs requested of it. After

its assembly, the board met twice in its first year to review the research and exploratory developmental programs in light of Army needs.

The Technical Advisory Board (TAB), consisting of research leaders primarily from the National Academies of Science and Engineering, also met for the first time in 1993 and began critical evaluations of research programs. The TAB provided a valuable service to ARL by giving expert, independent, and unbiased reviews of the quality of the ARL technical program—very difficult for a government laboratory to obtain but absolutely essential if it is to achieve world-class status. The TAB also suggested improvements in the operation of the lab, assisted in evolving long-term research goals, and monitored technological advances and how they impacted ARL research. Consolidating LABCOM and other organizations into ARL also required a restructuring of personnel. Total consolidation would save the DoD $55 million, commencing in 1993. It was recognized that recruitment and retention of personnel with necessary skills and knowledge was critical to maintaining ARL's viability. In conjunction with AMC and various state and local agencies, ARL initiated a number of actions intended to reduce the effects of these relocations. Consequently, the ARL Human Resource Management Division established Transition Assistance Offices that

ARL Fellows

The ARL Fellows represent the highest accomplishments in science, mathematics, engineering, and analysis. In 1989 Brigadier General Malcolm R. O'Neill, U.S. Army Laboratory Command (LABCOM) Commander, and Mr. Richard Vitali, Director of Corporate Laboratories, conceived the idea of an honorary advisory body of senior scientists and engineers, drawn from throughout the command. Patterned after similar organizations, the LABCOM Fellowship was to be a semi-independent, peer-elected, self-perpetuating consultative asset to the Commander. This group quickly proved its value, serving as LABCOM's screening panel for technical competitions such as the Army Science Conference and the R&D Achievement Awards. The organization also drafted and approved its charter, which codified the purposes of the organization and provided a mechanism for the election of new members.

With establishment of the Army Research Laboratory (ARL) in October 1992, Vitali became the Acting Director. Soon after, he requested that members of the LABCOM Fellows form the nucleus of an ARL fellowship. Accordingly, the charter of the LABCOM Fellows was adapted to the new organization. Soon after the appointment of John Lyons as ARL Director in 1993, the charter was accepted. Under Lyons' guidance and enthusiastic support, the ARL Fellowship charted an active course. In 1993 Dr. Lyons initiated the award of an annual stipend (originally in the amount of $25,000) which each Fellow could use to enhance his/her research capability, provide for literature, cover conference travel and fees, and so on.

The first group of nominees to be considered for election to the Fellows was solicited from the Directorate directors and elected to the Fellowship in 1993. In 1998, by amendment to its charter, and at the suggestion of Dr. Lyons, the Fellowship decided to automatically recognize ARL employees who have attained the "super grade" of Senior Research Scientist (ST) as members.

In subsequent years, the ARL Fellows performed a variety of services to ARL at the request of the Director, including evaluations of ARL technical awards, reviewing Director's Research Initiative proposals, organizing special symposia, and chairing directorate promotion panels. The Fellowship, whenever requested, will participate in reviews of the ARL Technical Program and will serve on ARL award or promotion panels.

The Vulnerability Assessment Laboratory (VAL) began in 1951 as Field Station 1 of the Signal Corps Engineering Laboratory. After several name changes, Field Station 1 eventually became the Signal Missile Support Agency (SMSA). SMSA was a component of the Electronics Research and Development Activity. In the 1962 Army reorganization, it became part of ECOM, conducting research in missile electronic warfare, missile vulnerability, missile surveillance, and environmental sciences. It also coordinated the missile electronic countermeasures effort of the Army.

In the mid-1960s, the element was renamed the Missile Electronic Warfare Division and assigned to the newly organized Electronic Warfare Laboratory (EWL). After another name change to the Missile Electronic Warfare Technical Area, it became the Office of Missile Electronic Warfare (OMEW). ERADCOM was then established, with EWL/OMEW as a major unit.

In 1985, the Commander of ERADCOM/LABCOM recommended including OMEW, which had been renamed the Vulnerability Assessment Laboratory (VAL), within the new command. VAL was tasked with providing independent assessments of the electronic warfare vulnerability of Army weapons and communications-electronics systems and recommending electronic countermeasures for reducing or eliminating those vulnerabilities. The VAL mission covered air defense, close combat and fire support, communications electronics, and advanced concepts. VAL was also charged with determining the vulnerability of threat missile systems. VAL transitioned into the Survivability/Lethality Analysis Directorate with the creation of ARL.

provided placement and referral opportunities for employees affected by transfer of function, downsizing, reduction in force, or similar action during the transition.

Even in the midst of all of these changes, ARL scientists and engineers performed research leading to the development of revolutionary technologies for which ARL is known today. Indeed, the many projects tackled by ARL in its first year was a succession of exciting opportunities. Among these was the Warrior's Edge program, which involved virtual-reality simulation to identify the technology needs of individual Soldiers. Another, "Owning the Weather," coordinated previously existing information systems to give friendly forces the ability to see, maneuver, fight, and win in all types of weather by providing commanders and staff with advance knowledge of battlefield environmental conditions and likely effects. This enabled selection of the best mix of sensors, weapons systems, and tactics.

However, the most significant of ARL's first-year projects was to upgrade the effectiveness of U.S. fighting forces. Because of friendly fire fatalities ("fratricide") in the recently concluded Persian Gulf War, the (then) Sensors, Signatures, Signal and Information Processing Directorate continued work on the Battlefield Combat Identification System, which would better identify both enemy targets and allies in

the field. Also, the need to detect targets employing camouflage, concealment, and other deceptive techniques spurred research in ultra-wide-band–foliage-penetrating synthetic-aperture radar. Battlefield information was also enhanced by the development of a prototype system, the Commander's Visualization Research Tool, which promised to give commanders real-time, formatted battle information. Finally, the lethality of U.S. armaments was advanced through development of the High-Capacity Artillery Projectile, representing a major milestone in substituting composites for steel in future shells, thus permitting the weight savings to be allocated to greater payload or longer range.

While developing technology was the most significant part of ARL's mandate, its first year also saw immediate returns on the organization's work. The Clinton administration had committed U.S. forces to peacekeeping and humanitarian operations throughout the world, and AMC staff was providing rapid technological support to U.S. troops in Southwest Asia, Somalia, and Macedonia. Among these technologies were infrared lights, thermal tape, and Kevlar blankets, all vital in fitting and protecting American Soldiers abroad.

But perhaps the most important of ARL's first-year initiatives was establishing cooperative programs with various academic, industrial, and international institutions, most of which still function today. ARL fostered relationships in academia, including those with the Massachusetts Institute of Technology (MIT), University of Delaware, University of Maryland, University of Massachusetts, New Mexico State University, University of Texas at El Paso, and the University of Arizona. Further, it expanded partnerships through the Small Business Innovative Research (SBIR) program and pursued stronger ties with historically black colleges and universities and minority institutions (HBCU/MIs) through educational partner agreements. In addition, in April 1993, ARL signed a memorandum of agreement with the U.S. Military Academy to establish an ARL-sponsored Mathematical Sciences Center of Excellence at the Academy.

Furthermore, the AMC tech-base community conducted an active program in pursuit of cooperative projects with several of America's foreign allies. Much of the international program was accomplished through working groups and reciprocal visits, in coordination with the AMC Office for International Cooperative Programs. ARL's bilateral program centered on three senior-level working groups in Israel, France, and Germany, with reciprocal meetings conducted with Japan and Korea. In late September and early October of 1992, AMC hosted the third visit of the Japanese Armament Study Team. In 1993, an international robotics investment strategy was coordinated, and a technology assessment of electric power sources began. An engineers and scientists exchange program was initiated, with seven ARL scientists spending 60 to 90 days in labs in France, Germany, or the United Kingdom. Under the Nunn Program, ARL proposed a project on lithium batteries with France and another on machine translation with Japan. The U.S.–Israeli Technology Working Group completed four technology assessments, in ballistics, human research, acoustics, and robotics.

ARL had accomplished much in its first year of operations. The foundation of what eventually became five directorates had been established; workers had moved into existing facilities and plans for future facilities were being implemented; research projects from LABCOM had been integrated into the organization; and partnerships with external entities in industry and academia were formed. However, much had to be done that could not be accomplished in the span of one year. Now that the various pieces were in place, the need to coordinate more effectively among them remained. And while technology continued to be developed by the new organization, long-range plans for basic research had to be formulated. Finally, ARL had to adjust to the ever-changing demands of the modern battlefield. All of these goals and more would be addressed by ARL's first director, John Lyons.

Building ARL,

1992–1998

As the presidential election of 1992 approached, it was clear the world had changed. The Cold War was over. America redirected from its arms race with the Soviet Union and began addressing problems at home. Realization set in that a federal government that had grown in every administration since President Kennedy's had not completely addressed the needs of American citizens. Suddenly, Americans wanted not more government, but less; more efficient agencies, not more bureaucracy. While politicians from both parties expressed these sentiments for several years, the issue became one of the most central themes of Bill Clinton's presidential campaign in 1992.

"Reinventing government," the Clinton administration's plan to consolidate the federal workplace and make it more efficient, would affect the entire DoD. With the threat of the Soviet Union gone, and the United States standing as the lone superpower after the Persian Gulf War, the military budget became one of the first items discussed under plans to reshape the federal government.

As these directives were being implemented, Dr. John Lyons assumed the helm as ARL director. His tenure would involve accommodating the consolidation initiatives while continuing to build ARL's organizational structure and heightening its reputation. It was at times a delicate balance to maintain.

Dr. John Lyons

Lyons, who had formerly served as director of the National Institute of Standards and Technology (NIST), became ARL director on September 14, 1993. A former chemist, Lyons had worked his way up in the National Bureau of Standards (NBS), serving as director of its National Engineering Laboratory for 13 years. After the NBS transitioned into the NIST, Lyons served as director of the entire organization. He was also well known as a scholar, having published four books and more than 60 papers. He had also been a member of the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, a group that established the initial parameters for creating ARL. Soon after his appointment, Lyons carried forward Vitali's ARL Fellows initiative and accepted the Fellows' charter. He proceeded to enthusiastically guide and support the group to become more active within ARL and expand its numbers and responsibilities.

Lyons quickly forged a reputation as a leader who wanted to understand how the various components of ARL worked. After reviewing some of the technology ARL and LABCOM had already produced (he even went so far as to drive an Abrams tank and test its cannon at the Aberdeen site), Lyons visited several of the directorates. He became convinced that the laboratories were confronted with several serious difficulties in their operating environments that threatened their ability to perform. Moving swiftly to adapt suggestions as well as opportunities provided by President Clinton's administrative campaign to "reinvent government," Lyons requested assistance from AMC in securing program reforms that included a modified and flexible personnel system, a consolidated funding authority, further emphasis on basic research (known as "6.1" research), and opening the laboratories to facilitate increased numbers of staff exchanges.

Among the management initiatives that Lyons undertook was to make ARL a National Reinvention Laboratory under the National Partnership for Reinventing Government. ARL won four Hammer Awards under this initiative. The Hammer Award was created by Vice President Gore to recognize government efficiency as a part of the program. Made simply of a $6 hammer, a striped ribbon and an aluminum-framed note from Gore. The Hammer Award is presented to teams of federal employees who have made significant contributions in support of reinventing government principles. Lyons also volunteered ARL to be a pilot project under the Government Performance and Results Act of 1993 (GPRA), the only pilot of more than 80 across the government to represent the R&D sector. Under

this program, ARL developed new and innovative approaches to strategic planning and performance evaluation as applied to basic research.

Another study of DoD management provided the impetus to consider some radical new constructs. In December 1993, the Under Secretary of Defense chartered a task force on Defense Laboratory Management, chaired by retired Army Gen. Paul F. Gorman in the spring of 1994. A new proposal emerged that addressed digital-communication issues and put ARL construction programs back in motion. This significant shift in ARL's mission during Lyons' tenure resulted from both the drive to consolidate the federal government and the Army Chief of Staff's aim to "digitize the battlefield." As Army strategists and technologists approached the 21st century, they realized a revolution in warfare was coming. The late 20th century's explosion in the information sciences and the ever-increasing speed and ease with which information could be gathered and distributed positioned information technology to become a paramount tool on the future battlefield. Success therefore depended on the Army's ability to apply existing and emerging information technologies to provide commanders with complete, accurate, and detailed information about battlefield events as they happened. As Gen. Gordon Sullivan, the Army chief of staff from 1991 to 1995, remarked, "winning the information battle is the key to decisive victory."

Operation Just Cause, which deposed Panamanian dictator Manuel Noriega in 1989, and Operation Desert Storm had provided a glimpse of the future battlefield. America's military was able to successfully conduct swift, simultaneous, and synchronized attacks on numerous objectives at night using forces stationed in various locations. The application of modern technologies, organization, and doctrine achieved decisive results that would not have been possible

ARL Fellows—An Organization of World-Class Scientists

Brief Timeline

1992

In October 1992 ARL Acting Director Richard Vitali requests LABCOM fellows to form the nucleus of an ARL fellowship.

1993

In 1993 Dr. Lyons succeeds Vitali as ARL Director and accepts the charter of the ARL fellows.

In 1993 Dr. Lyons initiates award of an annual stipend (originally $25,000) presented to each Fellow to enhance his/her research capability, provide for literature, and cover conference travel and fees.

First group of nominees to be considered for Fellows election was solicited from Directors of directorates, then elected to Fellowship in 1993.

1998

In 1998 Fellows amend charter to automatically recognize ARL employees who have attained the "super grade" of ST as Fellows.

From 1998 onward the role of ARL Fellows grows and continues to the present with Fellows performing a variety of services to the ARL Director, including evaluations of ARL technical awards, reviewing Director's Research Initiative proposals, organizing special symposia, and chairing directorate promotion panels.

The Human Engineering Laboratory (HEL) was formed in 1952 to assist in the development of engineering designs. A 1953 Ordnance Corps bulletin set the path, emphasizing that Army equipment had to be designed so human operators could use it in the best possible way. Thus, the capabilities and limitations of humans had to be given thorough consideration in the development of new technologies. Early studies included observations of operations under arctic and desert conditions, a study of padding for protection in military vehicles, and comparisons of positions for driving tanks.

During the 1962 Army reorganization, HEL became a corporate laboratory within AMC, charged with coordinating all of the human-factors-engineering initiatives within the Army. In 1968, HEL, BRL, and other elements were combined into the Aberdeen Research and Development Center (provisional), officially established in 1969. In the new organization, each laboratory retained its own civilian technical director but shared a common commanding officer. The Center was short-lived, lasting only until 1972, when HEL again became a corporate laboratory reporting to AMC Headquarters.

In 1975, AMC agreed to a pilot project to convert the human engineering groups at its MSCs into HEL detachments. HEL also gained field-office representatives at the major centers and schools of the U.S. Army Training and Doctrine Command. In 1982, HEL moved into a new building at Aberdeen, and it became part of LABCOM in 1985.

HEL helped AMC and its system-design contractors develop materiel that was simple to operate and maintain. It also implemented the MANPRINT initiative to ensure that manpower, personnel, training, safety, medical, and human-factors-engineering issues were given high priority throughout the acquisition, development, testing, and fielding processes. When ARL formed, HEL became the Human Research and Engineering Directorate.

just a few years earlier. However, the demand for research never ends—military leaders knew the technology and tactics that won in Panama and in Kuwait and Iraq wouldn't win the battles of the 21st century. Consequently, Gen. Sullivan made "winning the information battle" the first objective of the Army's modernization strategy for Force XXI. The foundation for winning this battle was in successfully applying information technology throughout the battle space.

ARL worked with the Training and Doctrine Command (TRADOC), the Communications–Electronics Command (CECOM), AMC's research, development, and engineering centers, and other Army organizations to meet Sullivan's mandate to digitize the battlefield. As "the architect of the future," it was important for TRADOC to understand the emerging technologies ARL and the RDECs were pursuing. TRADOC would be able to anticipate the impact that the technology would have on doctrine and, at the same time, ensure evolving operational concepts for the digitized battlefield were supported by ARL's research program. The foundation to this partnership was "Futures Concepting"—a TRADOC–ARL initiative designed to bring physical and military scientists together to simultaneously develop future technology and doctrine, thereby eliminating any gap. Thus, when a technology is ready for battlefield application, so is the doctrine.

However, many challenges would have to be overcome to close the gap. Primary among them was the divide that had opened between commercial and military technology. New information technologies were being developed rapidly for commercial applications; hand-held computers, cellular telephones, direct-broadcast television, and wireless computing emerged and new generations of devices followed, all priced for the mass market. The challenge for the Army was to provide a small, affordable, deployable system for on-the-move collaborative planning and situational awareness—and base it on commercial technology and require little infrastructure. It also had to be compatible with systems currently in the Army inventory, yet provide a way of eventually moving beyond those systems.

Technical change has always led military doctrine. History has shown that an army that can apply evolving technical capability to the battlefield gains a tremendous advantage. In these early years of ARL, the consensus was that information technology (IT) would drive the next revolution in military doctrine. On the digitized battlefield, the goal was for computers to carry most of the routine load of a commander at all levels of command. In turn, the commander would have access to near-perfect information on the battlefield and a war-gaming capability enabling him to game in real time multiple courses of action to support his selection of the best one. Major advances in IT in the commercial world, however, were developed to operate in relatively benign conditions. The hostile environment of the battlefield was much different. Combat information must be gathered by automated sensors providing a near perfect perception of battlefield events. That data must be moved through and around a hostile environment under conditions of enemy jamming and deception and high noise with mobile nodes vulnerable to destruction. The raw data must then be turned into useful intelligence and presented in a format that can be easily and quickly understood by commanders and their troops—all in real time and as inexpensively as possible. ARL's task during this era was to supply scientific support to the Army as it closed the gap between military and commercial technology while ensuring future technology and doctrine are developed in tandem.

Concurrently, the downsizing of DoD—coupled with the explosion of IT—demanded a new approach in laboratory operations. It required ARL to become smaller while still providing state-of-the-art technology for military personnel. The end result, a federated laboratory, was a unique entity within the DoD. It drew upon the best of the public and private sectors to produce the research and technology needed for present and future Army land-warfare systems.

The twofold construct of the Federated Laboratory (FedLab) was to continue strong in-house research to meet Army-unique requirements in the absence of external expertise, or market, for such technologies; and, forge relationships with industry and university laboratories with recognized competencies in specific areas where the centers of expertise were outside the government and the technologies potentially had broad applications. FedLab eventually resulted in a "virtual ARL" that was distributed across the nation and one-third larger than ARL's actual size. Its program would be integrated into the ARL program in an open configuration, with large exchanges of staff in both directions. Included in the structure were two existing university centers of excellence that previously had reported to ARO: the Army High-Performance Computing Research Center (AHPCRC) at the University of Minnesota and the Information Sciences Center at Clark Atlanta University; and the Institute for Advanced Technology at the University of Texas, a University Affiliated Research Center (UARC) that had reported to the Army's Armament Research, Development and Engineering Center (ARDEC).

In July 1994, ARL was granted authority by DA to enter into research cooperative agreements. They were different from contracts because they were not governed by the rigid requirements of the Federal

The Wireless Emulation Laboratory, which is located at Adelphi Laboratory Center, Md., is a research test bed used to investigate fundamental issues in network science.

Acquisition Regulations. The use of these instruments played a key role in FY95 plans to implement the concept. Cooperative agreements made possible a close and very flexible working relationship between ARL and the recipients of the agreements; influenced the exchange of research personnel to best use available facilities; and established an environment for the exchange of scientific ideas and joint research that supported Army requirements as well as commercialization of research products. The cooperative agreements provided substantial Army programmatic involvement through management committees, which evaluated and set directions for future research objectives.

In December 1994, ARL issued its laboratory Broad Agency Announcement (BAA) to the private sector. It tasked industry and academia with assembling "consortia" around several technology areas deemed critical to Gen. Sullivan's directive to "digitize the battlefield." The BAA required a consortium to consist of at least one industry partner as the lead organization, one major research university, and one HBCU/MI. The results of the BAA solicitation were overwhelming. ARL received bid packages from 38 consortia from all of the leading technology centers in the private sector. After a rigorous selection process, three consortia comprising 27 partners in 17 states were selected—one each in the areas of advanced sensors, telecommunications/information distribution, and advanced/interactive displays. A total of $122 million was budgeted for them over the five-year period beginning in 1996.

Over the five-year period, FedLab was an outstanding success:

- More than 400 members of ARL's partners' staffs augmented 1,250 ARL scientists and engineers;

- More than 40 individuals participated in rotational assignments;
- More than 600 papers were published in refereed journals; and
- ARL leveraged more than $11 million of its partners' internal funds toward FedLab-related activities.

The two most important outcomes were the large number of products delivered from the FedLab activity to ARL's customers and ARL's new ability to amplify its own technical competence through association with this array of world-class partners. This enabled ARL to play the critical role of "smart buyer" for the Army's technology needs. ARL was specifically called out for recognition by the U.S. Senate Committee on Armed Services for this highly innovative approach to public–private partnering.

Transitions

The move toward the digital battlefield and the establishment of FedLab set off a flurry of consolidation within ARL's directorates. The process began in April 1995, when an ARL center of excellence in digital-communications sciences was developed. The former Signatures, Sensors, Signal and Information Processing Directorate (S3I) was separated into the new Sensors Directorate (SEN) and the Information, Science and Technology (IST) Directorate. The SEN, along with most of the S3I and three branches of the Electronic and Power Sources Directorate (EPSD) located at Fort Belvoir, focused its activities on infrared focal-plane arrays, microwave and millimeter-wave radar, optics, and acoustic sensors, as well as advanced sensor concepts. The Information Processing Branch of S3I, the Military Computer Science Branch of the Advanced Computational and Information Sciences (ACIS) Directorate, and some personnel from EPSD and the Battlefield Environment Directorate (BED) formed the IST Directorate. It contained technical expertise in sensor and data fusion, display integration, knowledge-based reasoning, high-performance wireless networks, automated information distribution, data and image compression, adaptive communications and networks, secure exchange, and architectures research.

Meanwhile, most of EPSD became the Physical Sciences Directorate (PSD). It focused on pervasive 21st century technologies including solid-state physics, nanotechnology, chemical science and technology, biological sciences, and manufacturing science. ACIS transitioned into the Advanced Simulation and High-Performance Computing (ASHPC) Directorate. ASHPC concentrated on advanced distributed-simulation technology, software engineering, artificial intelligence and expert systems, real-time language translation, supercomputing, distributed and parallel computing, and wide-bandwidth networks. The BED Atmospheric Analysis and Assessment team was moved to the Survivability/Lethality Analysis Directorate (SLAD), expanding SLAD's threat–effects analysis mission and consolidating all of the laboratory's "6.5" mission funds in one directorate. The restructured BED concentrated on signature distortions, atmospheric modeling, electromagnetic-energy propagation, remote detection and identification of chemical and biological agents, weather-analysis aids, weather-measuring techniques, and land–battlefield modeling. Finally, the Human Research and Engineering Directorate (HRED) reorganized internally to form a Soldier Information Division to support the laboratory's emphasis on digitalization and communications science.

While these changes occurred, the ASA (RDA) commissioned a study that examined options for the future of ARL. The study was a response to recommendations in an umbrella Functional Area Analysis (FAA) conducted by the Deputy Chief of Staff for Operations in light of changing needs, program transitions, and funding reductions. ARL had already achieved a 41-percent reduction in personnel since 1989 and undertaken a significant consolidation in compliance with BRAC 91, at a cost of approximately $328 million, in the 1991–1997 time frame. Nevertheless,

the report recommended ARL further decrease its number of directorates while focusing programs and achieving maximum overhead savings. This would sharpen technical focus and decrease overhead by focusing ARL on armor and armament, battlefield-information science, sensors and electronic devices, human research and engineering, and survivability analysis. All of these endeavors would have the greatest potential to support Army long-term readiness with the lowest implementation costs and difficulties.

Therefore, ARL began FY97 with five technical directorates and two centers, with a chief-of-staff-support function. By efficiently combining materials and weapons research, the Weapons and Materials Research Directorate (WMRD) positioned ARL to more effectively support future land combat systems. The IST Directorate addressed a broad spectrum of research aimed at the digitalized battlefield beyond Force XXI. The Sensors and Electron Devices Directorate (SEDD) developed technology for advanced solid-state components and the state-of-the-art sensor systems to provide battlefield awareness and targeting. HRED conducted a broad-based program of scientific research and technology directed toward optimizing Soldier performance and Soldier–machine interactions to maximize

Rodman Materials Research Laboratory, which is located at Aberdeen Proving Ground, Md., has nearly 300,000 sq. ft. of laboratories that enable the pursuit of disruptive and challenging research and characterization in advanced materials technologies for potential applications in Army weapon systems.

battlefield effectiveness, while ensuring Soldier-performance requirements were adequately considered in technological development and system designs. SLAD provided technical support in the analyses of the survivability and lethality of Army technologies and systems in the full spectrum of battlefield threats and environments. The Vehicle Technology Center (VTC) addressed propulsion and structure technologies for both air and ground vehicles while maintaining existing relationships with NASA. Finally, the Corporate Information and Computing Center (CICC) focused its efforts on ARL's business and high-performance computing assets and served as the management vehicle for the DoD Major Shared Resource Center (MSRC) and the AHPCRC.

The five directorates and two centers received a major addition in 1998, when ARO joined the ARL team. The shift went hand in hand with Lyons' emphasis on basic, or "6.1," research. Just after assuming the ARL helm, Lyons remarked: "[A]ny large laboratory like this needs strong scientific underpinnings. If you don't have that as a foundation, then you can't do the applied work."

ARO had existed separately from ARL and its predecessors for nearly 50 years, and the vast majority of its previous work had focused on basic research. The organization also had several strong ties to ARL, having established several "centers of excellence" that were brought into the FedLab structure. ARO was part of LABCOM until it became a separate reporting activity in 1992 just before the creation of ARL. With the Army's need to more tightly focus its basic research on future needs, ARO's director became the ARL deputy director for basic research, with a charter to coordinate all 6.1 research being performed at ARL, including that of the directorates.

ARL's organizational structure was not the only development in this period. The lab was also evolving in more tangible ways. ARL's success depended heavily on the availability of top facilities that would enable future cutting-edge research. In 1996–1997, several of these facilities were either completed or constructed sufficiently for initial use. At APG, the Target Assembly and Storage Facility on Spesutie Island supported work on classified targets. Construction of this facility was started in January 1996. The installation of the high-efficiency particulate air filter in 1998 provided personnel with the specialized capability of working with heavy-metal armors, such as those using depleted uranium. In July 1997, the Rodman Materials Research Laboratory was dedicated to accommodate scientists and engineers transferred from Watertown, Mass., and Fort Belvoir, Va. The $76-million facility supports a wide range of basic materials research for defense and government customers. It had begun operating a few months before its official dedication.

Zahl Physical Sciences Laboratory under construction at Adelphi Laboratory Center.

Construction also continued at Adelphi Laboratory Center (ALC). The High-Bay Facility was completed in February 1996 and occupied in May. It accommodated research in atmospheric science. In October 1997, ARL dedicated the Electromagnet Research Facility. Previously known as the Scale Model Laboratory, it was designed as an electromagnetic transparent scale-model experimentation facility. Personnel relocated from Woodbridge, Va., used this facility for research that included ultraband radar and high-power microwave programs. The Adelphi site also received its own administrative building when the Della Whittaker Building officially opened in August 1997. Finally, during this period, construction commenced on what would become the Zahl Physical Sciences Laboratory.

The $73.9-million project would eventually house SEDD, which was transferred from Fort Monmouth and Fort Belvoir. The facility also included a $6.7-million Military Construction Army project for CICC. This research-and-development computer center consolidated CICC at ALC and provided a central connecting point for ALC to tie the high-performance and simulation computers at APG. As a result of all of this construction, the Woodbridge Research Facility was closed in September 1994 and the ARL–Watertown site was closed on Sept. 29, 1995.

During this period, there were also major innovations in the management of ARL's workforce. In the FY95 Defense Authorization Act, Congress empowered the National Performance Review Science and Technology Reinvention of Laboratories to design—"demonstrate"—alternative civilian-personnel systems. The purpose was to enhance the effectiveness of DoD laboratories by allowing greater managerial control over personnel functions and, at the same time, expand the opportunities available to employees through a more responsive and flexible personnel system. For the Army, the personnel demonstration involved almost 8,000 civilian employees in four science and technology organizations: ARL; the Missile Research, Development, and Engineering Center (MRDEC); the Corps of Engineers Waterways Experiment Station (WES); and the laboratories of the U.S. Army Medical Research and Materiel Command (USAMRMC). In January 1995, Lyons organized an executive steering committee that drafted plans to implement a revised personnel-management system that included broad pay bands, pay for performance, more generic job descriptions, and automated job grading.

The system would coincide with the consolidation of ARL directorates. The Operations Directorate was scheduled for reassignment under the Chief of Staff, and the position of Chief of Staff became a colonel who reported through the Deputy Director to the Director. ARL planned the implementation of the new Personnel Demonstration Project's Pay for Performance System for all eligible General Schedule employees in 1998. Effective Oct. 8, 1997, as part of the general DoD restructuring, most operations of the ALC Personnel Office were centralized in the Northeast Regional Civilian Personnel Operations Center at APG. Civilian Personnel Advisory Centers at ALC and APG gave on-site advice and assistance to managers and employees. Rationalization provided a new methodology of doing business and resulted in a staffing reduction of more than 50 percent within the ARL civilian-personnel community. ARL also stepped up its efforts in minority hiring, as Lyons established a minorities committee in early 1996 to address workplace issues and examine the recruitment and hiring processes. It would later transition into a wider-ranging diversity board in late 1998.

Army After Next

The FedLab concept had already emphasized the importance of reconciling Army digital capability with technologies developed for the commercial sector. However, the paradigm for technological development shifted once again in the later years of the Lyons regime. This occurred through the development of the Army After Next (AAN) concept. The principle of AAN was to augment ARL's shorter-term technological advances with longer-term goals that investigated the needs of the Army ten years hence. This goal would require an unprecedented advance in information systems, sensors, and weapons and radically new concepts for logistical support. As the Army's corporate laboratory, ARL would play a key role assuring that the technologies to win battles would be available and inserted in the next and future generations of combat and support systems. AAN provided a unique opportunity to focus ARL's research program on critical operational requirements. Even closer coordination with TRADOC and the Army community was needed to identify and ensure new initiatives supported a

smaller, lighter, faster, and more lethal force that was envisioned for AAN with specific emphasis on knowledge and speed.

In conjunction with AAN, ARL reformulated its strategic-planning process to focus on several major long-range problems the future Army would face. This set of "Grand Challenges" represented a subset of those strategic problems to which ARL could contribute its world-class technological expertise. The five Grand Challenges were:

- Survivable systems with lethality overmatch in complex terrains
- Lighter, faster, more fuel-efficient mobile platforms to reduce the logistics tail and enhance deployability
- Provide commanders with unprecedented real-time situational awareness of the battlefield
- Significantly improve the battlefield Soldier's ability to absorb information and make decisions
- Assure information dominance in diverse operating conditions and threats

Technology would be the principal enabler of the AAN battlefield, and it was essential for AMC and the Army to maintain a vigorous investment in basic and applied research to meet the needs of Soldiers.

Fortunately, as demonstrated by some of the technology already being developed, ARL was well on its way to fulfilling the needs of AAN. Lyons' tenure saw significant accomplishments by ARL scientists in such diverse areas as robotics, battlefield visualization, and live-fire prediction and assessment. All this was achieved while ARL provided support to Soldiers deployed in Somalia, Haiti, Bosnia, and other areas around the world. Perhaps the biggest technological triumph of this period occurred in December 1994 with the successful proof-of-principle demonstration of the Global Positioning System (GPS) registration fuze for artillery rounds. GPS had already been in use for a variety of military technologies. A joint-service program led by the Air Force, the technology provided accurate, continuous, all-weather, common-grid, worldwide navigational, positioning, velocity, and timing data to land, sea, air, and space-shuttle crews. Now, this tracking system could determine the position of a fired artillery round and whether that round had hit its intended target—eliminating the necessity of human verification of destroyed targets.

There were two other breakthroughs in information technology in this period. The first was the completion of the Integrated Meteorological System (IMETS) software, which used atmospheric data to give weather forecasts for specific areas of the battlefield. IST developments also assisted Soldiers in Bosnia, through development of the prototype Forward Area Language Converter (FALCon) systems to help evaluate documents written in Serbian or Croatian. FALCon helps the user with no foreign-language training convert a foreign-language document into an approximate English translation, enabling frontline Soldiers to assess the military significance of documents obtained in the field and decide whether to pass the items to a linguist for translation. (Such technology would later be helpful to the Global War on Terrorism.) This effort influenced the development of optical-character-recognition software to accommodate the unique characteristics of documents in the field, while increasing the language coverage of available translation software and incorporating an advanced multilingual retrieval capability.

ARL's technology advances were facilitated by its status as a high performance computing Major Shared Resource Center (MSRC). Recognizing the importance of computer modernization as integral to the future military, DoD initiated a High-Performance Computing Modernization Program (HPCMP) in 1994, designating ARL as one of four MSRCs in the country. Much of the upgrading process occurred throughout Lyons' tenure so that the ARL MSRC could manage several computational areas. Further, it was integrated with the other DoD MSRCs through the Defense Research

Forward Area Language Converter (FALCon)

and Engineering Network. These resources provided researchers with scientific visualization laboratories that enabled data interpretation and representation and supported ARL's Army High-Performance Computing Research Center (AHPCRC).

Continuing Partnerships

ARL pursued many types of partnerships involving academic institutions and private industries to focus state-of-the-art research on the Army's needs. In addition to FedLab, ARL operated cooperative programs and centers of excellence, as well as congressionally mandated technology-transfer programs and an extensive educational-outreach program, in addition to a broad spectrum of international cooperative programs. Notable external partners included the AHPCRC at the University of Minnesota, the hypervelocity-phenomena work at the Institute of Advanced Technology at the University of Texas at Austin, and the software-engineering efforts at the Information Sciences Center at Clark Atlanta University. ARL also had cooperative agreements that supported microelectronics at Johns Hopkins University and the University of Maryland. Collaborative programs in materials research were conducted with Johns Hopkins, the University of Delaware, and the Michigan Molecular Institute. ARL worked closely with several research and educational institutions that were designated as HBCU/MIs.

In addition to the five partners in the FedLab program (City University of New York, University of New Mexico's Center for High Technology Materials, Howard University, North Carolina A&T State University, and Morgan State University), the HBCU/MI partners in AHPCRC were Florida A&M University, Clark Atlanta, Howard, and Jackson State University.

The SBIR program also made great advances during this time. After SBIR's expansion in 1992, Congress increased its emphasis on dual-use opportunities and private-sector commercialization. Through the SBIR program, the Army gained access to the technological advances of small, innovative firms with fewer than 500 employees. The Army set aside specific funding for high-quality research or R&D proposals of innovative concepts to solve Army/DoD-related scientific or engineering problems, especially those concepts with high potential for commercial use.

ARL was a consistent leader in the Army's SBIR program and annually averaged 20 percent of its total funding by FY97. The program consisted of two phases. Awards under Phase I enabled recipients to demonstrate the feasibility of their proposals, resulting in 43 contracts at about $100,000 each. Successful Phase I recipients applied for Phase II funding to enable establishment of proof of principle and to produce a prototype. Thirteen Phase II contracts awarded in FY97 amounted to $750,000 for each award.

The Small Business Technology Transfer (STTR) program was created by Congress in FY94 to foster collaborations between the small-business community and research institutions and to involve both in federal R&D more effectively. ARO administered the program, and ARL provided technical support and evaluated technical proposals submitted by small businesses. During FY00, ARL monitored six of the Phase II STTR projects valued at $600,000 each. In addition to providing support to the Objective Force, as well as support to the Logistics Activity and the TRADOC Battle Laboratory, ARO addressed

congressional interest in the readiness and effectiveness of U.S. defenses against nuclear, biological, and chemical warfare.

End of an Era

A transition of ARL directorship occurred at the conclusion of FY98 with Lyons' retirement. His tenure was highlighted with achievements that included the receipt of four Hammer Awards, given by Vice President Al Gore to agencies that maximized efficiency while following the financial parameters set by the National Partnership for Reinventing Government. Awards were also given to ARL in recognition of the development of the Personnel Demonstration project (shared); its implementation of the FedLab initiative; its development of the Turbine Engine Diagnostic System; and the laboratory's reform of the DoD–SBIR process. ARL's support of TRADOC through AAN and its emphasis on information technology had helped establish its reputation as an integral part of the Army's future direction and visions. Finally, ARL was recognized by the defense community as one of the Army's centers of expertise in the computer-security area.

During Lyons' tenure, ARL engineers and scientists made great strides in establishing the state-of-the-art Army laboratory envisioned in the waning days of the Cold War. It would now be up to ARL's second director, Dr. Robert Whalin, to ensure the organization remained on the right track as it fulfilled the goals of Army Transformation.

The Experimental Unmanned Vehicle (XUV) with the dual-band forward-looking infrared (FLIR) camera attached.

Envisioning the Army of the Future,

1998–2001

"Good people working together will produce more technology relevant to the Soldier" was the motto espoused by Dr. Robert Whalin, ARL's second director. Whalin came to ARL in December 1998 and quickly set to work making the organization, in his words, "a fully functional, seamless, smooth-running, well-oiled machine for the Army." He was selected for the position after serving as director of the U.S. Army Corps of Engineers Waterways Experiment Station (WES) where he had more than tripled the size of its research and development and established a distinguished record. Whalin also brought with him a wealth of experience in both academia and the private sector, having worked six years in industry and as an adjunct professor at three universities.

Dr. Robert Whalin

Whalin would have to steer ARL through the initiative of Army Transformation, which was announced in October 1999 by Gen. Eric K. Shinseki, then Army chief of staff. The initiative would, in Shinseki's words, make the Army "a strategically responsive force that is dominant across the full spectrum of operations." Transformation would be accomplished through integrating three prongs: the Legacy Force (already-fielded combat systems and units), the Interim Force, and the Future Combat Systems (FCS). This integration would achieve the ultimate goal of Army Transformation, the new Objective Force, which would incorporate three priorities for equipment modernization: information dominance, physical agility, and lethality and survivability overmatch. Fortunately for the Army, ARL had already been developing technology with these goals in mind.

With much of ARL's organizational structure in place, Whalin focused on more specific goals that would meet the needs of the Army of the future. Among the objectives pursued during his tenure were management of the Army's basic-science research grants with academia; leveraging the technology investment of the commercial sector and tapping the leading-edge expertise and facilities of universities and the private sector; and working with TRADOC and the R&D assets throughout AMC to develop enabling technologies. In addition, Whalin emphasized human-resources development, both in training of the workforce and aggressive minority recruitment. Finally, he placed a priority on investment in technology and supported the construction of the Tactical Environmental Simulation Facility as well as an increase in ARL's computing power.

To meet the challenges of Army Beyond 2010, ARL worked closely with TRADOC and the robust research and development assets of AMC. Addressing the Army needs across the total spectrum, ARL focused on initial work required to deliver superior science and technology for the future Army. The process generated numerous recommendations for investment in basic research that included terrain- and environment-independent communications and data management, lightweight protective materials, and unmanned and robotics concepts. Some ARL technology areas identified for the Army Beyond 2010 were protection schemes for land systems, signature control, advanced materials, chemical and biological protection, alternative propellants and hybrid power systems, human and cognitive engineering, and fuel and logistics efficiencies. More specifically, ARL was interested in developing lighter armored vehicles, providing Soldiers with virtual-reality helmets, and developing weather-resistant clothing.

ARL also facilitated Army Transformation by improving on the FedLab concept, which expired in 2001. The follow-on program, the Collaborative Technology Alliances (CTAs), continued the very successful FedLab model by advertising for self-formed consortia to submit bid packages for cooperative agreements (CAs) in five areas: advanced sensors, advanced decision architectures, communications and networks, power and energy, and robotics. On May 31, 2001, five CAs were awarded and the CTAs were under way for a term of eight years and funded by a total of $300 million in 6.1 funds. In addition, another set of $250 million in five task-order contracts—$50 million per consortium—was

established, which would allow other sponsors to come into the program at the applied research (6.2) level and support individual efforts to enhance the probability of successfully transitioning technology to system-development programs as quickly as possible. Another new feature of the CTA gave government agencies the ability to join with the private-sector consortia and ARL, opening up the collaborative environment even further. Several government organizations came into the partnership, thus bringing in significant amounts of additional funding.

Organizational Transitions

In May 2000, the Computational and Information Sciences Directorate (CISD) was formed. In addition to infrastructural-support efforts, CISD had four basic-research areas: battlefield communications, data fusion and knowledge management, battlefield environmental work, and computational science and engineering. The focal point was the management of the DoD High Performance Computer Network and High Performance Computer Center. The proliferation of computers brought some security vulnerabilities requiring intrusion detection, management administration, and configuration. Further, information assurance became a necessity to prevent incorrect decisions—especially on the battlefield. The reorganization and realignment of information-assurance and knowledge-management functions increased ARL's capabilities and enhanced its contributions to the DoD community in terms of computational applications and science and engineering applications. High-performance computing also used modeling

and simulation tools with various applications and led to new research in the areas of nanotechnology and nanomaterials.

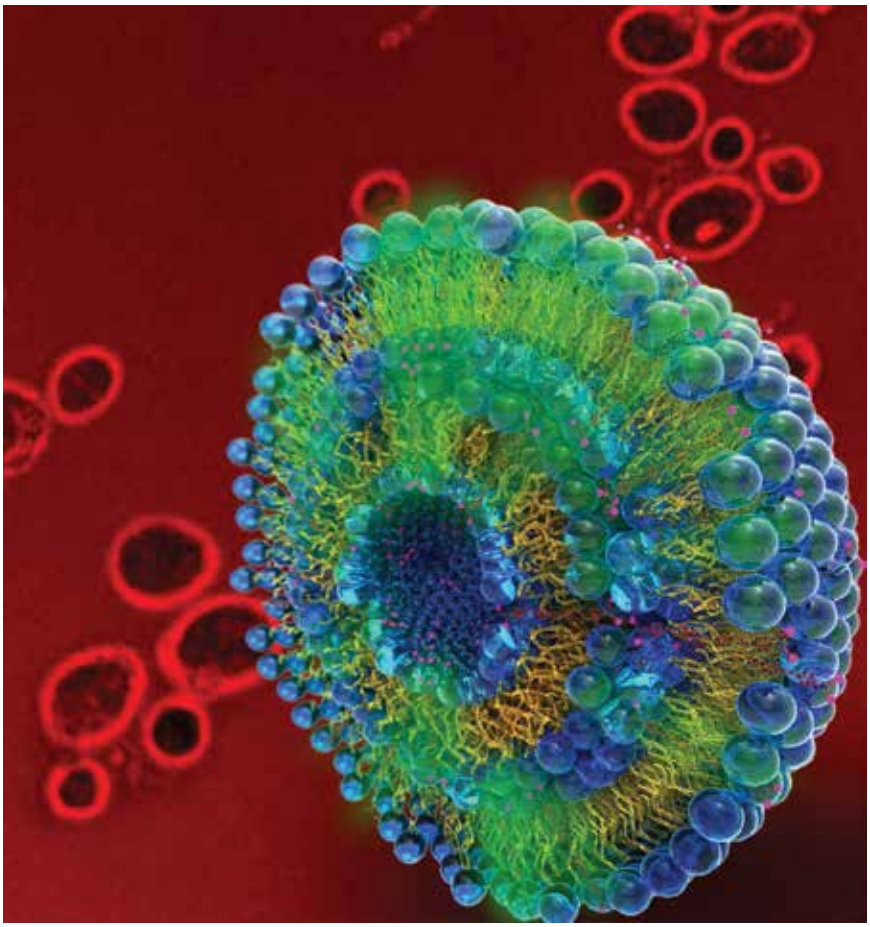
Research Directions

Efforts were also made during this period to improve ARL's internal cohesion, thus providing opportunities to re-establish more efficient and effective team operations. In creating new technology to protect the future Warfighter, the directorates focused their efforts on new and innovative ideas. ARL was a leader in battlefield sensors and electronic devices, providing revolutionary capabilities for Soldiers to preemptively detect and target the enemy. Scientists also developed novel power sources and sophisticated new radio-frequency (RF) and electro-optical devices, thus innovating signal-processing algorithms to make the next generation of weapons and platforms smart and survivable. In computation and information, ARL provided fundamental science needed to enable American Warfighters to forecast, plan, rehearse, and execute missions before the opposing force completed its basic mission-planning cycle. The development of collaborative training, mobile self-organizing networks, advanced simulation, interdisciplinary applications using high-performance computing, and battlefield effects were among the initiatives supporting these advances. Weapons and materials research advanced the science and lightweight-materials technology that made the Army's future weapon systems more lethal, survivable, sustainable, and strategically deployable to ensure dominance—while providing Soldiers' individual protection, advanced armors, armament technologies, and unmanned ground systems. Human research and engineering efforts ensured Soldiers' effective operation on the battlefield. Finally, in the area of vehicle technology, new components contribute to lighter, faster, and stronger future systems to reduce the Army's battlefield fuel consumption.

Basic Research

A fundamental aspect of ARL's contribution to forward-thinking technology is basic research which, while longer in scope, will often produce paradigm-shifting results. In the development of advanced protection against chemical and biological weapons, nanomaterials such as dendritic polymers represented a technological breakthrough that helped make emerging chemical–biological concepts and systems more practical and affordable for individual protection, detection, and decontamination. ARL designed, developed, and evaluated materials and material systems for application in protective clothing, masks, and detection and decontamination equipment. These enabling technologies were transitioned to the Soldier and Biological Chemical Command and the Army Medical Research and Development Command for inclusion in developmental programs focused on protecting military personnel from chemical and biological attacks. Major accomplishments in FY2000 included the development of a next-generation, reactive, topical skin-protective cream for chemical-agent resistance and decontamination; development of nanoencapsulated enzymes for Soldiers' clothing; and nanomanipulation conditioning for enhancing biological-agent detection.

Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman were Nobel Prize recipients in 2001 for their achievements in physics, supported by ARO. Past ARO/ARL-affiliated Nobel recipients included Robert F. Curl, Alan J. Heeger, Alan G. MacDiarmid, and Richard E. Smalley for their achievements in chemistry, and Zhores I. Alferov, Herbert Kroemer, David M. Lee, and Daniel C. Tsui for achievements in physics. ARL was a major participant in the revolution that influenced photonics technology; also in the technological effort to produce super-critical water oxidation in a detoxification effort to eliminate chemical and biological agents. An MIT objective was revolutionizing the warrior Soldier, where a major effort was developing and improving protective clothing against chemical and biological threats, and that would be capable of providing treatment before the arrival of medical personnel.



The cross section of a vesicle, a nonbiological model of a microorganism, reveals several lipid bilayer membranes with the new membrane-incorporated molecules. Blue spheres represent the polar, water-soluble heads of the lipids, which have yellow, nonpolar hydrocarbon tails attached. The new membrane-incorporated molecules are colored in pink. (Background) Fluorescence of the yeast cells demonstrated that the molecules were successfully incorporated into the cell membranes.

Investments were also made in infrared (IR) detectors, especially with the first false color prototype and in calibration technology for helicopters with Princeton University. Challenges pertaining to the future Army necessitated innovative ideas and influenced the introduction of biotechnology into the arena of engineering and physical sciences. The development of an electronic eye and of an electronic nose with the capability of smell were intended to enhance the use of robotics under battlefield conditions. Target recognition and land-mine detection were also primary challenges influenced by quantum computing.

Applied Research

Information Technology

During Whalin's tenure, information technology for the battlefield continued to drive ARL's contribution to the Army Beyond 2010. Many important breakthroughs occurred. ARL helped develop a dual-band forward-looking infrared (FLIR) camera, which enabled operations in a wider range of ambient conditions including day, night, fog, and smoke. The imagery from the disparate IR wave bands fused into a single, composite "false color" image providing the observer more information about a scene than could be previously obtained. This enhanced capability to view the battlefield greatly increases the system's ability to select targets out of clutter and to distinguish targets from decoys and defeat other enemy countermeasures. Battlefield-information issues were also addressed by the Warrior Extended Battlefield Sensors Program, whereby ARL developed energy-efficient networks and acoustic-propagation studies for battlefield sensors that enabled more effective communication among Soldiers and their commanders. The technology was envisioned to revolutionize surveillance and reconnaissance operations on the battlefield. Finally, work continues on the Integration Meteorological System with the goal of forecasting down to a 1-kilometer area. A similar technology, the Integrated Weather Effects Decision Aid, was developed to assist battlefield commanders' decisions to deploy tanks, helicopters or other aircraft, and weapons systems based on the expected weather conditions. In addition, sensors used during an operation would provide audio sounds that would disorient aggressor forces.

A fundamental aspect of obtaining battlefield information lies in trying to extract it from potentially dangerous areas. ARL was successful in robotic and autonomous-platform technologies and played a pivotal role in the development and demonstration of technologies that enabled the employment of unmanned ground vehicles (UGVs) in military applications. The Demo III Program aimed at developing technologies for integration of vehicle platforms and conducting field experiments using Army and Marine Corps personnel. The primary goal was to develop autonomous-mobility technology to enable an experimental unmanned vehicle (XUV) to tactically maneuver over rugged terrain as an integral part of a mixed force of manned and unmanned vehicles. Implicit in this goal was the requirements for the UGV to maneuver at speeds that were comparable to manned vehicles and function reliably without requiring additional specialized personnel. A new model of Demo III XUV was used in constructive and virtual simulations at the Mounted Maneuver Battlespace Laboratory (MMBL) at Fort Knox, Ky. A three-dimensional dynamic simulation of the base-case XUV was completed, which proved critical for the mobility and sensor stabilization system's design for the Demo III vehicles. Demo III demonstrated the capability to perform multiple functions in tactical operations.

Weapons/Lethality

Ensuring combat overmatch for the Future Combat Systems and the Objective Force continued to be a significant challenge. ARL focused its efforts on insensitive, high-energy propellants and munitions offering increased lethality in more compact weapon systems while reducing vulnerability to attack; kinetic-energy penetrator concepts that enhanced or maintained lethality in more compact configurations; and multifunctional-warhead concepts to defeat a full spectrum of targets (armor, bunker, rotorcraft, and troops). ARL was the leader in the investigation of terminal effects of direct-fire armament systems; it applied that knowledge to develop lethal mechanisms for penetrations and warheads delivered by large-caliber guns or small and medium missiles to defeat all classes of armor. This was critical to weapon-system developments at the Army Armament RDE Center and the Aviation and Missile RDE Center that included the compact kinetic-energy missile (CKEM); the tank extended-range munition (TERM); the line-of-sight antitank missile to provide lethal, accurate fire using kinetic-energy missile technology (LOSAT); and the advanced kinetic-energy penetrator. ARL also continued to investigate electromagnetic (EM) and electrothermal chemical (ETC) gun technologies because of their potential leap-

Abrams Tank

ahead capabilities to defeat future threats including enemy platforms equipped with reactive armor and active protection systems. These guns could be integrated with electric vehicle propulsion and armor systems to provide an efficient, highly mobile, and deployable ground-maneuver force.

ARL also continued to develop technologies to provide overwhelming lethal force and the highest levels of survivability to the U.S. Soldier. Technical and scientific accomplishments included enhanced lethality and survivability of the Abrams tank through research and development in armor mechanics and advanced penetrator-defeat technologies; also, by providing designs for reducing vulnerability in the ammunition compartments. In the area of lethality, ARL worked with the RDECs to provide integral technologies for the M829 family of Abrams kinetic-energy ammunition: the fielded M829A1 and M829A2 and the developmental M829E3. Contributions also included the lethal mechanism design (i.e., the subprojectile), high-performance propellant technology, launch and flight ballistics, and lightweight composite-sabot design. Finally, ARL developed a nonlethal munition fired from the M203 grenade launcher and a crack-resistant face shield for riot helmets, both fielded to U.S. peacekeeping troops in the Balkans and Somalia.

Soldier Performance/ Battlefield Coordination

A cornerstone of the FCS and the Objective Force was ensuring that Soldiers would function with maximum effectiveness under all conditions on the higher-technology battlefield. ARL conducted research to define and quantify Soldier capabilities and limitations and apply this understanding to the design and development of Soldier–system interfaces. Scientists and engineers worked closely with Soldiers to identify and develop solutions to current and future performance problems. Basic research in auditory and visual perception, and applied research in cognitive engineering provided the understanding required by material developers to build systems that greatly enhance Soldier performance. In addition to the research function, ARL championed the Soldier in the materiel-acquisition process by providing leadership in human-factors engineering and the application of Manpower and Personnel Integration (MANPRINT) to Army acquisition. During these years, ARL's support to combat developers, program executive offices (PEOs), product managers (PMs), and the Army's test and evaluation effort was critical to systems' success, and ARL's contributions significantly improved system performance and reduced life-cycle cost.

As the 21st century approached, the Army needed a command-and-control vehicle (C2V) that enabled staff to accomplish command–control operations on the move. ARL was asked to develop computerized modeling techniques similar to those used for the crew compartments of the proposed Comanche helicopter and the Fox nuclear, biological, and chemical (NBC) reconnaissance vehicle, but with the capability to simulate more personnel aboard. Cognizant of the requirements for effective communication and the need for the command staff to be close enough to the leading edges of the formation, the critical initiative was to have a C2V suitable for supporting the FCS. To some extent, the problems pertaining to command and control during the peacekeeping deployment in Bosnia influenced the requirement for the C2V. It led to further measuring of team behaviors or performance, especially the development of command-and-control tools. Another interesting aspect was the measurement of command and control involving multinational teams.

HRED efforts were also oriented toward Soldier system performance's impact on force effectiveness. MANPRINT stressed the integration of manpower, personnel, training, human engineering, system safety, health hazards, and Soldier survivability. Major successes in the use of MANPRINT were achieved in the development of the Fox vehicle that was accomplished by the Integration Methods Branch's use of the Improved

Performance Research Integration Tool (IMPRINT) and Human Figure Modeling. Success was also attained in the Joint USMC–Army Acquisition Program of the XM777 lightweight, towed howitzer—for which the Air Warrior Team received the MANPRINT Practitioner of the Year Award (for improvements of the process that produced the first aviator human-figure computer program). The lighter weight, smaller footprint, and lower profile of the XM777 improved strategic deployment, tactical mobility, and survivability.

MANPRINT

Survivability and Lethality Analysis Efforts

A prime example of the survivability, lethality, and vulnerability (SLV) mission was the vulnerability assessment of the Theater High-Altitude Area Defense (THAAD) missile system during its development. The comprehensive analysis evaluated major electromagnetic effects—EM interference, EM radiation operations, EM radiation hazards, EM pulse, electrostatic discharge, and lightning—on critical functions and critical subsystems and components of the THAAD system. This gave THAAD program managers and Army decision-makers early feedback on SLV-design options that had near-term and mid-term impacts, as well as anticipating far-term SLV improvements that addressed reactive threats, thus providing early insight into Planned Improvement Program options. On June 23, 2000, THAAD received program Milestone II approval; on Sept. 27, 2001, the U.S. governmental and industry team developing THAAD achieved a major milestone by successfully completing the critical design review for the radar segment. The THAAD Project Office was placed under operational control of the Ballistic Missile Defense Organization on Oct. 1, 2001, for the development and conduct of extensive ground tests. ARL developed realistic trajectory models for targets and missiles using available THAAD field data and threat-trajectory data, in addition to developing multiple

target trajectories for use with IR scene generation of infrared countermeasures (IRCMs).

Organizational Initiatives

At Adelphi Laboratory Center, Md., the completion of the Zahl Physical Sciences Laboratory was the last of the construction under BRAC. Movement into the facility began in August 1999 from ALC locations—the facility would houses the materials and device portions of SEDD and the SEDD front office, and the Corporate Information portion of CISD. The Zahl building also included the Advanced Material Growth and Processing Facility, Display Materials Research Facility, and the Advanced Microanalysis Facility. SEDD personnel who had moved from Fort Monmouth, N.J., and Fort Belvoir, Va., to a Shady Grove laboratory facility leased from Standard Properties in Gaithersburg, Md., were the first scientists and engineers to relocate into the Zahl Physical Sciences Laboratory. The Shady Grove facility was completely vacated by February 2000. Also during this time, ARL Director Whalin supported the construction of a tactical–environmental simulation facility, also known as the "thunder dome" for its planned 50,000 watts of audio power. The goal was to create a virtual environment for dismounted Soldier operations.

During the early years of Whalin's tenure, ARL recognized that despite the reputation of the scientists and engineers on staff, it still faced personnel challenges—that coming retirements would reduce both the scientific and organizational knowledge base. This would occur as the need for skilled, specialized scientists continued to increase. To this end, ARL initiated several personnel programs designed to ensure its position as a top recruiter of scientific talent. Perhaps the most significant of these during the Whalin era was the Science and Technology Academic Recognition System (STARS), which recruited minority scientists and engineers to ARL. The dual fellowship–recruitment initiative assisted top students from ARL's partner schools in HBCU/MIs. All of these programs clearly recognized that the U.S. military must stay ahead of the world not only in military technology, but also in the quality of scientists developing that technology.

September 11th and Beyond

At 8:45 a.m., on Sept. 11, 2001, terrorists crashed American Airlines Flight 11 into the World Trade Center's North Tower. While Americans scrambled to make sense of what had happened in downtown Manhattan, a second plane, Flight 175 of United Airlines, crashed into the South Tower only 18 minutes later. The horror in New York was compounded at 9:43 a.m., when American Airlines Flight 77 slammed into the Pentagon and United Flight 93 crashed in an open field in Pennsylvania. In 58 short minutes, the United States had been significantly attacked on its own soil for the first time since Pearl Harbor in December 1941. Americans knew the country was at war.

The events would also greatly impact ARL's mission and responsibilities. While ensuring the security of the American homeland was the first priority immediately following the attacks, it became clear the U.S. military would have to mobilize offensive efforts in order to undermine Al Qaeda's base of operations in Southwest Asia. The new campaign marked a transition in American military priorities, as the primarily peacekeeping emphasis of the 1990s made room for the additional need for the United States to wage an offensive war. Much of the technology intended for Army Transformation would now be deployed to assist American Soldiers in carrying out their duties. Technologies meant to protect American Soldiers were now accompanied by technologies developed to identify enemies and to help coordinate the United States' global responses and initiatives in the war against terrorism.

In the last year of his tenure, Whalin reaffirmed ARL's commitment to providing the technological underpinnings to systems being developed, improved, or recapitalized by its customers. With U.S. forces entering Afghanistan, and the prospect of war looming with Iraq, ARL focused its efforts on a number of technological developments. These included

- lightweight vehicular-armor technology for ballistic protection of medium- and lightweight future ground vehicles;
- improved individual ballistic protection critical to the Soldier;
- novel lethal mechanisms for gun and missile systems;
- microturbine engines to provide a power source that would have increased energy density;
- fuel cells capable of directly converting the chemical energy of a fuel into electrical power and water;
- robotics to expand a field unit's situational awareness, provide remote gunfire on demand, and reduce the logistical burden by shrinking the size of combat vehicles; and
- cognitive-engineering research to optimize the Soldier–machine interaction.

But the wars in Afghanistan and Iraq would require more than good technology planning and development. ARL's scientists and engineers would now be challenged to adopt quick-fix solutions to react to problems for Soldiers on the ground. With Whalin's departure in late 2002, balancing this new demand with ARL's already fundamental mission to provide technology for the future would be left in the hands of a new ARL director.

New Leadership at ARL

With Robert Whalin's retirement, ARL entered a new phase. The lab continued to face the ongoing pressure of providing technology for America's Soldiers in the field while staying ahead of the technology curve to produce cutting-edge scientific research for the long term. The task of leading this growing effort would be taken up by Acting Director John Miller, who was assigned as director of ARL in March 2003.

Miller would be the first ARL director with significant service within the organization. From 1971 through 1992, he held positions as project engineer, branch chief, and deputy laboratory director of HDL. From 1992 until his assignment as ARL director, he served in a number of management and leadership positions in ARL. He was the ARL associate director for plans, programs, and budget, responsible for strategic and operational planning, revenue allocation, and program formulation and direction. He held positions as acting director of the earlier S3I directorate, as well as division chief and deputy director of SEDD, where he was responsible for directing basic and applied research in sensors and signal- and image-processing technologies. The nine years of Miller's ARL directorship, which ended in June 2012, were a highly productive period for the lab. During this time ARL made significant breakthroughs in both basic and applied research. In addition, ARL met the challenge of providing unique solutions to American Soldiers, with numerous ARL innovations deployed to theater. Leadership made great efforts during this period to emphasize to the ARL

team the contributions they make to Soldiers. Providing new or enhanced capabilities for Soldiers would dictate research-program content, recruitment and development of human capital, investments in technical infrastructure, and refinement of business processes.

To this end, under Miller, ARL's vision was articulated in a theme statement with three integral elements. The theme statement was ***Many Minds, Many Capabilities, Single Focus on the Soldier***, with these elements:

Acknowledged for scientific, technical, and analytic excellence;

Recognized as the bridge between the nation's Science and Technology (S&T) communities and the Army;

Leader in providing innovative solutions for the current and future Army.

The theme statement guided organizational alignment and provided a comprehensive framework for critical review of investments in research programs, technical infrastructure, and workforce development. Performance standards at all levels would reflect the focus of each employee on achieving these goals.

Research Initiatives and Planning

Under Miller, ARL strengthened existing programs and initiated new ones to address growing and novel challenges. Leadership's focus on "One ARL" would encourage even further cross-directorate research in important areas of Army need, as ARL scientists and engineers continued to find creative ways to blend individual research areas. While the lab remained organized by individual directorates, ARL leadership now identified nine laboratory programs, or technology areas, upon which the lab's efforts would focus. These were extramural basic research, networks, human dimension, lethality, mobility, power and energy, sensors, protection, and survivability/lethality analysis.

In addition, because the research ARL performs is inherently long-term in nature and may require 10–20 years of R&D before delivering innovative capabilities to U.S. Soldiers, ARL selected seven high-payoff Strategic Research Initiatives (SRIs) that could expand existing or establish new core competencies in support of its Technology Focus Areas. These SRIs were materials, neuroscience, network science, computational sciences, electronics, energy science, and autonomous-systems technology. In addition, the ARL Director's Strategic Initiatives (DSIs) were introduced as two-year funded efforts ($500,000 per year) for emerging (revolutionary) research areas in support of SRIs to potentially expand or establish new Core Competencies. DSIs support higher-risk

Mr. John Miller

research that is collaborative and multidisciplinary/multidirectorate. These initiatives are meant to present the opportunity to attract new researchers, develop new infrastructure, and have long-term potential to deliver unprecedented capabilities to the Soldier.

To stimulate creative thinking within the workforce, ARL also maintained a robust Director's Research Initiative (DRI) program dating back to this period. The program was designed to support innovative and possibly high-risk research ideas with potential to significantly advance mission needs beyond conventional expectations. The program encouraged thinking "outside the box" in pursuing emerging or alternative

technologies for which direct application to today's problems might not be possible, but which could have potential to address military needs in the long term. The DRI program annually funded about 20 high-risk–high-payoff seed projects. The competition for the DRI funds was stiff and the selections were made upon the recommendation of the ARL Fellows.

A significant initiative was the adoption of the Program Formulation workshop from its original implementation within SEDD to an ARL-wide program in 2007. The workshop was conducted with ARL's customers and stakeholders to define annual research-mission priorities. The initiative created a forum to communicate and receive programmatic input and feedback from stakeholders on the proposed mission program. The program expanded in 2008 to include the CTAs, Centers of Excellence, and University-Affiliated Research Centers. The workshop was so successful, the U.S. Army Research, Development and Engineering Command (RDECOM) adopted it in 2009 as the Technology Planning Workshop (TPW). It became an RDECOM-wide program, and ARL was fittingly selected to host the first TPW.

Collaboration

Under Mr. Miller's guidance, ARL teams worked in partnership with the RDECs, Rapid Equipping Force (REF), Joint Improvised Explosive Device Defeat Organization (JIEDDO), and others on the following tasks: current operational technical challenges facing Soldiers in Iraq (Operation Iraqi Freedom [OIF]) and Afghanistan (Operation Enduring Freedom [OEF]); maturing and transitioning technologies in the two- to five-year time frame for existing systems; and generating scientific discoveries to provide the foundation for Soldier capabilities 15–20 years in the future.

ARL also made great efforts to augment its external collaborations during this period. The lab continued to partner and collaborate with academia, industry, and other government organizations through a variety of continuing and new innovative programs. The intent was to maximize the use of precious research dollars by leveraging the resource investments of partners through a variety of approaches ranging from single-investigator grants with individual university faculty, to large centers with group and consortia, to direct collaborations between university research personnel and ARL in-house scientists, engineers, and analysts. Vital research was facilitated through ongoing CTAs in Advanced Decision Architectures, Advanced Sensors, Communications and Networks, Power and Energy, and Robotics. The Advanced Sensors CTA ended in May 2007, except for the Technology Transition Contract, which remained active through September 2009. The Power and Energy CTA ended in December 2007, except for the transition contract, which remained active through September 2009. New CTAs in Micro Autonomous

Vital to ARL's research efforts are collaboration with external partners, including academia. Here, ARL Director John Miller (far right) greets University of Delaware President Dr. Patrick Harker during a July 2010 tour of ARL facilities, including the Army's Material Center of Excellence in Composites as well as the future site for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) technologies.

Systems and Technology (MAST), Neuroergonomics, and Network Science would later join the existing CTAs. In addition, ARL's connection to academia remained strong with University-Affiliated Research Centers in biotechnology, nanotechnology, and electromechanics and hypervelocity physics continuing to prosper.

A University Affiliated Research Center (UARC) is a strategic United States Department of Defense (DoD) research program that is associated with a university. UARCs were established to ensure that essential engineering and technology capabilities of particular importance to the DoD are maintained. University Affiliated Research Centers (UARCs) are designed to provide critical mass in research areas that meet Army and DoD future needs and anticipated combat requirements. UARCs are university-led collaborations between universities, industry and Army laboratories that conduct basic, applied and technology demonstration research. The universities, considered at the forefront of science and innovation in a specific research area, provide dedicated facilities and share space with Army and industrial participants. The industrial partners provide competence in related technologies, expertise in transitioning technologies from laboratories to markets and cost sharing. The emphasis for each UARC is to conduct research where breakthroughs are likely to enable revolutionary capabilities for our warfighters.

ARL also fostered collaboration through the Centers of Excellence, with focus on high-performance computing (Stanford University, New Mexico State University, Morgan State University, University of Texas at El Paso, High Performance Tech, Inc., and NASA–Ames) and in materials (University of Delaware, Johns Hopkins University, Rutgers University, Drexel University, and Virginia Tech). In 2007, ARL also helped establish the new Flexible Display Center (FDC) at Arizona State University (ASU). The Center's objective is to develop technologies and manufacturing processes to enable realization of lightweight, rugged, ultralow-power flexible displays and electronics. Flexible displays are creating novel applications (through the FDC partnership) such as wearable and conformal displays for Soldier situational awareness and ultralow-power, sunlight-readable displays for robotic-asset control. Other novel applications include electronic manuals and wearable maintenance aids for logistics; conformal, lightweight displays for vehicles; and ultimately roll-up displays.

Breakthroughs were made in international collaborative efforts during this period. The highlight was in 2006 with the International Technology Alliance, through which ARL and the United Kingdom's Ministry of Defence planned to award (at that time) up to $148 million over a 10-year period to a consortium of 23 of the two countries' top academic and industrial organizations to conduct research in network and information sciences. Specific areas of interest included network theory, security across a system-of-systems, sensor-information processing and delivery, and distributed coalition planning and decision making. The research, through an initial five-year agreement, focused on attacking the technological challenges of a networked battlefield critical to future coalition operations. The goal was to foster better collaborations between government, academic, and industry researchers in the United States and UK, bringing together private sector and government researchers who would help solve the technological challenges that must be met if future joint military operations are to be a success.

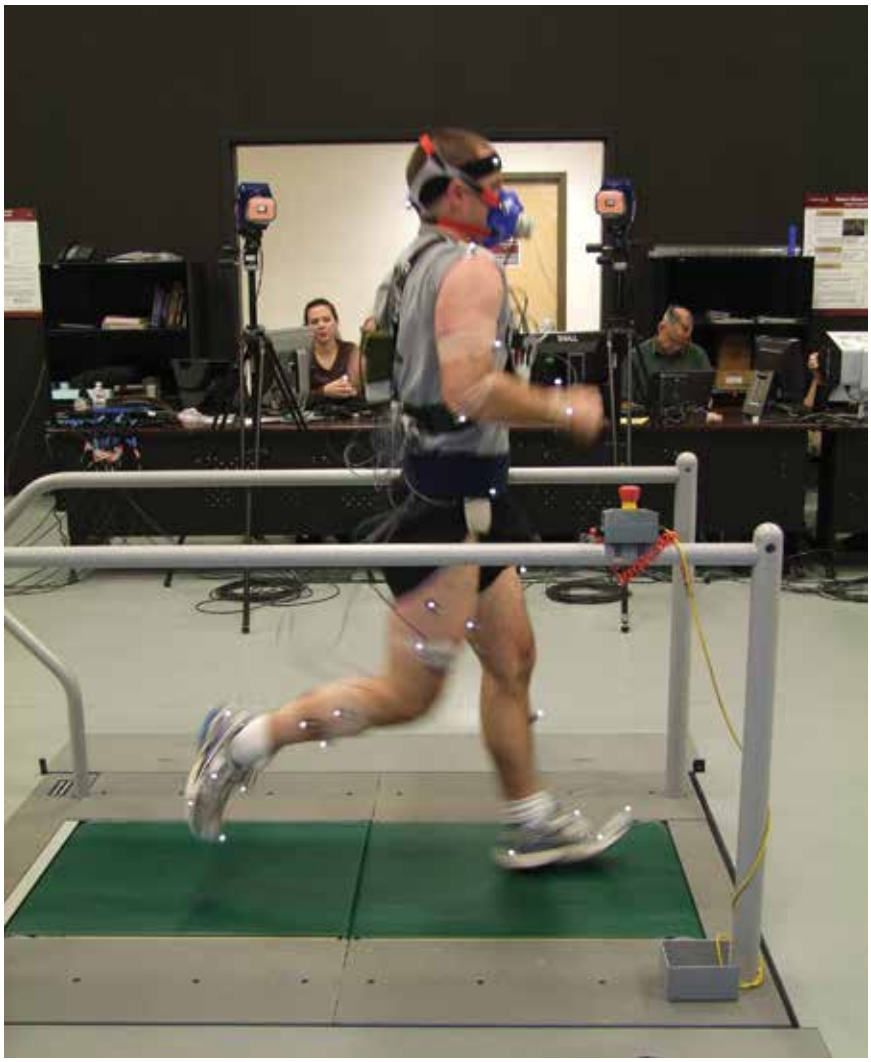
This 15,000 gross square feet Class 10 and 100 cleanroom facility houses a comprehensive set of semiconductor fabrication tools—including specialty material deposition, etch, lithography, and thermal—and research characterization systems for the next generation of sensors and electronic devices for the Soldier.

ARL Facilities

ARL's world-class facilities are staffed by approximately 2,000 employees, more than 1,300 of whom are engineers and scientists, with more than 1,000 of those employees holding advanced degrees. As one of the largest sources of science and technology R&D in the Army, ARL operates a complex network of R&D laboratories, experimental facilities, and computational capabilities. Headquartered in Adelphi, Md., ARL occupies major sites at APG, Md.; Research Triangle Park (RTP), N.C.; and WSMR, N.M. ARL also operates a research element located in Orlando, Fla.

ARL's technical infrastructure must be constantly evaluated and updated to remain relevant and on the leading edge of research and technology. ARL's overarching objective for facilities and equipment is providing access to the right technical infrastructure by the right set of researchers for the development of technologies critical to Soldier capabilities. ARL exploits outside research infrastructure as needed and has established a robust technical-infrastructure upgrade and enhancement program that supports internal research. This program is critical, for without access to the right infrastructure ARL cannot generate solutions for Soldiers' technology needs.

Among the many facilities' upgrades funded during this period were major infrastructural projects for several APG facilities. This included continued upgrades to laboratories supporting human research and renovations to accommodate expanded high-performance computing. In addition, ARL funded several projects at ALC including upgrades for materials and sensors laboratories.



The SPEAR facility enables researchers to study the interactive effects of physical and cognitive stress on Soldier performance in operationally relevant environments.

Soldier Performance and Equipment Advanced Research (SPEAR) Facility

The Soldier Performance and Equipment Advanced Research (SPEAR) facility enables researchers to study the interactive effects of physical and cognitive stress on Soldier performance in operationally relevant environments. The facility includes a state-of-the-art, indoor biomechanics laboratory; an outdoor mobility and portability course; a 2.5-mile cross-county course; and an 802.11 Wi-Fi network. ARL continued to plan for the future with a major update to the SPEAR facility. The updated facility would enhance ARL's capability to perform dismounted Soldier-performance research and be instrumental in developing a multidisciplinary, dismounted mobility and portability program as a core capability within ARL. The new facility would lead directly to an increased understanding of individual and team performance and to tools that improve Soldiers' cognitive awareness and knowledge management in stressful, militarily relevant conditions.

The High Performance Computing Modernization Program (HPCMP) spurred building renovation, since ARL's aging supercomputer facilities needed an upgrade to

support future requirements. By renovating a vacant facility at APG, in FY2012 ARL could stand up a Petascale HPC System, a Petabyte Storage System, and laboratory HPC systems (including HPCMP Dedicated HPC Project Investments) such as the Mobile Network Modeling Institute. ARL also approved SEDD projects for heterogeneous electronics, in both multilayer semiconductor devices and microelectromechanical systems (MEMS) and mixed structures. These initiatives enhanced ARL's heterogeneous electronics capability by establishing an internal electronics capability compatible with commercial microelectronics fabrication, as well as creating a SEDD-wide central packaging facility. Tools were acquired to support the Specialty Electronic Materials and Sensors Cleanroom (SEMASC) research infrastructure in three key areas: metrology, lithography, and thermal processing.

In the area of MEMS and mixed structures, ARL is a world leader in both PiezoMEMS and millimeter-scale robotics. ARL has optimized and explored new PiezoMEMS materials; fully characterized the PiezoMEMS device performance for incorporation of control theory developed from actual biosystems; integrated with other technologies; and rapidly prototyped devices—given the heavy demand on the PiezoMEMS capabilities at the SEMASC research facility. Initial funding was used to acquire new capabilities in automated chemical-solution deposition and automated rapid thermal annealing, and enable PiezoMEMS wafer processing of 150-mm substrates.

Other large construction initiatives during this period were the Electromagnetic Vulnerability Assessment Facility (EMVAF) and a new ARL facility at APG to accommodate the Vehicle Technology Directorate (VTD), which transitioned the remainder of its personnel and facilities from NASA–Langley under the 2005 BRAC legislation.

A ribbon-cutting ceremony for ARL–SLAD's EMVAF was held in 2008 at White Sands Missile Range. It was hosted by the RDECOM's commanding

From left, Maj. Gen. Fred D. Robinson, Jr., RDECOM commander; John Miller, ARL director; Paul Tanenbaum, SLAD director; and Richard Flores, chief, Information and Electronic Protection Division, SLAD, prepare to cut the ribbon at the opening of SLAD's Electromagnetic Vulnerability Assessment Facility.

general, Maj. Gen. Fred D. Robinson, Jr., and ARL Director John Miller. The EMVAF is a state-of-the-art, secure electromagnetic-spectrum-research facility housing two double-shielded anechoic chambers and associated control rooms and laboratory, mechanical, storage, and office space. It is the Army's premier facility for performing controlled measurements of RF and microwave survivability, lethality, and vulnerability of electronic systems. The EMVAF addresses the complete electromagnetic threat being encountered in theater and anticipated for the Future Force. Among its uses are low- and high-power, directed-energy experiments; measuring RF emissions and susceptibilities of electronic systems; and addressing issues related to interoperability, co-site interference, and atypical antennas.

ARL hosted a groundbreaking ceremony in 2009 at Aberdeen Proving Ground for its VTD laboratory for specialized research, development, test, and evaluation. The U.S. Army Corps of Engineers, Baltimore District, initially awarded a $14.8-million contract to Walbridge Aldinger Co., of Detroit to build the 35,930-square-foot building to house VTD's Mechanics divisions relocating from NASA sites in Virginia and Ohio. The move consolidated and streamlined VTD, which already had elements at APG. The fully functional laboratory, including specialized equipment, would enable the directorate to conduct innovative in-house research in robotics, mechanics, propulsion, and vehicle modeling as well as simulation. The building would also include advanced capabilities to research aeromechanics and structures, mechanical systems, and propulsion materials, among other areas.

The Zahl's cornerstone is its "cleanroom." The lab enables basic and applied research and analysis in nanobiotechnologies; flexible electronics; advanced specialty electronics material growth; nonlinear material research and characterization; and power electronics.

A Few of ARL's Current Stand-Out Facilities

Army's World-Class EAR Facility Raises the Bar in Auditory Research

Led by the ARL Fellows, ARL completed the Environment for Auditory Research (EAR) at APG in 2008–2009. EAR's research spaces and capabilities are unmatched at any military, academic, or industrial facility worldwide. This facility addresses the Soldiers' need to hear a wide range of sounds, separate useful signals from background noise, and ensure survival and mission success. The EAR facility is critical to determining both the limits of human hearing and the effects of Soldier equipment on perception of sounds on the battlefield. ARL researchers conduct basic and applied auditory and speech perception research, aiding situational awareness and survivability of ground troops. Research areas include the perception of acoustic signatures produced by military-relevant sound sources, speech communication in adverse environments, effects of mental and physical

workload on the human auditory system's performance, effects of headgear types on detection, and identification and localization of specific acoustic signatures.

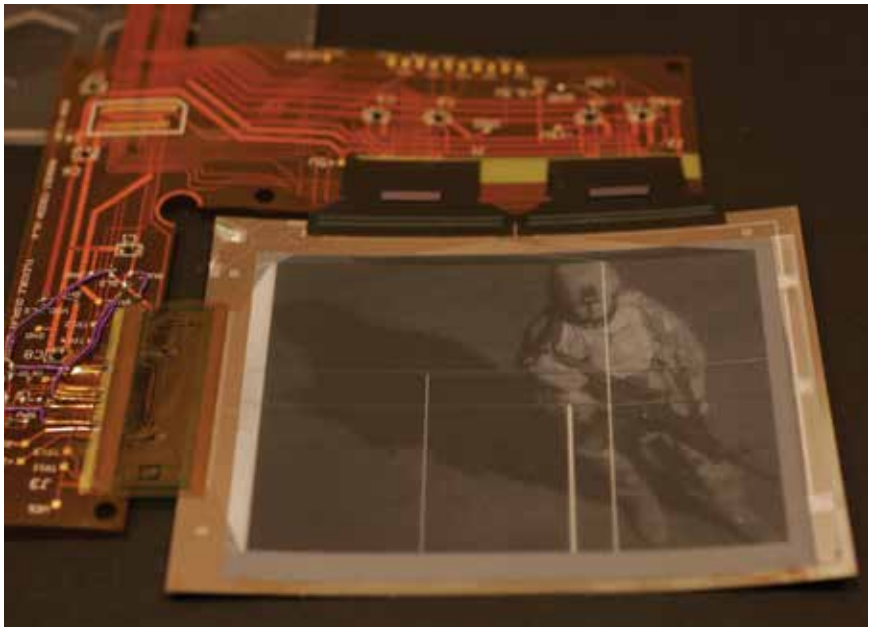
Cognitive Assessment, Simulation, and Engineering Laboratory (CASEL)
APG's CASEL is a stand-alone, behavioral-research facility providing several capabilities to better understand and improve individual and team performance, Soldiers' cognitive readiness, and knowledge management in stressful conditions relevant to the military. The laboratory features a 300°, interactive 3-D virtual-reality system with tetherless simulation that allows construction of unique scenarios to investigate a range of operational environments.

Zahl Physical Sciences Laboratory
The cornerstone of this multidisciplinary building at Adelphi is its "cleanroom" lab. The Zahl houses multiple facilities/labs. The Specialty Electronic Materials and Semiconductor Research Nanofab Center, a cleanroom plus material characterization equipment is highly noteworthy. Another stand-out facility within the Zahl is the Electrochemical Laboratory Suite, which encompasses a world-class Dry Room. The state-of-the-art Zahl building was occupied in 1999–2000.

Flexible Display Center (FDC) Develops Flexible Displays and Electronics
The U.S. Army established the FDC at ASU in 2004 to promote the next revolution in information displays. The center is a partnership where Army, academia, and industry collaborate on rapid technological development, innovation, and integration to create a new generation of innovative displays that will be ultralow power, flexible, lightweight, and rugged and developed with high-yield manufacturing processes. These revolutionary displays will usher in a new era of powerful, real-time information sharing through ubiquitous commercial and military application—everything from portable pocket-held and vehicle-mounted devices to permanent and temporary conferencing–command rooms. In 2011, the FDC and industry partners significantly advanced color displays and processing at Generation II (GEN II). A major advance was incorporating conventional electronics onto plastic via existing electronics manufacturing, enabling the Army to leverage traditional manufacturing paradigms, reduce overall display costs, and enable fabrication of electronics on plastic. To date, teams of FDC researchers have made significant breakthroughs, with more than 50 patents.

As flexible-electronics technology matures, other applications emerge such as flexible MEMS, imaging arrays, and sensor-array elements such as neutron detectors. These longer-term applications will demand higher-performance thin-film transistor (TFT) arrays, novel sensor architecture, and unique manufacturing paradigms—enabling large-area flexible electronics at low costs to meet ever-increasing commercial and military needs.

The objective of the U.S. Army's Flexible Display Center (FDC) is to develop technologies and manufacturing processes that will enable the realization of lightweight, rugged, ultralow-power flexible displays and electronics.



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ARL Organization

During Miller's tenure, ARL was organized into ARO, six directorates, and the Office of the Director. By combining in-house technical expertise with those from academic and industry partners, ARL maximized every dollar invested to provide the best technologies for our Soldiers. ARL applied the extensive research and analytical tools developed in its direct mission program to support ongoing development and acquisition programs in the RDECs, PEOs, PM offices, and industry. Technology and analytical products were moved into RDECs and to other Army, DoD, government, and industry customers.

The U.S. Army Research Office (ARO) mission is to execute an extramural basic-research program in the physical sciences (physics, chemistry, and life sciences), the engineering sciences (mechanical, electrical, materials, and environmental), and the mathematical and information sciences (mathematics, computing, and network sciences). The goal of this research is to provide new technical options for the Army and explore high-risk–high-payoff opportunities. The scope of ARO research is broad and decidedly long range.

The Computational and Information Sciences Directorate (CISD) plays a key role in information sciences and technology research within the Army and the DoD. CISD serves as the principal Army organization for basic and applied research in computational and information sciences to ensure the Soldier's superiority and victory through "Decisive Engagement." CISD creates, exploits, and harvests innovative technologies to enable knowledge superiority for the Soldier through basic and applied research in advanced computing, network and communication sciences, information assurance, and battlefield environments. CISD concentrates on four specific, major research areas: Tactical Communications and Networks; Battlefield Information Processing; Battlefield Weather for Mission Command Networks and Systems; and Computational Science and Engineering. CISD provides the Army with the necessary advances in IT required to achieve the Future Force. Additionally, CISD promotes the use of high-performance computing technologies across ARL directorates, RDECOM RDECs, and the DoD test and evaluation community; critically reviews the current MSRC hardware and software architecture; and develops a strategic plan for the MSRC future.

The Human Research and Engineering Directorate (HRED) has a dual mission:

- conduct a broad-based program of scientific research and technological application directed toward optimizing Soldier performance and Soldier–machine interactions to maximize battlefield effectiveness; and
- provide the Army and ARL with human-factors-integration leadership and MANPRINT support to ensure Soldier-performance requirements are adequately considered in technological development and system design.

HRED ensures that Soldiers can operate effectively on the high-technology battlefield with enhanced survivability in its lethal environment, while reducing their equipment weight and workload. HRED combines the Army's human factors and MANPRINT resources at APG. Extensive research in human perceptual, cognitive, and psychomotor performance builds the framework for human-factors and MANPRINT advances, thus improving the effectiveness of fielded and developmental systems.

The Sensors and Electron Devices Directorate (SEDD) serves as the principal Army organization for R&D in sensors and electron devices technology. This ensures U.S. military superiority and provides the Army with affordable technology for sensing, communications, and threat engagement across the EM spectrum of the battlefield, and in power and energy to provide the Soldier with reliable, affordable, and portable power. SEDD conducts innovative research in four major areas: electro-optic and photonic devices; electronic RF sensing and electronic-device technology; sensors; and power and energy. The objective is to provide the Army with affordable enabling technology in electro-optic smart sensors, multifunction RF, autonomous sensing, power generation and management, and signature management. SEDD focuses on R&D initiatives that contribute to technological advancement in solid-state physics, radiation effects, electrochemistry (including fuel-cell technology and power conversion), high-frequency electronics, photonics, microelectromechanics, wide-band-gap electronic materials, nanoscience, optoelectronics, biodetection, display phosphors, and fabrication-process sciences.

The Survivability/Lethality Analysis Directorate (SLAD) mission is to be the premier source of expertise in survivability, lethality, and vulnerability assessments for senior leaders, developers, and evaluators—helping ensure U.S. personnel and equipment survive and function effectively in hostile circumstances. SLAD's strategic goals are to provide SLV-design trade-off decisions based on solid technical analyses; provide survivability analyses of current and Future Force systems and Soldiers; contribute to winning the information war; develop new methodologies to quantify System-of-Systems (SoS) SLV; identify issues and recommendations on SLV enhancements in concepts and technologies; and leverage activities of other ARL mission areas and RDECs. SLAD focuses on materiel-acquisition programs, including Soldier survivability assessments and support for the Army's SLV-analysis program requirements. Both DoD and the Army recognize that the survivability and lethality of U.S. systems and Soldiers are critical to the success of the Army, and SLAD is the only source within the Army that meets DoD's regulatory requirement for a fully integrated analysis of survivability and lethality across all threats. The directorate performs information operations, vulnerability assessments, electronic-warfare investigations, and survivability analyses, thereby reducing the overall

ARL Director John Miller stands with the 2009 ARL Summer Student Research Symposium presenters, their mentors, and the ARL Fellows following the awards ceremony.

Each summer, an influx of fresh talent arrives at ARL. For three months, they work closely with mentors to produce research that will benefit the Army and broaden their own educational horizons.

In 2008, an exciting new program was initiated to help these students better channel their intellectual capacities. Through the Summer Student Research Symposium, each ARL summer student writes a paper describing his or her work and the results of their research. Papers highlight both educational and scientific aspects of the student's ARL experience and demonstrate to ARL the progress made during the summer. The program was developed by the ARL Fellows after Director John Miller identified a need to better coordinate the work of summer students at ARL. The symposium is designed to provide summer students with a more focused summer experience. Each student gets an individual mentor from ARL who provides technical guidance, but the papers are completely written by the individual students. Students also make a seminar presentation to scientists and engineers of their respective directorates.

In addition, the end of each summer features a competition that allows students to present their work to the ARL community. Each directorate selects the top undergraduate and graduate students (plus an alternate) to compete in the symposium, where the selected students give their presentations to the ARL workforce. The top three presentations are awarded the ARL Student Summer Research awards, Gold, Silver and Bronze. All summer students receive a Certificate of Appreciation for their participation in the program. Each mentor also receives a certificate from the ARL Director.

The 2014 Summer Student Research Symposium presenters showcased their research findings, with winners awarded cash prizes during the awards ceremony held Aug. 7 at the ARL Conference Center, Aberdeen Proving Ground, Md.

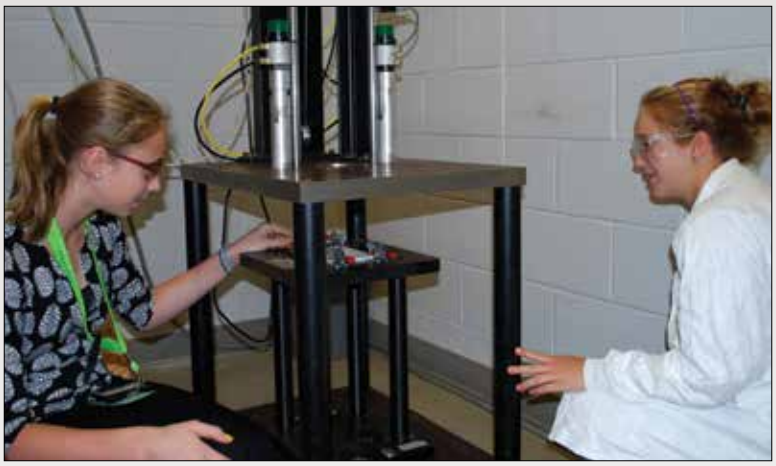
A GEMS student participates in a rocket demonstration at ARL's White Sands Missile Range location.

For the past few years, ARL has had significant involvement in a program that allows young students to perform experiments and learn scientific principles under the supervision of Army scientists. Through the Gains in the Education of Mathematics and Science (GEMS) program, students are given the opportunity to explore new interests in science and math through unique hands-on laboratory experiences at ARL. Younger junior and senior high-school students perform short experiments illustrating basic scientific principles while being guided by senior high-school and college students. They are assisted by a full-time program administrator and a resident teacher for the summer.

At APG and ALC, students from several Maryland counties, as well as from seven different states, work under the direction of ARL scientists. The Army program is designed so that successful students may return in future summers to do even more sophisticated research. Scientists, in conjunction with their college assistants, design age-appropriate research protocols.

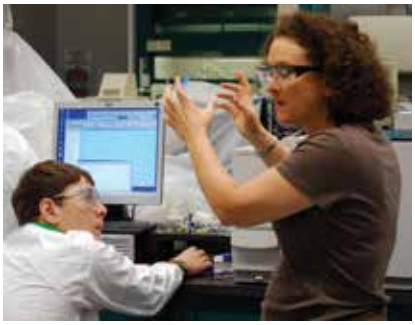
Program directors and GEMS leaders also offer help to students with respect to guiding/working with parents, raising teacher expectations, aiding in SAT Reasoning Test preparation, and providing information for financial-aid resources for a variety of educational services and tips for the college-application process. The program is divided into four one-week segments from late June through early August.

Students evaluate impact samples as part of the Aberdeen Proving Ground GEMS program. Participation in the program allows students to gain hands-on education that they may not receive in a traditional classroom setting.



cost by identifying vulnerabilities and solutions early in the design phase. Research generated by SLAD supports assessments for major military milestone decisions. SLAD also investigates new technologies that could radically change the way combat simulations and war games use key data to evaluate the survivability of the Future Force. It provides the ultrarealistic portrayal of damage within Army simulations to support training, mission rehearsal, and development of battlefield tactics.

The Vehicle Technology Directorate (VTD) is the principal Army organization responsible for the pursuit of mobility-related science and technologies leading to advanced capabilities and improved reliability for Army air and ground vehicles. Located at APG, VTD conducts innovative research in robotics, mechanics, propulsion, and vehicle modeling and simulation. VTD's research areas include aerodynamics, flight controls, propulsions, structures, and transmission technologies. VTD also manages the ARL Robotics Collaborative Technology Alliance, which develops perceptual and intelligent control technologies—so robotic vehicles can "understand" their environment and autonomously plan, execute, and monitor tasks—and human–machine interfaces that allow Soldiers to effectively task robotic systems and minimize operator workload.



Students use a spectrometer to analyze the ingredients in gum. The GEMS program targets students in middle school and high school.

The Weapons and Materials Research Directorate (WMRD) mission is to assure dominance on the future battlefield by providing the science and technology that make the individual Soldier and the Army's future weapons systems more lethal, survivable, and strategically deployable. WMRD provides the Army with technology that is essential to the Soldier and to future lightweight platforms. WMRD offers responsive solutions and enabling technologies for a more lethal and survivable land force. WMRD strives to understand the fundamental aspects of chemistry and microstructure that influence the performance and failure mechanisms of advanced materials such as ceramics, advanced polymer composites, advanced metals, and multifunctional materials. Coupling theoretical and experimental studies with advanced high-performance computing and state-of-the-art experimental facilities, WMRD focuses applied research on future combat vehicles' protection, integrated personnel protection, advanced lethality concepts, smart weapons and munitions, weapons for the light forces, and advanced materials for armor and armament.

Outreach Efforts

Because ARL leadership understood that excellence in discovery and innovation in science and engineering are the direct results of a well-educated workforce, the need for expanded and more efficient outreach efforts became increasingly apparent during the first decade of the 21st century. ARL was poised to intervene in helping educate science and engineering (S&E) students from all demographic groups but especially those historically underrepresented in S&E careers. With these national concerns and challenges in mind, ARL leaders made a corporate commitment to help develop the next generation of Army scientists and engineers by establishing an Outreach Program (OP) Office. The OP was expressly designed to address the projected shortfall of scientists and engineers among diverse populations of the 21st century; leverage technical capabilities of academia (including HBCU/MIs); fulfill ARL requirements; and expand the involvement of HBCU/MIs in ARL's ongoing research. The objective of the OP Office is to develop and execute programs that provide learning and teaching aids, incentives, and rewards for students and teachers while ensuring opportunities for socially and economically disadvantaged students.

Key programs were eCybermission, the Science Fair for the Nation; For Inspiration and Recognition of Science and Technology (FIRST); Gains in the Education of Mathematics and Science (GEMS); and the Junior Science and Humanities Symposium (JSHS). In 2007 ARL held its first Summer Student Research Symposium, providing undergraduate- and graduate-level students interning at ARL the opportunity to each prepare a technical report summarizing the major activity they carried out. Student reports were presented to directorate judging panels that selected students to compete at the corporate level during the symposium. The event enables students to showcase their work in ARL S&E programs.

Gains in the Education of Mathematics and Science (GEMS) program students learn some meteorology basics during the 2010 summer GEMS program at the Adelphi Laboratory Center, Md.

Support to Soldiers in the Field

ARL is very active in working with RDECOM and Army partners to provide technical expertise and assistance in support of ongoing operations. ARL mission investments over time are bearing fruit as technologies are spun off for applications to current force-capability gaps and requirements. ARL provides a full spectrum of support that includes the development of technological solutions to current force issues; providing technical field assistance for fielded equipment; training troops to use the fielded prototypes; and analytical support.

ARL has aggressively pursued solutions to support current operations through the ARL Director's Quick Reaction Initiative (QRI) program, responding to needs identified through the Rapid Equipping Force (REF) and Field Assistance in Science and Technology (FAST) programs, and through the RDECOM Current Operations Integrated Product Team. The goal of the QRI program is to develop and demonstrate technologies that can solve current force problems and be put into the hands of the troops in a very short time.

Among the many key contributions ARL has made to U.S. armed forces (including legacy technologies built on advances developed by ARL predecessor organizations) are the following:

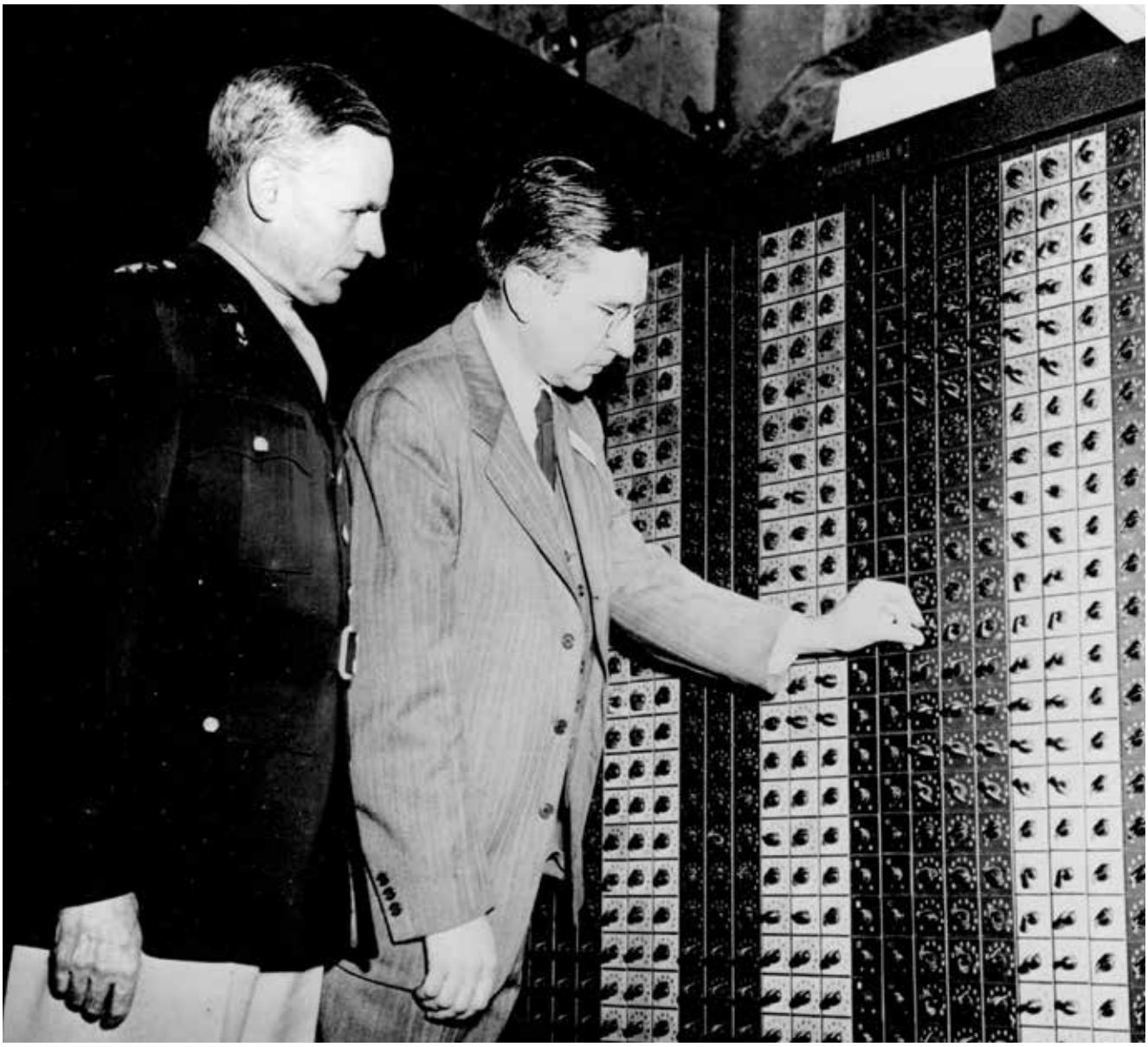
Proximity Fuze—During World War II, a new type of fuze for bombs, rockets, and mortars was developed by a group at NBS under the leadership of Harry Diamond. The fuze allowed gunners to cause a munition to detonate during a close encounter with an air target or at a chosen height above the ground. Later the War Department recognized Harry Diamond's proximity fuze as "one of the outstanding scientific developments of World War II ... second (in military importance) only to the atomic bomb."

During World War II the proximity fuze was recognized by the War department as "one of the outstanding scientific developments of World War II ... second (in military importance) only to the atomic bomb."

Electronic Numerical Integrator and Computer (ENIAC)—The forerunner of today's digital computers, ENIAC was developed and built in 1946 through a joint venture between the Army and the University of Pennsylvania. The Army's BRL—later one of the seven Army corporate laboratories organized under LABCOM before the creation of ARL—worked with the university to use ENIAC at first to calculate artillery firing tables. A year after its operation began, in 1947 ENIAC was transferred to APG, where it was used for scientific modeling until October 1955.

Method for Semiconductor Construction and Miniaturizing Circuits—In 1959 ARL's predecessor HDL patented one of the seminal methods for creating solid-state circuits, or semiconductors—today known as microchips. The inventors used photographic techniques to fabricate transistors and coined the term "photolithography" to describe the process. Engineers miniaturized the transistor and embedded it in semiconductor material. The invention had an enormous impact far beyond military applications, and went on to revolutionize the entire electronics industry.

BRLESC—Designed as the third computer to succeed the groundbreaking ENIAC, the Ballistic Research Laboratories' Electronic Scientific Computer (BRLESC) was a large-scale, highspeed digital computer built by the engineers, scientists, and technicians of the computing lab at ARL's predecessor organization. The next in line after the EDVAC (Electronic Discrete Variable Automatic Computer) and ORDVAC (Ordnance Discrete Variable Automatic Computer) computers, BRLSEC was developed primarily for scientific and military tasks requiring high precision, such as ballistics and Army logistical problems and weapons systems' evaluations. When it went into operation in 1961 it was the world's fastest computer—two to eight times faster than commercial systems of its time.



In 1946 a joint venture between the Army and the University of Pennsylvania developed and built ENIAC, the progenitor of today's digital computers.

Army Artificial Heart Pump—In the early 1960s ARL's predecessor organization HDL, in cooperation with Walter Reed Army Institute of Research (WRAIR), developed a group of life-support equipment for sick and wounded Soldiers. By employing the concepts of fluidics discovered at ARL, the Army artificial heart pump used a fluid amplifier to control the gases squeezing the heart's ventricle, with a design that eliminated electronics, and minimized moving parts, weight, size, and production costs. It could be synchronized with the heart's electrical action potentials and used to augment failing hearts and circulations. The pump demonstrated very low hemolysis, enabling long-term perfusion of living circulation. The blood pump was a significant advance over previous devices used in heart surgery. In addition, it demonstrated the value of fluidics and paved the way for later medical devices that today incorporate fluidics technology.

Army Volume-Cycled Respirator—In the early 1960s the Army Volume-Cycled Respirator was a versatile unit capable of cycling a set volume

It never has been easy to risk precious time and funding on emerging or alternative technologies that might—or might *not*—pay off in the long term. In 1993, however, the Director of ARL formally encouraged "out of the box" thinking that might lead to battlefield-relevant breakthroughs. The Director's Research Initiative (DRI) supported innovative and possibly high-risk research ideas that potentially could advance mission needs significantly beyond conventional expectations.

The DRI played a similar role as the In-Laboratory Independent Research Program funded by the Assistant Secretary of the Army for Acquisition, Logistics and Technology, for which ARL had been ineligible due to Army policy changes. Proposals submitted in the DRI program were ranked according to degree of innovation and risk balanced by soundness of scientific approach. Proposals could be either for basic or applied research and new or sufficiently novel work. They had to be consistent with the ARL mission and exclusively or primarily in-house. ARL scientists and engineers were encouraged to submit proposals that addressed an Army problem with a scope and budget for one year—renewable for three years if the proposal was successful.

In 2016, the multifaceted Director's Research Awards (DIRA) program replaced DRI. Section 219 funds support DRI as well as the Director's Strategic Initiatives (DSI: a separate program for cross-disciplinary basic and applied research). Within DIRA are three categories of award:

- The ARL Early Career Award (DIRA-ECA), which is for a government scientist or engineer who 1) demonstrates exceptional scientific or technical excellence (or both) during his or her ARL employment and 2) is fewer than five years removed from the last academic degree or postdoctoral research associateship.
- The ARL External Collaboration Initiative (DIRA-ECI), which supports ARL principal investigators (PIs) in new innovative research in collaboration with external partners.
- The Director's Transformative Research Challenge (DIRA-TRC), which provides quarterly opportunities for seedling funding of high-risk, highly innovative efforts with transformative potential. Moreover, DIRA-TRC researchers who achieve exceptional results may be invited to submit a Full Proposal that expands upon the seedling initiative.

of air to a patient's lungs, as well as being able to breathe with or for a patient. Controlled through flueric amplifiers, it had a highly adjustable breathing pattern, could be pressure cycled, and was highly reliable for prolonged use. Models were evaluated and used in Vietnam while evaluation continued at WRAIR.

Army Heart Monitor—As part of the group of life-support equipment developed in the early 1960s by HDL, in cooperation with Walter Reed Army Institute of Research (WRAIR), the Army Heart Monitor monitored the electrocardiogram and sounded an alarm when certain cardiac states were reached, providing rapid warning for medical staff to perform resuscitation. In addition to sounding an alarm when high and low rate measurements occurred, the device recognized cardiac arrest and ventricular fibrillation. The monitor was portable, battery operated, and designed to fulfill the need for electrocardiogram information in situations where oscilloscopes and paper writers (the technology of that time) were not available or feasible to use. The monitors were evaluated and used at WRAIR, as well as in Vietnam.

IR Detector Materials—Infrared detectors and sensors are incorporated over a wide variety of platforms, even down to the individual Soldier's infrared-imaging Thermal Weapon Sight. ARL and CERDEC are the main driving force behind the Army's R&D of infrared technology. Imaging night-vision technology

grew from its early days in the late 1960s with primitive image-intensifier tubes that enhanced existing light from the moon and stars—such as with the Vietnam-era "Starlight" rifle scopes—to the development in recent years of megapixel focal-plane arrays capable of imaging thermal radiation with enough resolution to identify potential targets in complete darkness many kilometers away.

Automatic Step and Repeat Camera—In 1961 the process used by industry to make silicon integrated circuits involved making stepped and repeated photomasks. The step and repeat camera used in this process underwent rapid development and commercial version for manufacturing. In 1968, ARL's predecessor organization HDL tasked engineers to significantly improve this device and they built the first-in-the-world Automatic Step and Repeat Camera. Once this technology was introduced to manufacturers, the manufacturing process changed tremendously. The invention enabled greater throughput in manufacturing and also reduced the costs of manufacturing integrated circuits. Today the Automatic Step and Repeat Camera is considered the workhorse of the integrated circuit industry.

Integrated Printed Circuit Board—ARL was a leader in the development of integrated circuits. They are used in almost all electronic equipment in use today and have revolutionized the world of electronics.

Kevlar Military Applications—In the 1970s when DuPont developed a high-strength aramid fiber called Kevlar for tire-cord applications, ARL's predecessor organization HDL recognized the fiber's potential. ARL, together with the U.S. Army Natick Soldier RDE Center, combined the best fiber configuration with the best resin for applications in armor protection. Many innovations resulted, including Kevlar spall liners for the M113 Armored Personnel Carrier and Bradley Fighting vehicles, combat helmets, and ballistic vests. DuPont transitioned the technology into the private sector with soft body armor for police officers.

Special Armor for M1 Abrams Tank—Equipped with armor developed by ARL, not one hull was penetrated by enemy fire during Operation Desert Storm. Since it was fielded in 1980, the M1 Abrams tank has been deployed by PEO Ground Combat Systems (GCS) in modified and improved versions as the M1A1 and the M1A2, incorporating further armor, protection, and electronics upgrades as the vehicle is modernized.

Operation Bird Borne—In the early 1980s, Army scientists at Edgewood Arsenal, Md., (today part of APG) developed and fielded the smallest (140 grams) satellite-tracked and globally positioned transmitter equipment with environmental sensors. Operation Bird Borne tracked bald eagles fitted with the transmitter and determined essential habitats for the conservation of what was then an endangered species. The transmitter used some of the most sophisticated globally positioned electronics available at that time. Much of the technology found a home with the intelligence community and other government agencies.

Magnetic Resonance Imaging—In the 1980s Army researchers, working with New York University's medical center, laid the foundation for the development of a new MRI system. This system was more economical and transportable than previous systems of its day due to advances in high-energy magnetic cavity design made possible by Army science.

Air-Land Battlefield Environment (ALBE)—In development from 1984 to 1990, the ALBE program developed, evaluated, and demonstrated the first Tactical Decision Aid (TDA) software and products capable of integrating weather and terrain in the prediction of battlefield environment effects on operations.

High-Power Microwave Devices—Before the 1990s the armed forces' traditional method of defeating incoming missiles was to fire an air-defense projectile or missile to intercept it. ARL's predecessor organization HDL proposed using RF directed energy as a nontraditional solution to defeat incoming rounds. In 1991, responding to an immediate

need during Desert Storm, the Short Stop AN/VLQ-9 program was fielded in only five months. Operating on the battlefield as an RF proximity fuze–electronic countermeasure system, the Short Stop system prematurely detonated incoming artillery and mortar rounds. It countered the threat of RF proximity-fuzed munitions by causing them to detonate before reaching intended targets, while protecting friendly ground troops, vehicles, structures, and other equipment under fire. The system could reduce casualties to group troops by as much as 50 percent during the initial stages of an enemy attack. ARL coordinated the interagency push to develop the technology quickly, working with Army, Navy, Air Force, DARPA, DNA, and three Department of Energy (DOE) laboratories: Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Sandia National Laboratories.

Family of Abrams Kinetic-Energy Tank Ammunition—ARL improvements in advanced composite-sabot materials, novel penetrator designs, new propellants, and 3-D computational-mechanics analysis greatly increased the lethality of the M829A3 tank round (produced and fielded in 2002). The forerunner of this tank ammunition was the M829A1 "Silver Bullet" used so successfully in the Gulf War. An improved version of the line-of-sight kinetic-energy cartridge, the M829A4, is intended to provide enhanced lethality beyond the M829A3 tank round.

Artificial Intelligence Module Test Bed (AIMTB) and Hawkeye—In 1992 the Artificial Intelligence Module Test Bed (AIMTB) was a program sponsored by the U.S. Army Intelligence Center and School (USAICS). The AIMTB was a custom-configured shelter mounted on an HMMWV and containing the Hawkeye processor. The system was ultimately fielded to Southwest Asia after five test-bed systems were successfully demonstrated in Germany to operational units. The program aimed to provide timely and accurate intelligence support to battlefield commanders, using the Module that contained functional application software to support analysts on the battlefield by processing intelligence information. ARL's predecessor organization HDL had 18 months to develop hardware and design, fabricate, and support four complete shelter-based systems. Very complex, state-of-the-art processing technology was incorporated into the AIMTB. Its architecture was designed around the Versa Modular Eurocard (VMEbus) "open architecture" electronic and mechanical standards which gave designers a wide choice in the selection of high-performance components. In field usage, the AIMTB-bearing HMMWV was backed into, and became an integral part of, the battlefield command post. Essentially a message epicenter, the AIMTB received battlefield intelligence messages, processed information, and then translated it into sophisticated graphics and analysis tools. As a result the commander on the battlefield had improved situational awareness. The AIMTB was fielded to Southwest Asia, and was seen as meeting a critical need in theater.

RF-Insensitive Electric Primers—In 1992 ARL, working with the Navy, developed and patented an RF-insensitive system, designed as an ignition element for insertion into the primers of the Phalanx Close-in Weapons System (CIWS). All Navy combatant ships throughout the fleet are equipped with one or more Phalanx CIWS, typically situated on the ship's weather deck. The high level of RF radiation on Navy ships' weather decks was sufficient to accidentally detonate the Phalanx CIWS ammunition rounds while they were being transported or handled. For that reason Navy ships shut down their radars and communications systems to reduce emissions of RF radiation while the Phalanx CIWS was being loaded with ammunition, and literally went dark during those periods. Navy leaders feared that in wartime enemy ships would recognize this vulnerability and wait for these occasions to strike. ARL solved this problem with the new electric igniter system. The technology created tremendous safety improvements for Navy

The Phalanx Close-in Weapons System fires during a sinking exercise aboard the guided missile cruiser USS Gettysburg (CG 64) in the Atlantic Ocean Oct. 26, 2010. (U.S. Navy photo by Mass Communication Specialist Seaman Kevin J. Steinberg/Released)

combatant vessels, and solved the Navy's worst Hazards of Electromagnetic Radiation to Ordnance (HERO) problem.

Biological Integrated Detection System (BIDS)—Developed at Edgewood Arsenal, Md., (today part of APG) BIDS is a dedicated vehicle equipped with a biological detection suite for detecting large-area biological attacks. The prototype, completed in 1993, was the Army's first interim biological detection system. It was a jointly developed venture among the services, with the Army in the lead. The final version provided a fully automated, broad-spectrum biological detection and identification capability.

Semiconductor Slapper Chip—In 1994 ARL developed and patented an advanced microsized slapper detonator for the Air Force. This technology also enabled Soldiers to more safely carry plastic explosives that could be detonated by this device. The device was very small and extremely insensitive to shock or heat, making it very difficult to activate except by choice, and posed no physical threat to individuals carrying or working with them. Previously Soldiers were in danger when carrying particular types of explosives that could be easily detonated by accident, shock, or heat. The microsized slapper represented a significant advance for the Soldier's safety and provided increased options for carrying explosives.

Atmospheric Decision Aids—ARL's work with atmospheric decision-support applications has led to development of technology designed to increase mission-success rates, reduce friendly forces losses, and allow more efficient employment of systems and personnel. The applications designed and implemented by ARL include 1) My Weather Impacts Decision Aid (MyWIDA), an updated version of the Integrated Weather Effects Decision Aid the Army fielded in 1995; 2) Automated Impacts Routing (AIR) application for routing through adverse weather; and 3) mobile weather technology contained in multiple apps for handheld devices, smart phones and tablets.

Research at ARL on weather's effects on battlefield operations, focusing on adverse weather and path optimization to avoid it, has led to predictive data systems that aid in strategic routing.

The Agentase Nerve Agent Sensors technology won the Army's Greatest Invention Award in 2003.

Agentase Chemical Agent Detector Kit—ARL research supported the development of the Agentase Chemical Agent Detector Kit and the Chemical Agent Disclosure (CAD) spray technologies with colorimetric sensors for nerve, blood, blister, and other agents of interest. The Agentase kit uses enzyme-detection technology combined with light-emitting chemistry for detection. In 2003 the Agentase Nerve Agent Sensors technology won the Army's Greatest Invention Award.

Combat Trauma Patient Simulation (CTPS)—CTPS trained Army medical personnel—from combat medics to providers in field hospitals—on most tasks related to battlefield injuries. The significance of CTPS as an Army research program was that it led to development of a medical prototype training system that laid the foundation for the Army's Medical Simulation Training Centers. CTPS also defined numerous technology gaps that continue to drive medical-simulation and training-research efforts.

Infrasonic Sensing Array—This technology supports the Army's 501st Military Intelligence (MI) Brigade in South Korea and was fielded in 2001. In 2004 it was fielded to Iraq and Afghanistan. Infrasound is acoustics at inaudible frequencies (< 20 Hz). Infrasonic-sensing arrays can detect artillery, missiles, helicopters, blasting, and perhaps even tunneling at long ranges. Fusing information from an array with information from other intelligence-collection sources helps paint a clearer picture for military leaders. ARL continues to monitor, sustain, and upgrade existing infrasonic arrays in various parts of the world and responds to requests from the MI community for new sites and locations. Today, infrasonic-sensing arrays remain operational with the 501st MI Brigade in South Korea.

Armor Survivability Kit for the High Mobility Multipurpose Wheeled Vehicle—ARL produced the prototype Armor Survivability Kit (ASK) for the M998 HMMWV in 2003, using rolled, homogenous armor steel and ballistic glass to provide an up-armored solution with maximum balanced protection against small-arms projectiles and fragments from improvised explosive devices (IEDs). The ASK gave Soldiers in combat immediate needed protection before the M1114 HMMWV was fielded in 2004, with ballistic-resistant windows, added steel plating against IEDs, and almost 2,000 pounds of steel plating for improved protection.

Mine Resistant Ambush Protected (MRAP) Vehicles—ARL and Aberdeen Test Center teams developed aggressive weight-reduction goals for better and lighter protection from IEDs. A partnership between RDECOM

and the MRAP Joint Program Office (JPO) spurred RDECOM to accelerate development of IED protective technology and JPO to redirect original equipment manufacturers to add vehicle-payload capacity. The program's technical approach scaled known technologies for defeat of IED threats, then introduced lightweight composites, new materials, and enhanced ballistic mechanisms to reduce the add-on weight of final armor packages. A one-year MRAP Armor Weight Reduction Spiral (MAWRS) program resulted in armor technologies 40 percent lighter, with technologies fielded on more than 10,000 MRAP vehicles. Dozens of spin-out designs were provided to almost every major combat and tactical wheeled-vehicle program in production. Currently, as PMs have rolled out improvements to these vehicles, ARL has worked closely with them to assess their ballistic performance.

IED Countermeasure Equipment—The IED Countermeasure Equipment (ICE) was a radio-controlled IED countermeasure fully comprising commercial-off-the-shelf technology. The Army's IED task force identified ICE as a preventative solution to IED casualties and vetted the system through its confirmation process. ICE was fielded in 2004 and used through 2007. Today the ICE technology is now integrated into other analysis assets to create dynamic electronic-warfare environments.

ARL's research and development of new armors is providing increased protection for the family of Mine Resistant Ambush Protected (MRAP) vehicles.

Persistent Threat Detection System (PTDS) with Airborne Acoustics—ARL successfully developed and then mounted to an aerostat (a tethered, lighter-than-air craft) an acoustic-sensor array that detects, locates, and cues a collocated imager to transient sounds, such as enemy mortar, rocket launches, and IED attacks, and calculates the ground location of the threat source. Adding this unique airborne detection–localization–cueing capability provides more accurate intelligence. PTDS was first deployed in 2004. The Unattended Transient Acoustic MASINT Sensor (UTAMS), developed by ARL, was and still remains the primary cueing sensor for this platform. ARL later deployed the Aerostat-Mounted UTAMS System (AMUS). This system was designed to provide acoustic event detection at extended ranges. The elevation of the sensor payload on the aerostat provided enhanced detection with the capability to detect straight-line propagation of acoustic signatures versus detection at the ground level, which is prone to interference. The first AMUS was fielded in August 2009 for an operational assessment on a PTDS aerostat located at Forward Operating Base (FOB) "Site C" in Afghanistan. Nine AMUS systems were transitioned to Program Manager Robotics

PTDS aerostat provides acoustic event detection with UTAMS payload mounted on the underside of the balloon.

and Unmanned Systems (PM RUS) for installation onto existing PTDS aerostats in OEF and OIF.

Fido XT Explosives Detector—The Fido XT explosives detector is a lightweight (less than three pounds) integrated explosives-detection system based on a sensitive amplifying fluorescent polymer. Fido XT can be used by Warfighters in many modes, including handheld either through direct detection or as a tethered sensor, mounted on a robotic platform such as unmanned ground or aerial vehicles, or on underwater autonomous vehicles. Fido XT's explosive-vapor sensing can detect explosives at femtogram levels, comparable in field tests to bomb-sniffing dogs—the historical "gold standard" for finding concealed explosives. Fido XT fielded to the Army in 2005.

Current Force Unattended Ground Sensors (UGS)—ARL developed unattended ground-sensor technologies for detection and tracking of personnel and vehicles for perimeter defense and border-monitoring applications. In 2005 the OmniSense system was commercialized and fielded. Subsequently ARL integrated OmniSense, Northrop Grumman Scorpion, and Harris RF systems Silent Watch sensors into a common PED (Processing, Exploitation and Dissemination) environment. This was fielded by Program Manager Robotics and Unmanned Sensors (PM RUS) as the Current Force UGS program for U.S. Central Command (CENTCOM) and operated by U.S. Army Intelligence and

As a Quick Reaction Capability (QRC) for ground-sensor technology for border and perimeter defense, OmniSense (pictured above), Scorpion, and Silent Watch were rapidly fielded to Soldiers by PM RUS for CENTCOM.

The Fido XT system's explosive-vapor sensing is capable of detecting explosives at minute particle levels, comparable in field tests to bomb-sniffing dogs, the historical "gold standard" for finding concealed explosives.

Robert Dumais of WSMR's Atmospheric Modeling Application Branch demonstrating the 3-D gridded analysis of the current weather and the 3-D short-range gridded prediction counterpart provided by the Weather Running Estimate–Nowcast (WRE–N) program.

Security Command (INSCOM). In 2008 ARL procured and integrated additional imaging capabilities under the Intelligence, Surveillance, and Reconnaissance (ISR) Surge program.

Weather Running Estimate–Nowcast (WRE–N)—ARL has developed methods to rapidly create and update local weather forecasts for battlefield applications including target-area analyses and forecasts; defenses against radiological, chemical, and biological weapons; and detailed route planning for manned and unmanned aircraft. The WRE–N is an important tool for providing necessary high-resolution mesoscale atmospheric-input data for meteorologist's use of atmospheric decision aids. A version of WRE–N based on objective analysis and time-extrapolation methods is currently fielded. In recent years a more sophisticated physics-based version of WRE–N using a full numerical weather-prediction model (called WRF), including an atmospheric-data-assimilation system, has been under steady development, testing, and refinement. This version is anticipated to become the next-generation fielded WRE–N iteration in the near future.

Rhino II Counter-IED—At the request of then-Brigadier General Votel (Joint IED Task Force), ARL evaluated a Soldier improvised counter-IED system, nicknamed Rhino. ARL quickly improved the electrical and mechanical components of the system and conducted extensive field testing for effectiveness and durability. Within 90 days of the original request, ARL produced 200 improved "Rhino II" systems in house and shipped these to Task Force Troy in Iraq. Due to the success of the ARL-developed Rhino II Counter IED system, the newly formed Rapid Equipping Force (REF) tasked ARL with integrating Rhino onto eight additional tactical vehicles, including the: RG31, Stryker, M915, Heavy Equipment Transporter, M1078 Family of Medium Tactical Vehicles, M1117 Armored Security Vehicle, Joint EOD Rapid Response Vehicle (JERRV), and Medium Tactical Vehicle

The Rhino II Counter-IED system has been implemented on more than 20,000 Army vehicles in Southwest Asia.

Replacement. ARL enlisted Letterkenny Army Depot (LEAD) to mass produce the Rhino II systems, then transitioned the Rhino II program to Program Manager Counter Explosive Hazard (PM CEH). Together ARL, LEAD, and PM Combat Explosive Hazards implemented Rhino II on more than 20,000 Army vehicles in Southwest Asia.

Tactical Questioning Trainer—Between 2006 and 2011, this state-of-the-art, interactive virtual environment was developed using photorealistic virtual humans with advanced speech recognition allowing Soldiers to practice and refine skills related to human intelligence gathering. Incorporating this technology into the PEO for Simulation, Training and Instrumentation (STRI) Intelligence Electronic Warfare Tactical Proficiency Trainer (IEWTPT) resulted in a savings of $34 million in software-development costs. Currently, virtual-human technology continues to advance and has been incorporated into other applications focused on the training and development of cultural and social-interaction skills associated with counter insurgency, stability operations, and leader development.

'Blow Torch'—The vehicle-mounted RF–directed-energy system was designed to prematurely detonate IEDs at operational speeds. Detonating the charge at a safe stand-off distance caused minimal damage to vehicles and, most importantly, Soldiers. The JIEDDO and the Rapid Equipping Force fielded several Blow Torch systems to deployed forces in 2006. The system was used in route-clearance and convoy-protection roles.

M1114 HMMWV Interim Fragment (Frag) Kit 5—The Interim Frag Kit 5 was fielded as an expedient ballistic improvement for the M1114 HMMWV in April 2006. The evolving ballistic threats encountered in theater had exceeded the design limits of the baseline M1114. A prototype door solution with fabrication and mounting instructions was provided within one week, with automotive testing and safety certification following shortly after. A few years later, as threat levels increased, the Fragment Kit 6 was developed.

Constant Hawk—Constant Hawk (CH) is a surveillance capability that leverages an electro-optical payload to collect high resolution day/night imagery intelligence over areas of interest. This capability offers a unique combination of coverage and high spatial resolution required to detect and characterize events of interest along with their relevant tactical context. Typically, a CH system maintains surveillance for a period of time while building a history of activity. CH was the first operational persistent, wide-area surveillance forensic tracking capability. ARL developed the technology to meet an urgent need, and in 2006 fielded the capability with INSCOM. Eventually five aircraft were added before the program was decommissioned in September 2011. The CH systems operated continuously since initial deployment and served as the basis for CH-Afghanistan, which

Constant Hawk with camera area toward rear of plane.

used the same technology with a different air platform. More than 3,000 analysis products were generated in Iraq alone by CH surveillance. The program transitioned to PM ACS in August 2007, but ARL continued to manage the program for the PM until it was retrograded in 2011.

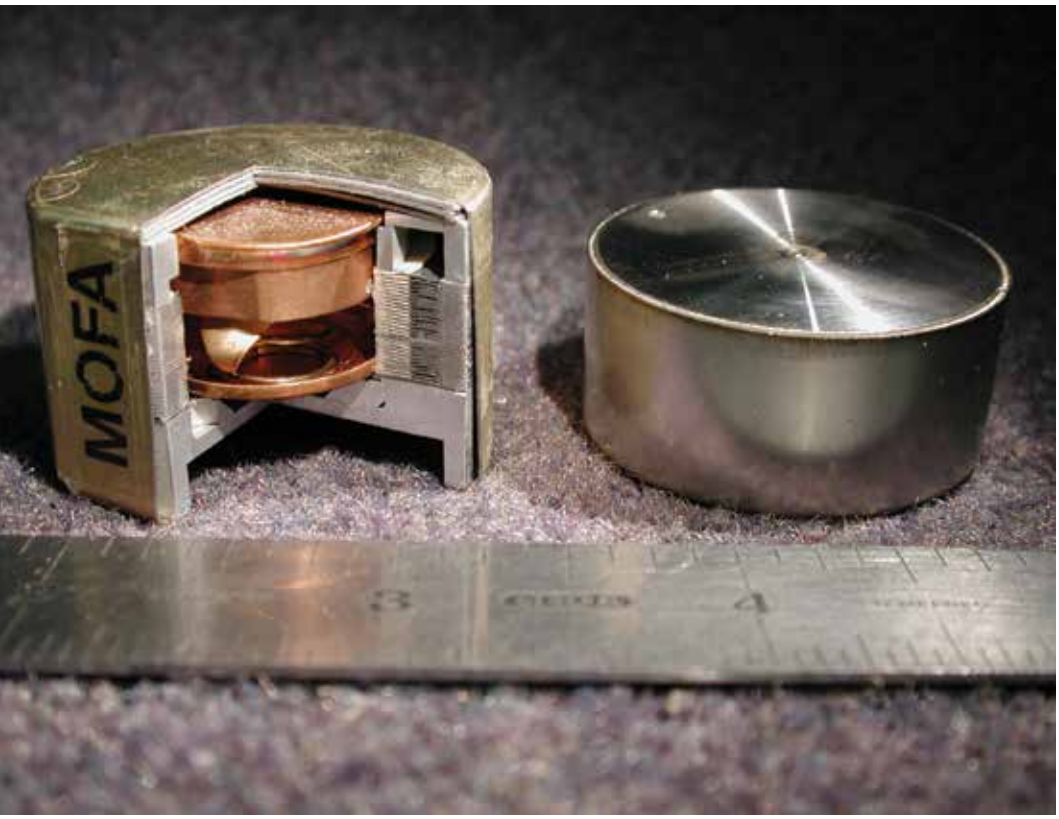
Interrogator Intrusion Detection for Computer Networks—In 2006 ARL developed an architecture called Interrogator for protection of network-accessible Army–DoD research information—a mission requirement for the ARL Center for Intrusion Monitoring and Protection (CIMP). Interrogator comprises more than 20 tools that provide network-attack sensing and warning; also, it has a repository of accurate, current network data for constant validation and improvement of the toolset—critical to protecting the network-centric Warfighting capability. ARL is providing cutting-edge support to 50 organizations with the deployment of more than 230 Interrogator sensors.

Radar Signal Processing—ARL has explored the phenomenology associated with ground-penetrating radars (GPRs) using advanced computational models, and from this developed advanced radar signal-processing algorithms designed to improve performance by reducing and minimizing noise and artifacts in radar data and imagery. Through ARL's support to CERDEC's NVESD and JIEDDO, these signal-processing techniques are providing better hazard-detection capabilities for down-looking GPR, forward-looking GPR, and multiple airborne developmental GPRs.

Bilateral Negotiation Simulation (BiLAT)—BiLAT is a game-based simulation used in training Army leaders on skills required to plan and conduct successful bilateral meetings and negotiations in foreign settings. The simulation helps students develop their negotiation skills through practice scenarios that involve virtual characters representing local community officials and tribal-clan leaders. The BiLAT was developed as part of a multiagency research effort that included ARL, Army Research Institute, the University of Southern California Institute for Creative Technologies, and the Army School for Command Preparation. The simulation was initially evaluated at the Army Pre-Command Course in 2007 and became part of the Army Games for Training portfolio in 2009. The application is available for distribution through the Army MilGaming web portal, https://milgaming.army.mil.

Phraselator—In 2007 ARL led the testing of IBM's two-way English–Iraqi-Arabic speech translation software called Multilingual Automatic Speech-to-Speech Translator System (MASTOR), which was installed on a handheld Phraselator device. With deployment of FAST teams in Iraq, the language center sent Phraselator P2 devices, established call-back channels to provide feedback from the users, and identified shortcomings in the systems.

Phraselator in the testing and development phase



A more reliable fuze battery, the Multi-Option Fuze for Artillery (MOFA) battery, was developed at HDL/ARL during the technology demonstration phase of the MOFA fuze development program.

Exposures to Airborne Particles in Deployed Areas in Southwest Asia—Troops are frequently deployed to areas where the air quality has not been well understood. A better understanding of particle-size distributions along with the chemical and biological makeup of aerosols is needed to assess potential health effects on Soldiers. ARL worked with RDECOM FAST teams to deploy two novel aerosol samplers (drum impactors): one each in Baghdad, Iraq, from 2008 to 2010, and Bagram, Afghanistan, in 2010, along with complementary meteorological instrumentation. Data and experience obtained from the samplers are being shared with the Army Public Health Command to evaluate their potential use of the technology to help monitor occupational exposure to biological and chemical hazards.

Improved Munitions Batteries—ARL's research into munitions batteries led to the production of a more reliable fuze battery by incorporating a metal reservoir that provides better protection against rough handling by gunners and provides depots and ammunition-storage points with a capability that reduces storage degradation concerns. This technology is currently being fielded in reserve batteries.

Fragment Kit 6—To address ballistic and IED threats that had escalated since 2006, ARL and ATC engineers worked with TARDEC and Rock Island Arsenal to develop an armor package that provided increased Explosively Formed Projectile (EFP) survivability for the M1151 HMMWV. After a comprehensive armor-system development and the vehicle integration phase more than 1,100 Fragment Kit 6 (FK6) units were delivered to theater in June 2009, with the final FK6 design about 25 percent lighter and with a reduced thickness of 13 percent. The final FK6 design was engineered to integrate seamlessly with Fragment Kit 5 (FK5). The research produced an FK6 design that enabled a compromise between protection capability, weight, cost, integration complexity, and manufacturability.

Civilian Scientists and Engineers Deploy to Iraq and Afghanistan to Support Soldiers
Three ARL S&E personnel volunteered to deploy to Iraq for 179-day tours as part of the FAST Program, beginning in the winter of 2009. Their mission was providing operational commanders with immediate access to RDECOM laboratory and engineering capability, expedite the delivery of critical technology solutions to Soldiers, and directly support the Soldier.

One S&E staffer served a tour as the Army III Corps' Science and Technology Acquisition Corps Advisor (STACA) assigned to the Multi-National Corps–Iraq, while others served separate tours as science advisors on Science and

Soldiers and FAST science advisors reviewing technology fixes.

Technology Assistance Teams (STATs) assigned to the 402nd Army Field Support Brigade. During their interactions, the three STACA and STAT personnel gathered feedback on how fielded equipment met mission needs and identified unmet capability and technology gaps. They funneled more than 75 Soldier issues to the FAST headquarters that were forwarded to ARL or to one of the RDECs and to program managers for resolution and/or information.

Solving a problem with Mine Resistant Ambush Protected (MRAP) vehicles' towbar stowage is one example of a "field fix" sent back to RDECOM. The S&E personnel noticed Soldiers used many methods to secure towbars to the MRAPs. Apparently these vehicles had no external mounting brackets for stowing a towbar. Soldiers made their own brackets and installed them on the MRAPs. But mounting them reduced the angle of the grade the vehicle could traverse. They looked to RDECOM to design and fabricate a better bracket solution. Further, they recommended future vehicles be equipped with built-in towbars that operate like railroad freight cars' automatic couplers. Another S&E investigation focused on weapon-mounted light kits that had been sent in response to an earlier STAT request. A combat engineer unit was asked to use the kits and assess their combat effectiveness. After one month, the Soldiers completed questionnaires on critical system attributes and were interviewed for critical qualitative data. The resulting report was shared with each kit's manufacturer so they could understand the best way to modify their designs to better meet our Soldiers' mission needs.

One ARL employee reported on his volunteer experience: "This was the most rewarding assignment in my civilian career, and the most humbling." Another ARL S&E volunteer remarked later, "The ability to serve and support our Soldiers in the combat zone and genuinely serve our country is something that I will never regret and would do again in a heartbeat."

A recent offshoot of the FAST program was the U.S. Army Research, Development and Engineering Command Field Assistance in Science and Technology-Center (RFAST-C). From 2011 through 2014 this program embedded a one-of-a-kind Prototyping and Integration Facility (PIF) in theater in Afghanistan to bring engineers and technicians directly to the battlefield. This PIF was an extension of the Contiguous United States (CONUS) RDEC PIFs located in each RDECOM center. This unique RFAST-C PIF created new parts, improved products, and instituted fixes with direction from the S&E teams. Even minor engineering fixes made significant improvements for the Soldier. Hundreds of success stories arose from the PIF's capacity to close capability gaps when end-user Soldiers had access to engineers and machinists with the expertise to improve their equipment and vehicles.

Today, the FAST program involves approximately 30 scientists and engineers from RDECOM deployed to major commands that include combatant commands, Army Service Component Commands, and Combat Training Commands. These advisors provide the supported commander with immediate access to the R&D Enterprise to expedite technology solutions to Soldiers.

Electromagnetic Protection System (EPS)—Army vehicles in forward areas face continued threats from rocket-propelled grenade (RPG) attacks. Requirements to increase protection have added considerable weight to vehicles. To reduce these burdens, ARL researchers developed, matured, and transitioned the EPS technology, which is capable of defeating multiple impacts of RPGs. Working with industry partners, ARL integrated EPS onto MRAP platforms. Currently EPS has reached the highest

maturity level of any electrical armor system. EPS is currently being considered for other platforms.

Mobile Counter-IED Interactive Trainer (MCIT)—ARL provided Soldiers with state-of-the-art, interactive training system to help put the Soldier "into the enemy's head" to better combat the IED threat. The design consists of a series of four modified 40-foot Conex boxes (CBs) with each CB focused on different training goals and aspects of IEDs and how they are employed on the battlefield. The trainees are guided through the CBs using narrative story vignettes that deliver the training through different OPFOR and BLUEFOR viewpoints. Deploying and moving the MCIT to multiple locations throughout the continental United States, the system was able to train more than 20,000 Soldiers, U.S. Marines, and Sailors. A Multinational MCIT was developed and deployed throughout Europe to train U.S. and coalition forces in ways to recognize and defeat a wide variety of IED types that could be encountered in Afghanistan and Iraq under various complex attack scenarios.

Enhanced Combat Helmet—The Enhanced Combat Helmet (ECH) uses novel composite materials and thermoplastic processes that were developed, integrated, and deployed in the revolutionary manufacture of new ballistic helmet shells. ARL executed both mission and ManTech programs to fully exploit the disruptive potential of new fibers that PEO Soldier had stimulated industry to develop. Geometrically complex helmet shells are fabricated from a new generation of materials known as "ultra-high molecular weight polyethylene" (UHMWPE) and composite hybrids. The ECH geometry and system weight are identical to those of the currently fielded ACH helmet. However, the ECH has greater than 35-percent increase in resistance to frag penetration (over the ACH helmet), and ECH is the only fielded ballistic helmet with a specified level of small-arms protection. The ECH represents the successful collaboration of the Army and Marines, and in particular, extensive collaboration between ARL, U.S. Army Natick Soldier RD&E Center (NSRDEC), Army ManTech Office, PEO Soldier, and the U.S. industrial base. The ECH helmet is an historic transition from aramid (e.g., Kevlar) to newer classes of thermoplastic UHMWPE materials for U.S. ballistic head protection. In FY2014 the ECH helmet was fielded to both the Marines and the Army. In August 2014, a Soldier wearing the ECH survived a 7.62-mm small-arms bullet strike in a documented and confirmed incident. In 2013 *Popular Science* magazine recognized the ECH helmet as one of the "Best 100 Innovations."

Enhanced Combat Helmet (ECH)

Statistical Machine Translation for Security Assistance to CENTCOM—Producing high-quality translated texts in specialized military topics—from small-unit leadership to legal–criminal justice to medical care—required subject-matter expertise as well as expert knowledge of languages. This work first began with ARL's Statistical Translation Engine for English-to-Dari (STEED). U.S. Navy doctors serving in Afghanistan with the Combined Security Transition Command–Afghanistan Embedded Training Teams (ETTs) strongly endorsed the product, as did the medical corps of the Afghan National Army. Team leaders needed to train Afghan doctors and provide reference materials. STEED and the original translation task were carried out by recruiting an Afghan medical doctor and former translator. STEED produced a full, 800-page translation of the Fundamental Critical Care Support manual, which was released in FY11. This method was extended to include Pashto translations

and to address the needs of security transition in other domains, including the rule of law, detention operations, and most recently in agribusiness development. At the peak of the U.S. military's presence in Afghanistan in 2012, this advanced translation technology expedited and made more precise the work of more than 7,300 contract linguists in theater. In 2014 one member of the surgeon general's team of medical advisers in Afghanistan remarked on the continuing value of the translation technologies: "When U.S. forces are gone from the region, the U.S. documents will remain. As I see it, what ARL has done translates to tremendous training value to the physicians, as well as goodwill to the nation."

Thrown Object Protection System (TOPS) Kit—U.S. Soldiers driving in Iraq and Afghanistan experienced ever-evolving threats—among them, objects thrown by enemy combatants. The Army conceived and developed the TOPS kit, which was fielded in 2010. It uses an elastic screen that repels thrown objects and causes them to bounce away from the vehicle and its crew. These extremely lightweight, modular kits are easily customized to a wide variety of vehicles.

M295 Individual Equipment Decontamination Kits—ARL sponsored basic research discoveries in catalysis and nanomaterials at Kansas State University that led to the creation of the NanoScale Corporation and its development of state-of-the-art decontamination technologies. The basic-research breakthroughs led to a successful new decontaminant program and, eventually, to the manufacture of the M295 Individual Equipment Decontamination Kit. Soldiers can use the kit to rapidly and effectively decontaminate their individual equipment through physical removal and absorption of chemical agents.

M855A1: Enhanced Performance Round (EPR)—ARL developed the M855A1 by applying to small-arms ammunition the science of interior ballistics, delivery/aerodynamics, and terminal ballistics originally developed in large-caliber cartridges. The result was significant improvements to the lethality of both 5.56-mm (M855A1) and 7.62-mm (M80A1) systems. The EPR produces consistent effects against soft targets such as enemy personnel; increased effectiveness at long ranges; increased defeat of hard targets; and reduced muzzle flash (to help conceal Soldiers' firing positions). The battle-tested M855A1 has demonstrated these improvements in Afghanistan since mid-2010. The cartridges also reduce the environmental impact by removing more than 2,000 metric tons of lead per year that otherwise could end up in the environment. The 5.56-mm ammunition was fielded in 2010, and the 7.62-mm ammunition was fielded in 2014.

Expedient Crew Protection for Stryker Armored Vehicles—Continuing threats from buried IEDs led to major up-armoring of a wide variety of ground vehicles, including the Stryker family. The use of ARL's Defense Supercomputing Resource Center in addition to materials research, onsite fabrication, and high-fidelity experiments at ARL research facilities quickly yielded expedient crew-protection solutions for the Stryker using advanced armor materials and improvements in

Thrown Object Protection System (TOPS) Kit

energy-absorption capability for crew shock-mitigation seating. These technologies were quickly transitioned to PM Stryker and General Dynamic Land Systems for rapid production and fielding in 2010.

Mission-Specific Armor Packages—DoD vehicles face a myriad of ballistic threats. Previous approaches of layering armor add considerable weight and thickness to vehicles, impact mission loads, hinder mobility, and reduce overall systems durability.

New modular armors that matured in 2010 use cutting-edge, ballistic-protection mechanisms to deliver the same protection at less weight, allowing for more area coverage and protection of the vehicle. Armor designs were transitioned to the Army's Tank Automotive, Research, Design and Engineering Center (TARDEC) for packaging design, system integration, and prototype fabrication.

UrbanSim is a practice environment allowing trainees to take on the role of an Army battalion commander, planning and executing operations in the context of a difficult fictional training scenario.

UrbanSim—Understanding the principles of counterinsurgency and stability operations was the genesis of developing the first game-based software focused on training commanders, staff, and Soldiers.

Since 2011, UrbanSim has provided commanders with a low-cost training solution. UrbanSim is currently being leveraged to support research investigating adaptive training technologies in support of self-regulated learning solutions. This includes solutions to improve information processing and decision making in counter-insurgency operations in the absence of live instruction.

In Ah Slama, Iraq, a Bradley combat vehicle from C Company, 1st Brigade, 1st Armored Division moves off the road after a Traffic Control Point on Sept. 8, 2003. Soldiers from the 1st Armored Division in Iraq supported Operation Iraqi Freedom. (U.S. Army photo by Spc. Jason Heisch/Released)

Joint Tactical Radio System (JTRS)—Warfighters' feedback to ARL human-factors researchers helped drive the final design of the JTRS, a software-programmable, IP-based digital radio system. Since the JTRS concept began around the year 2000, it has grown into a family of radios. The first radio developed was the single-channel AN/PRC-154 Rifleman Radio for dismounted Soldiers, first fielded between 2010 and 2011. The latest JTRS is the AN/PRC-155 Manpack, a 2-channel, 2-radio system now under low-rate production. JTRS allows mobile, ad hoc, secure networking for use by Soldiers anywhere in the joint battle space, with the capability to plan, engineer, deliver, and manage voice and position reports via radio waveform files.

Integrated Weather Effects Decision Aid—ARL's research into the effects of weather on battlefield operations (adverse weather and path optimization to avoid adverse weather) has led to technology transitions from 2011 to the present as Army Programs of Record. Programs include the Distributed Common Ground System-Army (DCGS-A), the Army Tactical Airspace Integration System (TAIS), and the Army/Marines Advanced Field Artillery Tactical Data System (AFATDS).

Doppler LiDAR Wind Profiling System for Aviation Operations—In 2012, ARL developed the Doppler LiDAR Wind Profiling System (DLWPS), significantly enhancing wind-profiling capability for operational forces over previously available methods. DLWPS for Aviation Operations was deployed in December 2014, for the Copperhead UAS operations, Detachment 3. The system is used on all missions for aircraft launch and recovery operations, providing UAS operators with expanded information regarding atmospheric wind and turbulence profiles. Detachment Officers-In-Charge and Aerial Vehicle Pilots (AVP) all confirm the system works well and provides highly valuable information. ARL and the Engineer Research and Development Center Cold Regions Research and Engineering Laboratory (ERDC-CRREL) will follow up for additional feedback on specific technical elements and opportunities for improvement. The Copperhead Detachment 3 AVP reports: "The mission commander does receive winds locally from the tower, but tower always reports calm winds. Crews are able to see what the winds are doing at different flight levels to choose the proper runway direction for takeoff or landing. The LiDAR system has been working great for us here at Det 3!" In FY15, using OCO funds supporting the U.S. Army Africa (USARAF)/Southern European Task Force (SETAF) need for improved wind measurement for U.S. Pathfinder operations, the DLWPS is being modified into a man-portable system capable of providing wind and turbulence information for forward-area aviation operations. These systems will be delivered to USARAF in early FY16, with potential for additional systems being produced in FY16.

Three radios comprising the JTRS family of radios: the Rifleman Radio or AN/PRC-154 (pictured above); a Mid-Tier Vehicular Radio (AN/VRC-118); and the latest 2-channel, 2-radio system (AN/PRC-155 radio) enabling Soldiers to conduct mobile, ad hoc secure networking anywhere in the joint battle space.

Detector Special Purpose No. 27 (DSP-27)—The DSP-27 is a hand-held detector designed to provide the operator with an audio alert when the system is passed over a target IED component. It provides U.S. Soldiers and Marines with a capability that did not previously exist. ARL has transitioned support of the DSP-27 to PM CEH.

Stalker XE UAS—The ARL fuel-cell group supported the Defense Advanced Research Projects Agency (DARPA) program manager, who transitioned fuel-cell-powered unmanned aircraft systems (UASs) to the Army

82nd Airborne Division's 307th Engineer Battalion. These UASs provide valuable intelligence, surveillance, and reconnaissance (ISR) capabilities for infantry units, for example, allowing over-the-next-hill imagery monitoring of convoys. State-of-the-art battery power for a Stalker UAS has a limited mission duration of about two hours. To power the Stalker XE, DARPA's Tactical Advanced Power (TAP) program developed and matured the compact propane-fueled solid oxide fuel cell (SOFC). The Stalker SE must perform back-to-back flights on a single airframe and a single fuel cell with turnaround times of less than 30 minutes. The Stalker XE powered by this fuel cell has provided extended mission endurance for more than eight hours, a four-times improvement in flight endurance. Since February 16, 2013, the 307th Engineer Battalion operated the fuel-cell-powered Stalker XE UAS successfully in Afghanistan. In 2015 this technology has been transitioned to United States Special Operations Command (SOCOM) for deployment through Overseas Contingency Operations (OCO) funding.

Tactical Combat Casualty Care Simulation (TC3)—ARL produced the first PC game-based simulation to train combat medics. This simulation trains medics how to perform the correct procedure at the required time, thus preparing them to save lives on the battlefield. A Marine Corps version of TC3 was also developed and fielded. Additionally, a new effort is underway to update the original TC3 game and broaden its scope to the other services.

Artillery Meteorological Computer Message and Ballistic Meteorological Message (METCM, METB3)—ARL meteorologists developed software in 2013 for Meteorological Computer Messages (METCMs) and Ballistic Meteorological Messages for surface to surface fires (METB3s) for use on ruggedized personnel digital assistants (RPDAs). The software provides these essential meteorological messages for Army and Marine first-in units. ARL continues as the primary source for Artillery Met expertise for Army and Marine land-based systems. In the near and longer term these efforts will help enable more accurate artillery fires while reducing collateral damage.

Revolutionary Prosthetics—ARO/ARL-supported researchers, funded by DARPA and headed by DEKA Integrated Solutions of Manchester, N.H., developed a novel upper-extremity prosthetic device to meet the needs of injured Soldiers. The DEKA Arm System allows for simultaneous control of multiple joints using a variety of input devices including wireless signals generated by innovative sensors on the user's feet. The battery-powered arm system is of similar size and weight to a natural limb and has six user-selectable grips. The research offered an extraordinary opportunity to establish the greatest advancement in upper-extremity prosthetics in the past several decades and addresses the Army's need to rehabilitate and care for its wounded Soldiers. The U.S. Department of Veterans Affairs (VA) conducted in-home trials of the system, coordinating with the USAMRMC, which funded completion of tests and trials required to meet FDA requirements. In 2014, DEKA Integrated Solutions Corporation received FDA approval to commercialize the system—the first prosthetic arm that can perform multiple, simultaneous powered movements controlled by electrical signals from electromyogram (EMG) electrodes. Currently researchers are exploring the promising possibility of direct brain control of the DEKA Arm System, since the battery-powered system is compatible with direct neural control.

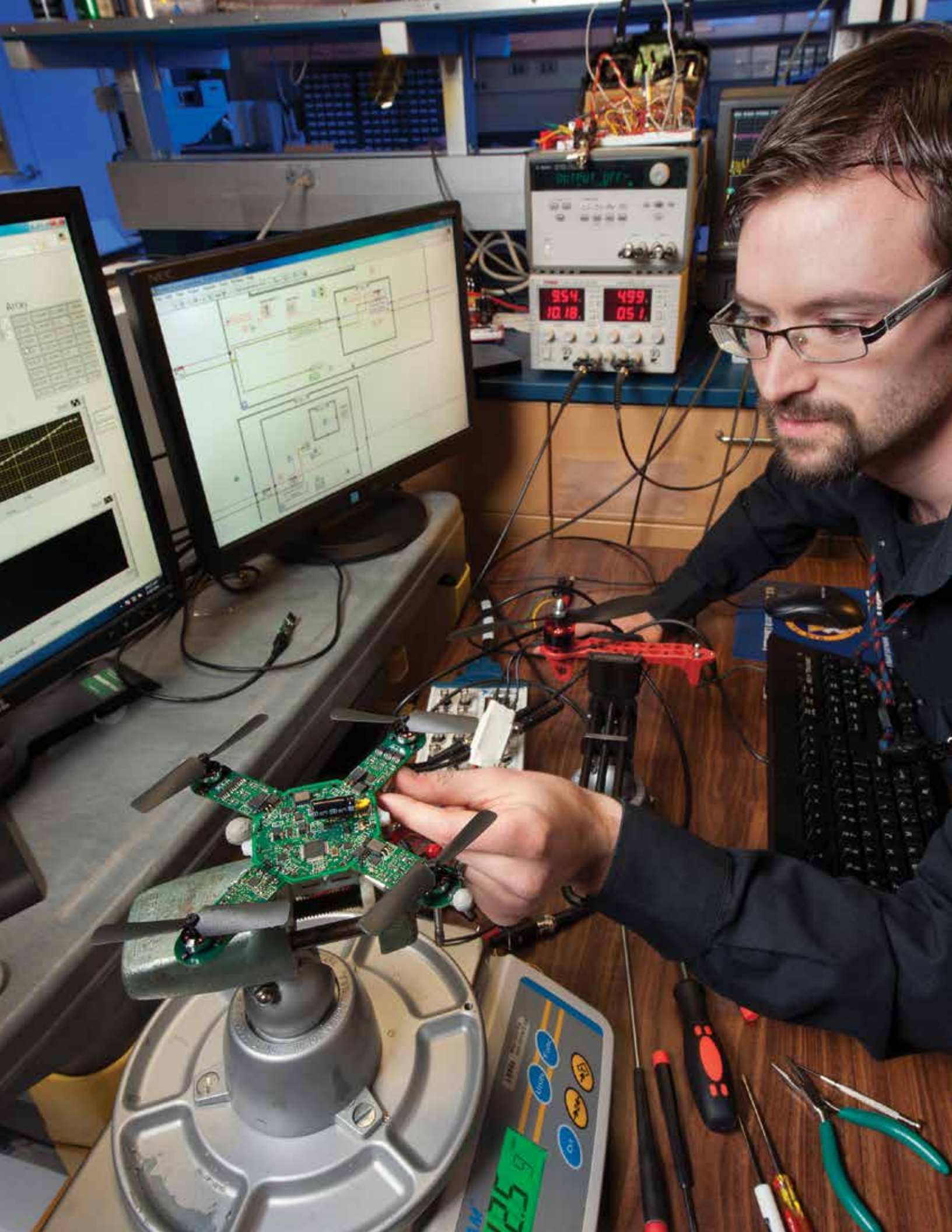
Strider Body-Worn IED Detection—ARL completed development of the Strider body-worn detection system. Strider provides an IED-component-detection capability that is hands-free—resulting in enhanced situational awareness that satisfies the required capability in the relevant Joint Urgent Operational Need Statement (JUONS). Production systems were shipped directly to Afghanistan in support of a JIEDDO-sponsored Operational Assessment.

Open Standards for Unattended Ground Sensors (OSUS)—ARL sensor-integration efforts such

The DEKA Arm System developed by ARO/ARL-supported researchers has the dexterity to perform multiple, simultaneous powered movements, incorporating the fine motor skills necessary to grasp a grape.

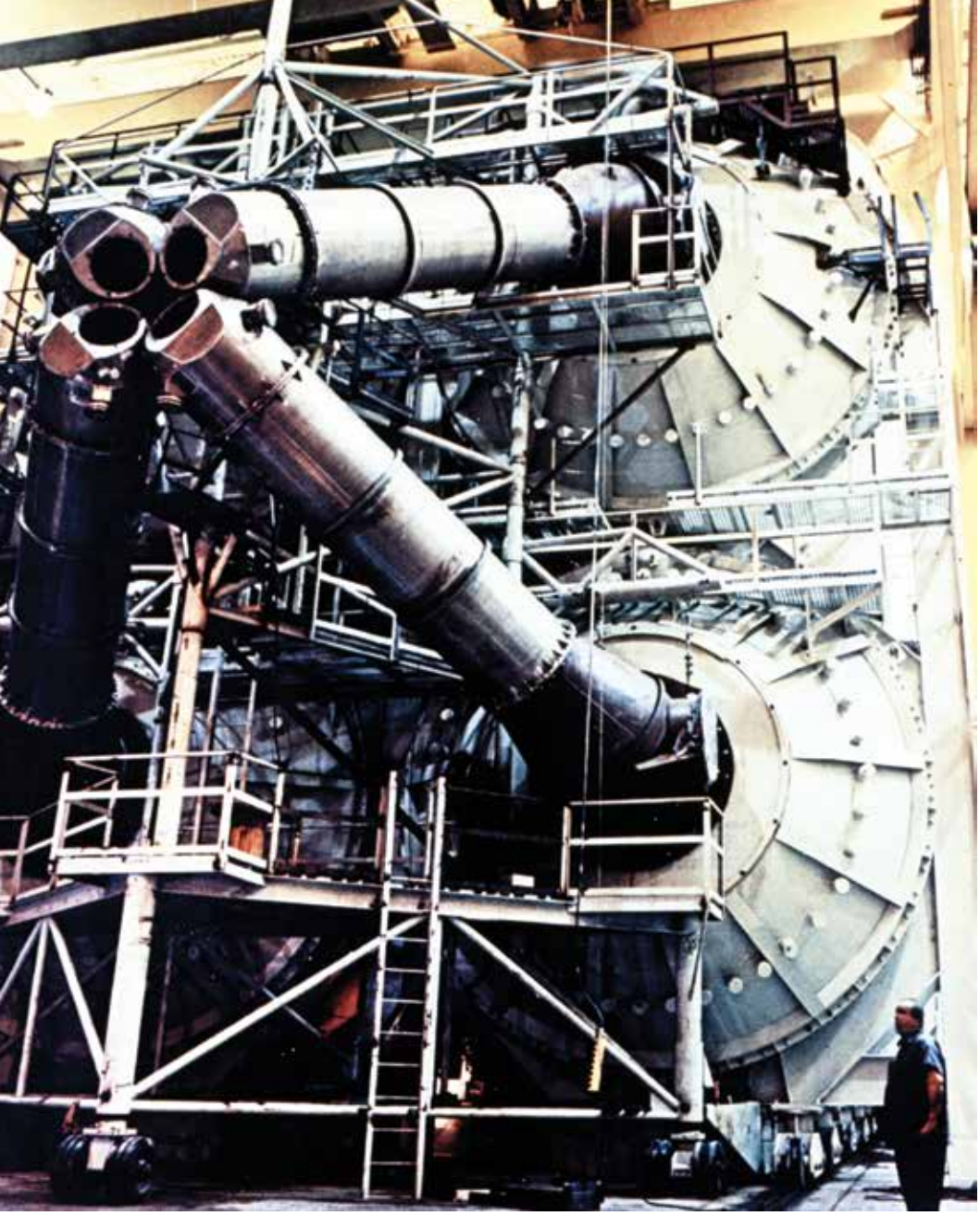
as Current Force UGS and ISI programs highlighted the need for greater levels of interoperability of sensors. Starting in 2009 ARL led a technical team under the Defense Intelligence Agency (DIA) Terra Harvest program to develop a software-based open sensor controller architecture that allowed for sensor interoperability at the component level. This core architecture was matured and a series of demonstrations including Trident Spectre 2012 proved the ability to exchange sensors, radio communications channels, and algorithmic processing using a common data model and "plug-in" software architecture. In 2014 this effort transitioned to the Open Standards for Unattended Ground Sensors (OSUS) program, with the public release of OSUS 1.0.0 planned for 2015.

Dshell Advanced Cyber Threat Detection—Dshell is a forensic analysis software project in use for the last five years as a framework to help the Army and the U.S. government understand events of compromise occurring on DoD networks. The Dshell framework is designed to make it easier for Soldiers to analyze large volumes of network traffic and identify cyber threats attempting to exploit or access government information systems. The framework enables users to better understand network activity and respond quickly to cyber intrusions. Dshell can be easily extended by nontechnical users and includes contextual information that makes it a powerful tool for network defenders and cyber researchers. Additionally, software developers can develop custom analysis modules to detect and understand compromises they have encountered. The project authors anticipated that other developers could contribute to Dshell by adding modules that will benefit others within the digital forensic and incident-response community. To promote better collaboration between government, industry, and academic partners within the cybersecurity domain, a version of Dshell was published on Dec. 17, 2014, on GitHub, an online-developer community platform. By the end of February 2015, Dshell was downloaded more than 2,000 times and the project page on GitHub had been visited by more than 80,000 users from all over the world. By publicly releasing the framework, the overall security community will benefit from global cyber-threat research and development, and respond more effectively to emerging cyber threats. Since the initial public release the Dshell software project has received positive feedback and technical contributions from the security community.



Advances in Science That Precede Soldier Technologies

Fluidics—Originally called fluid amplification, fluidics was discovered in 1959 by scientists at ARL's predecessor organization, HDL. Since 1970, dynamic applications of fluids have been applied in the areas of military systems, aerospace, medical technology, consumer items, and factory automation.



In 1986 the Aurora facility generated a world-record amount of high-power microwave power form a virtual cathode oscillator.

Buckyballs—The discovery of buckminsterfullerene, commonly known as Buckyballs, has been compared to Columbus' voyage of discovery to the New World. In the 1990s the Aerosol Science Program at Edgewood Arsenal, Md., (today part of APG) joined other sponsors including ARO in funding the work leading to this unexpected discovery. This new molecule, resembling a soccer ball, is a third form of solid carbon in addition to graphite and diamond. The properties of Buckyballs were the subject of intense worldwide research in the 1990s.

Aurora Gamma-Ray Simulator—Operated by ARL's predecessor organization HDL from 1969 to 1996, the Aurora Gamma-Ray Simulator was sponsored and funded by the Defense Nuclear Agency (DNA). The Aurora Gamma-Ray Simulator was the first gamma radiation simulator of its size and capacity in the world. The simulator achieved a new plateau of nuclear-effects simulation, able to test complete weapons electronics packages critical for both strategic and tactical nuclear-weapons design. Throughout the first part of its life, the Aurora Simulator primarily served military agencies and contractors for testing the warheads of intercontinental ballistic missiles (ICBMs). During the second half of its life, the facility expanded its technical capabilities to test the hardening of very large finished systems, such as those for satellites.

In 1986 the Aurora facility generated a world-record amount of high-power microwave power from a virtual cathode oscillator. This accomplishment won HDL recognition by the American Defense Preparedness Association (ADPA) in 1987.

Nuclear Weapons Effects Research—Beginning in the 1960s, system designers at ARL's predecessor organization HDL were greatly concerned over the effects of nuclear detonations on military electronics and weapon systems—both the transient radiation effects on electronics (TREE) and the effects of electromagnetic pulses (EMP) generated by nuclear bursts. Measurements in each of the programs required extensive, very specialized, instrumentation design and application studies. Only HDL obtained significant EMP data. During this period the Defense Atomic Support Agency (DASA) and the three military services created intensive large-scale programs to develop hardened recorders

and instruments to use in their experiments. HDL possessed a unique capability with the Aurora Gamma-Ray Simulator, and achieved a new plateau of nuclear-effects simulation for testing complete weapons electronics packages critical for both strategic and tactical nuclear-weapons design. In the 1970s HDL used Aurora for testing the warheads of intercontinental ballistic missiles (ICBMs), many other types of military electronics, and on a few occasions even tanks. As a result of its pioneering work in acquiring and analyzing data for the TREE program (supported by DASA), HDL had a tremendous impact on the design of most military weapon system electronics of that time, especially ICBM weapon systems. In 1970 HDL was designated as the AMC lead laboratory for Nuclear Weapons Effects, providing technical guidance to some 14 separate installations.

Transparent Spinel Armor Manufacturing Scale-Up—ARL's pioneering use of spinel in transparent armors reduced armor's weight 33–50 percent. Moreover, this revolutionary technology soon was embraced by at least one other branch of the U.S. military.

ARL developed the current method of hot-pressing spinel; the technology's scale-up continued under a Cooperative Research and Development Agreement (CRADA). Transparent ceramic spinel's state-of-the-art fabrication capability (up

Spinel-based transparent armor on FMTV 1080 A1P2 demonstrator undergoing TARDEC–ARL Tactical Wheeled Vehicle testing

to 600 square-inch panels) was smaller than what tactical vehicles required. The 2010–11 program increased manufacturing capability to larger than 600 square inches of transparent ceramic-spinel armor for improved ballistic protection. One example was the front windshields for the Family of Medium Tactical Vehicles (FMTVs)—according to threats forecast in the Long Term Armor Strategy (LTAS) initiative.

Advances in spinel powders and spinel-powder processing now contribute to technology to make electromagnetic domes. Sizes of spinel plates available for DoD applications increased from 170 to 300 square inches, making the following possible:

- The Navy flight-tested spinel for a window in the latest AN/ASQ-228 Advanced Targeting Forward Looking Infrared (ATFLIR) targeting pod for the F/A-18 warplane.
- Lockheed Martin evaluated spinel for the lens of the aircraft-mounted Sniper targeting pod.

Currently ARL's CRADA partner, Technology Assessment and Transfer of Millersville, Md., has completely taken over manufacturing and is actively marketing spinel parts and material.

Joint Trauma Analysis and Prevention of Injury in Combat—In Iraq and Afghanistan, U.S. Soldiers faced lethal and battle-hardened enemies and many Soldiers paid a heavy price. To capture critical information from those injuries and deaths, the DoD established the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program. It analyzes and reconstructs casualty-producing battlefield events to identify lessons learned for improved material, tactics, or intelligence value. ARL is a key partner in JTAPIC.

For actionable analysis to enhance survivability, detailed information is received about actual combat events. Starting with metallurgical analyses on the projectile fragments recovered by military physicians, experiments are conducted on the interaction of specific threats and targets. Computer simulations help investigators analyze and "reverse engineer" individual battlefield events. Analytical products developed by JTAPIC support solutions and decisions for improving vehicle and body armor design as well as Tactics, Techniques and

Procedures (TTPs). JTAPIC's efforts successfully identified threat munitions and likely battlefield scenarios and provided detailed analyses on specific cases of IED, direct and indirect fire, and close combat. To support JTAPIC, ARL reactivated and refurbished Experimental Facility 10 (EF10) in 2009 to experiment and determine threat and target characteristics for IEDs and kinetic-energy penetrators.

In 2014, ARL's SLAD designed a customized software system, the Distributed Incident Collaborative Environment (DICE), to manage the JTAPIC program's information and data and enhance communication among its partners for the day-to-day program implementation. DICE provides a virtual environment for communication and resource-sharing among JTAPIC partners and other government users. The system also provides access to the Combat Evidence Database, the online repository for images, physical attributes, and metallurgy from autopsies, vehicle forensics, and experimentation; VisualAID, a tool that displays injury data on the human anatomy to classify and study combat injuries; and the Data Management Tool, which manages knowledge and data-artifacts for sharing and archiving.

Simulated wound pattern in an anatomical geometry resulting from the impact of a kinetic-energy projectile

Combat Medical Simulation Research Boosts Training Authenticity and Effectiveness—A pressing challenge for today's medical community is developing authentic medical simulation technologies and prototypes for military training. ARL researched methods to improve anatomical and physiological accuracy to

- broadly characterize human tissues and strive to appropriately simulate their behaviors;
- enhance training authenticity;
- develop new measures of self-efficacy to assess training performance;
- create a high-fidelity, upper-airway model keying on anatomical features and task-specific requirements for training;
- develop innovative methods for representing anatomy and injuries with three-dimensional imagery and other advanced visualization techniques;
- develop correct protocols for the use of malodors in medical training scenarios and measuring their effect on performance; and
- create a prototype simulator for "pain cue" facial expression—a significant,

Shown on the left is the card back of the Combat Medic educational card game and on the right is the Needle Chest Decompression (NCD) card from the card game.

under-researched source of diagnostic information for doctors and medics.

Researchers worked closely with combat medics, nurses, physicians, and Combat Casualty Care Training Consortia experts to experiment, socialize prototypes, and identify additional needs of the military medical community. ARL transitioned its virtual Tactical Combat Casualty Care Simulation into the PEO STRI Virtual Battle Space 2 Trainer. ARL also transitioned stand-alone medical simulations consisting of the Multi-Amputation Trauma Trainer (MATT) and other mannequin developments, Severe Trauma Moulage kits, TRACER learning management system, and Combat Medic, Combat Lifesaver, and Improved First Aid Kit (IFAK) educational card games. PEO STRI directly provided these simulations to the 19 medical-simulation training centers at major Army posts and to Brigade Combat teams worldwide.

ARL 'Crosswalk' Analyses Validate Lessons from Live-Fire Tests—Since 2010, decades of ARL test-and-evaluation experience led to improved vehicle designs used in Iraq and Afghanistan; more accurate assessment of threat and combat damage by operational and intelligence units in theater; and validation of Army practices in live-fire test and evaluation (LFT&E). ARL performed the first-ever analysis, known as a crosswalk, comparing LFT&E results with assessments of combat damage from Iraq and Afghanistan. The insights into critical injuries from combat incidents resulted in new instrumentation and criteria for capturing data and assessing outcomes during live-fire testing. The MRAP vehicle benefited through design changes to the underbody, a redesigned crew floor, and new crew seats—improvements that later reduced the potential for crew injury.ARL performed crosswalks using operational, intelligence, and medical data from the JTAPIC program, including events involving the MRAP, Stryker, Medium Tactical Vehicle Replacement (MTVR), Logistics Vehicle System Replacement (LVSR), Husky, and Buffalo. The comparisons addressed both vehicular damage and occupants' injury, and illustrated the efficacy

An example of a Live-Fire Test in which injury assessments based on anthropomorphic test device (ATD) data were made. Vehicle/System damage was correlated to tested threat to enable theater comparisons/crosswalks analyses.

of design improvements ARL recommended from live-fire testing—specifically, redesign of seats, Remote Weapon Station (RWS) integration, and vehicle floor and hull design changes.

Transcranial Magnetic Stimulation Helmet Enables Direct Signal Transfer Between Two Human Brains—In ARO/ARL-funded research conducted from 2010 to 2014, researchers at the University of Washington demonstrated the first-ever direct transfer of signals between the brains of two human subjects, which may be the first step in the long-term development of brain-to-brain interfaces (BBIs) for applications ranging from covert communication to more effective warfighter training. As reported by CNN and other news outlets, the researchers created a BBI by fitting one subject with an external cap utilizing electroencephalography (EEG) to record brain signals, which was connected via a transcranial magnetic stimulation (TMS) cap to a researcher across campus. When the first researcher imagined moving his hand, it was immediately detected through his EEG cap as a specific pattern of neural impulses and a signal was sent over the Internet to the TMS cap worn by the second subject, who then involuntarily (subconsciously) moved his hand. Although this experiment demonstrated that a brain impulse from one human can be used to control involuntary movement in a different subject, it represents only a one-dimensional control of a preselected movement. Researchers are now attempting longer-term studies to determine if this approach can be expanded to detect other types of conscious intent from subjects and then transmit that information remotely to a device or another person. If successful, this research could lead to developing new training paradigms based on BBI and brain–machine interfaces (BMIs) to permit unprecedented control over the battlespace.

Advanced Injury Criteria and Instrumentation Minimize Soldier Casualties from Underbody-Blast Events—As part of the Army's Warrior Injury Assessment Manikin (WIAMan) program, vital information about the under-body blast environment is being used to develop enhanced injury criteria and an advanced test manikin, estimated to be fielded in 2021. ARL researchers received data on vehicle-loading regimes at the occupant's floor and seat, based on hundreds of vehicle blasts as well as data from anthropomorphic test devices and theater injuries. ARL, TARDEC, and university research partners in 2015 also detonated explosives under an accelerative loading fixture to demonstrate the under-body blast environment. These and other test results—in addition to new modeling and simulation capabilities—will help researchers develop injury criteria and advanced test manikins necessary for test and evaluation communities to more accurately assess and minimize Soldier injuries and casualties from under-body blast events.

Harnessing Bacteria for Microscale Transport and Manipulation—ARL-sponsored researchers and academia in 2010 made a significant advance to control the trajectory of bacteria-propelled microstructures for engineering micromanipulators and microrobotics. For the first time, researchers constructed a stochastic model for microscale locomotion and manipulation using flagellated bacteria for actuation, which lends itself to controlling the trajectory of bacteria-propelled microstructures. Uniquely, this research uses

Bacteria depiction—four flagellae

actual microorganisms as microactuators, which offers advantages over other means of locomotion—including easy and inexpensive production—and eliminates the need for a separate energy source as bacteria harness energy from their nutrient-rich environment. Researchers constructed a microbarge powered by a swarm of bacteria and demonstrated their theoretical model accurately predicts the behavior of the microbarge's motion; further, it could provide the means for controlling the swarm.

Ultraviolet Light Enhances Communications Capabilities—Employing ultraviolet (UV) light for communications offers Soldiers potential for a new means of communication and networking that can supplement conventional systems. Particularly in challenging environments—urban, mountainous, RF denied, or bandwidth congested—today's technologies can have extremely limited functionality. Unique to UV communications is their ability to establish non-line-of-sight (NLOS) optical communications links, due to atmospheric effects in deep-UV wavelengths. Strong atmospheric absorption of deep-UV radiation (e.g., solar) results in a virtually noiseless channel, while rich atmospheric scattering of deep-UV radiation provides the channel mechanism for NLOS–UV communications. In an ongoing program begun in 2010, ARL scientists are researching the fundamental science of UV communications and networking while leading the research community in developing this field and advancing its technology. Through theory and measurement, validated modeling of the atmospheric propagation channel has produced key insights into the expected performance of various communication approaches and has guided the development of system designs. Recently, ARL scientists have produced the first-ever hybrid RF–UV radio, augmenting a conventional RF system with UV communications functionality and demonstrating voice communication over an RF–UV multihop link.

Laser Cooling of Molecules Drives New Research Areas and Sensor Applications—Researchers sponsored through numerous ARO/ARL single-investigator awards over the past decade have made several significant breakthroughs in the cooling of molecules to milli-Kelvin temperatures and below. These are expected to enable revolutionary new capabilities in sensors and information processing. Academic physicists (building on prior ARO-sponsored work) in 2010 discovered a method for the laser cooling of strontium monoflouride (SrF). Prior to that, laser cooling of molecules had been considered close to impossible. This was the first-ever demonstration of the laser cooling of a molecule. A parallel breakthrough the same year enabled the formation of Feshbach molecules of KRb at nano-Kelvin temperatures, and measured their subsequent bi-molecular reaction rates forming K2 and Rb2. An ARO/ARL Multidisciplinary University Research Initiative in 2012 leveraged these results to develop a new scientific field of state-dependent chemical reactions. Then, researchers sponsored through another ARO/ARL single-investigator award in 2013 demonstrated the first cooling of a molecular ion using laser-cooled neutral atoms. Most recently, in 2014, the original ARO/ARL investigator who demonstrated cooling in 2010 reported the first demonstration of a three-dimensional magneto-optical trapping of the originally laser-cooled diatomic molecule (SrF), at a temperature of approximately 2.5 milli-Kelvin, the lowest yet achieved by direct cooling of a molecule.

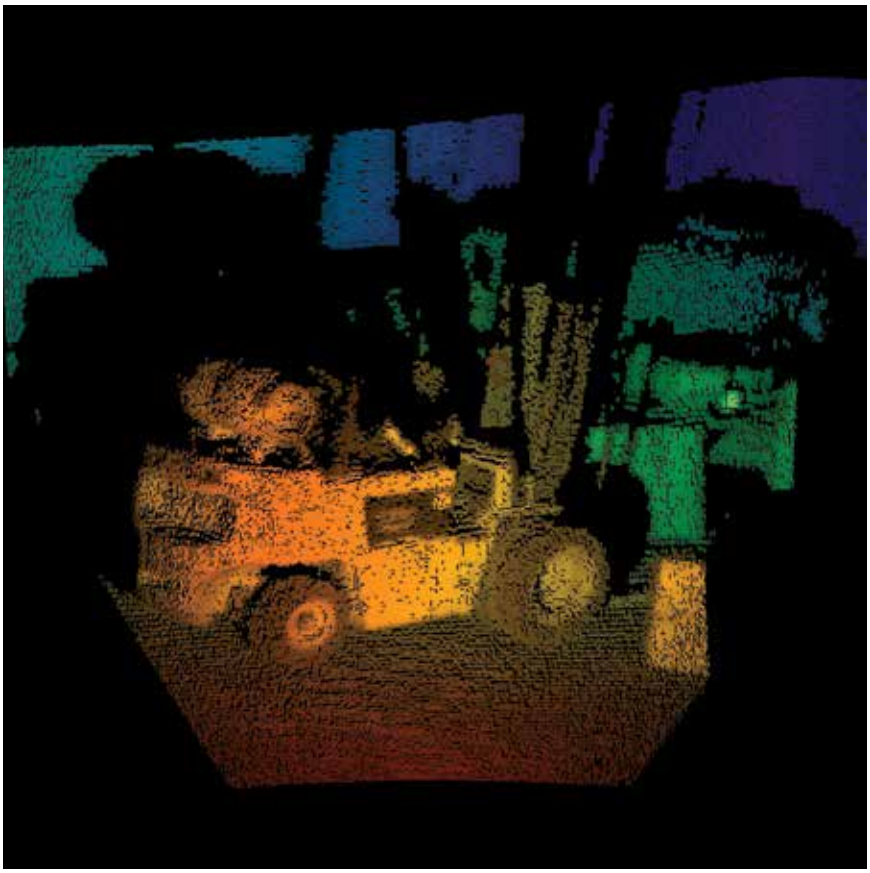
Cooled molecules offer an important test bed for further fundamental studies; for example, when loaded into optical lattices to explore and simulate exotic condensed-matter systems, such as chiral spin-fluids and possible topological quantum matter. Moreover, such cold and ultracold molecules are expected to have enormous civilian and military implications, as have the laser cooling of atoms. For example, molecules cooled near absolute zero can provide phenomenal control over chemical reactions, enabling the future development of new functional material—with uses ranging from power generation to electronics, to active and passive

armor. In addition, interferometry with ultracold molecules can exceed the precision of atom interferometry, further extending the capabilities of highly accurate and jam-proof gyros (for navigation), accelerometers (for inertial guidance), and sensors such as magnetometers (for mine detection) and gravity gradiometers (for remote tunnel/bunker detection). All of these applications have significant impact for the Soldier.

A Pioneer DX robot nicknamed "RIC," short for the Symbolic and Sub-symbolic Robotic Intelligence Control System (SS-RICS), used in HRED's Cognitive Robotics research.

Autonomous Unmanned Systems—Rapid advances in robotics technology—both aerial and ground, midsized to palm-sized and smaller—since about 2002 have enabled UGVs to provide Soldiers increased awareness, extended reach, and multiplication of force. As an alliance of government, industry, and academia, the Robotics Collaborative Technology Alliance (RCTA) provides the underpinning science to enable autonomous robotic platforms. The RCTA developed, then transitioned, technologies that enable UGVs to autonomously operate in dynamic, unstructured environments. Development areas for size- and resource-constrained systems include sensing, perception, and processing; communication, navigation, and coordination; and, mobility, control, and energetics (explosives). Because of the RCTA's accomplishments Soldiers have better management of the platform and the information it provides; more intuitive and rugged operational-control units giving them adequate feedback; and improved future designs including experimentally tested human–robotic-interaction principles. In conjunction with the RCTA, in-house autonomous systems research by the directorates within ARL made significant contributions to autonomous systems operations, improving human–robot interaction, advancing cognitive robotics methods, and expanding intelligent control principles. HRED developed the Symbolic Sub-symbolic Robotics Intelligence Control System (SS-RICS) using lessons learned from computational cognitive psychology as a means of robotic control. This system mirrors the cognitive problem-solving methodologies and the memory-decay functions found in humans. The system also provided robots with greater problem-solving ability, increased situational awareness, and improved human–robot interaction.

Ladar in Small Ground Robots Reduces Risk and Workload for the Soldier—Future Army combat operations will team with small robotic ground and air vehicles to minimize risk and reduce Soldier workload by performing missions in intelligence, surveillance, logistics, and reconnaissance. Robotic vehicles will perform the tasks using sophisticated algorithms requiring high-resolution, 3-D imagery from ladar (laser radar) sensors. Current ladars for small ground and air platforms are flawed by high cost and performance issues. ARL's research on adapting commercial MEMS-scanned mirrors to create new compact ladars solves many of these shortcomings. It led to a demonstration/test design; many of the



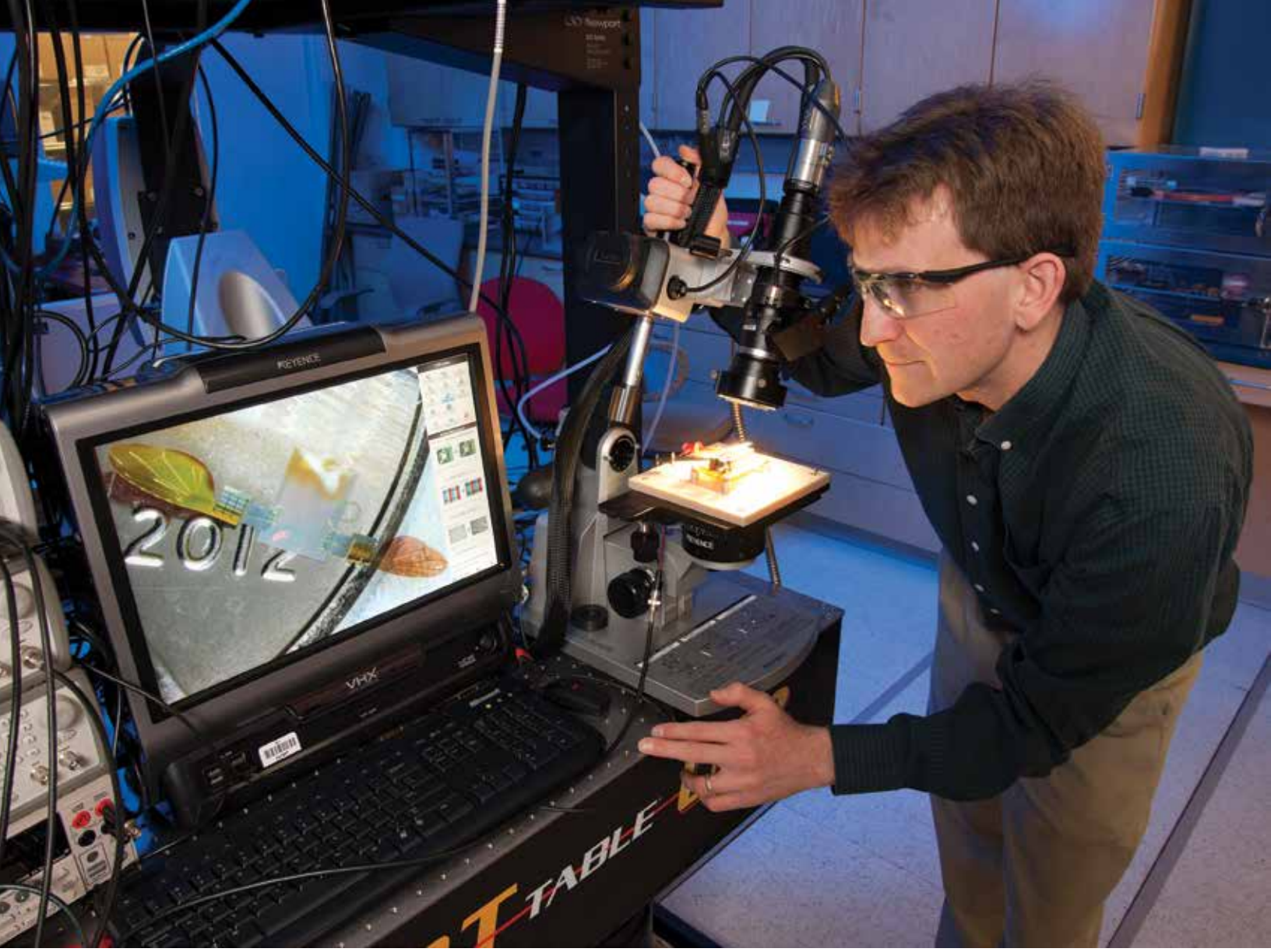
ARL Ladar Image

prototypical subassemblies and circuit boards were simplified and reduced to a compact size. Currently, in addition to supporting ground applications, ARL is funded to enhance and modify the ladar's performance for use on small unmanned air vehicles and as a landing aid for helicopters in degraded visual environments. ARL's CRADA partner Boeing Spectrolab of Sylmar, Calif., is now building a version of ladar for small ground robots and near-range surveying.

High-Voltage Batteries for Extended Mission Duration—Reducing batteries used for extended missions is a well-recognized Army need. A typical 72-hour mission in Afghanistan required Soldiers to carry 70 individual batteries total, weighing 16–30 pounds (nearly one-fifth of total equipment weight). ARL achieved a breakthrough in Lithium (Li)-ion battery technology with components that can operate at 5 volts (V). This is up to a 30-percent increase in energy density over current Li-ion technology. ARL was the first to develop a combination of electrolyte additives and cathode material at high cell voltage (5V), operating for hundreds of cycles without cell degradation. Battery manufactures can easily adopt this drop-in technology, which can reduce the battery weight a Soldier carries for the average 72-hour mission by approximately 20 percent.

From 2013 through 2015 ARL developed the high-voltage cathode for Li-ion batteries even further. ARL has substantially improved the cycling-charge efficiency of lithium cobalt phosphate (LCP) high-voltage cathodes from 96 to 99.7 percent, as well as its capacity retention in a full Li-ion cell versus graphite over 200 cycles from 20 to 80 percent. Researchers have achieved higher-capacity utilization, higher-capacity retention, and lower reactivity with the electrolyte. ARL improved the energy-storage capacity over standard LCP by more than 60 percent, and the technology is still under development.

Multifunctional Flapping-Wing Technology for Micro Air Vehicles—Unmanned aircraft systems (UASs) and micro air vehicles (MAVs) are platforms designed to be the Soldiers' eyes and ears. One approach is to develop a biologically inspired, flapping-wing "insect" that can hover and maneuver into confined areas. Research in MAV actuation used newly designed piezoelectric MEMS actuators to produce insect-like motion by achieving multiple-degrees-of-freedom wing motion with orthogonal unimorph actuators that drive the bio-inspired wing structure. Prototype devices capable of flapping-only motion were developed in 2007. In 2010, the ARL Director's Research Initiative supported an effort that demonstrated wing rotation and flapping motion with comparable performance to



Unmanned aircraft systems (UASs) and micro air vehicles (MAVs) are designed to be the Soldiers' eyes and ears. One approach studied is that of a biologically inspired, flapping-wing "insect" to hover and maneuver into confined areas. This technology enables flight-capable MAVs.

what is achieved by most flying insects. The cross-directorate effort in 2012 successfully showed aerodynamic lift produced by a microfabricated, tether-supported flapping wing platform. This effort also established the feasibility of using piezoelectric MEMS technology to create flight-capable micro air vehicles.

Advances in Infrared Imaging Enhance Military Surveillance—Modeling, fabricating, and testing new state-of-the-art photodetectors brings significant advances in infrared imaging. ARL is driving key advancements in focal-plane arrays (FPAs) for IR imaging, improving size, weight, and sensitivity. ARL fabricated and delivered state-of-the-art Corrugated-Quantum Well IR Photodetector (C-QWIP) FPAs to L3-Cincinnati Electronics, Inc., which operates a C-QWIP production line. These high-density FPAs offer standard resolution for 25-micron FPAs, but the smaller pitch of 15 microns reduces the size, weight, and power consumption by one-third, making the cameras much more portable for Soldiers.

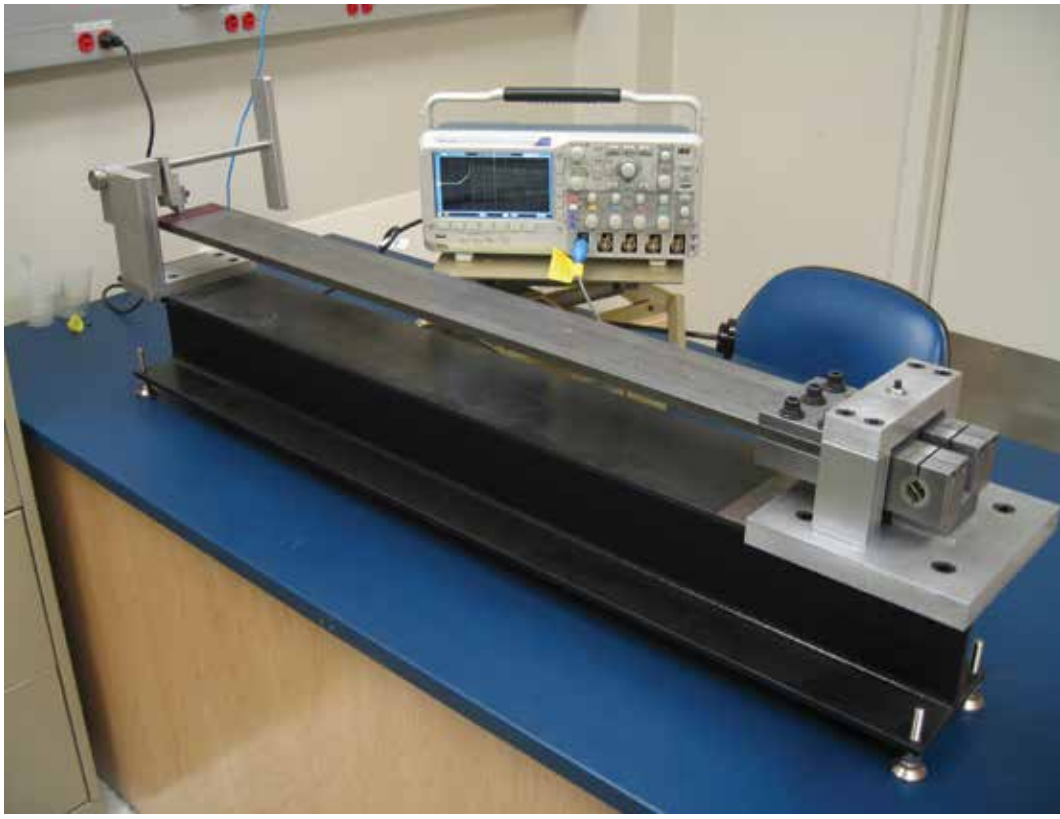
Concurrently, ARL produced and demonstrated the world's highest resolution, 4-megapixel, broadband, long-wave infrared (LWIR), C-QWIP FPAs under NASA's 2013 Landsat program, improving today's satellite standard by a factor of four with a wider view field and surveillance for Army operations. ARL also increased density and resolution of QWIP FPAs with a

dedicated electronic-readout circuit, further miniaturizing Soldiers' highly sensitive and high-resolution handheld IR cameras. Additionally, ARL established the world's first highly accurate electromagnetic model to predict detector quantum efficiency (QE), subsequently inventing a new sensor structure, the resonator-QWIP (R-QWIP), with a predicted QE of more than 70 percent. Enabling the modeling of arbitrary detector structures ensures ARL's leading role in this critical technology.

DEMO I OSD Robotics Test Bed—Starting in the mid-1980s numerous experimental robotics projects were being conducted by the Army, Marine Corps, Navy, DARPA, and several non-DoD agencies. The Office of the Secretary of Defense began to coordinate these robotics projects in 1989, and in 1990 consolidated them under a single program element, the Unmanned Ground Vehicle (UGV) program. Under ARL's program management, DEMO I invited the agencies developing robotics technologies to hold in 1992 a military-relevant demonstration at APG to attract Army interest and show the current state-of-the-art in vehicular robotics technology. During that event robotics technologies were evaluated for several modes of vehicle control including advanced computer-aided teleoperation, semiautomated control, and highly autonomous control such as retroreverse and autonomous road following. The DEMO I event was an ARL initiative and significant as the first of its kind. It was also the first major integrated push for military robotics. The successful event led to the follow-on DARPA DEMO II program, which was already in the works to develop a new fully autonomous actuation and control system from DEMO I assets. Later on DEMO III was held to further develop capabilities in autonomous mobility as well as intelligent system architectures, human–machine interfaces, mission packages, and communications. These robotics demonstration programs were precursors to the DARPA Robotics Challenge events that continued into the 2010s.

Graphene-Based Supercapacitors Enhance Electronic and Munitions Systems' Performance—Army electronic and munitions systems require efficient, compact electrical-energy storage. With higher power density and longer lives than batteries, plus higher energy density than other capacitors, supercapacitors are extremely promising. ARL aims to increase supercapacitor performance and decrease size by investigating graphene and other nanomaterials. ARL and Stevens Institute of Technology of Hoboken, N.J., in 2011 jointly demonstrated the first inkjet printing of graphene supercapacitor electrodes onto

Shown is the apparatus used to test graphene supercapacitors for a munition-energy-harvesting application. This device simulates the launch conditions the energy harvester will experience.



ARL Twice Awarded 'Laboratory of the Year'

ARL has been recognized for its excellence in Army science as a two-time recipient of the Department of the Army Research and Development Laboratory (RDL) of the Year for large research laboratories. It won the award in 2004 and 2006. In both cases, ARL was selected from a strongly competitive pool. The award is based upon a number of criteria including excellence of staff, strategic management of human capital, state of facilities, world-class nature of ARL research, significant research accomplishments, and support to the Global War on Terrorism.

In 2004, upon being notified of ARL's first Lab of the Year award, ARL Director John Miller said that it was "a testament to the entire ARL team, which is consistently at the forefront of Army science and makes invaluable contributions to our Soldiers in the field." Leonard Huskey, ARL's Associate for Corporate Programs who has chaired the last several committees that draft ARL's annual nomination package, has also noted that the award "is truly a reflection of ARL's scientific and organizational excellence in support of the Soldier."

The RDL awards program was established in 1975 to honor Army research and development labs that have made outstanding contributions in science and technology. All 15 Army laboratories are evaluated annually. In addition to the awards for large research laboratories, the Army also announces awards for large development laboratories, small development laboratories, and collaboration teams. ARL has been recognized with collaborative awards on numerous occasions.

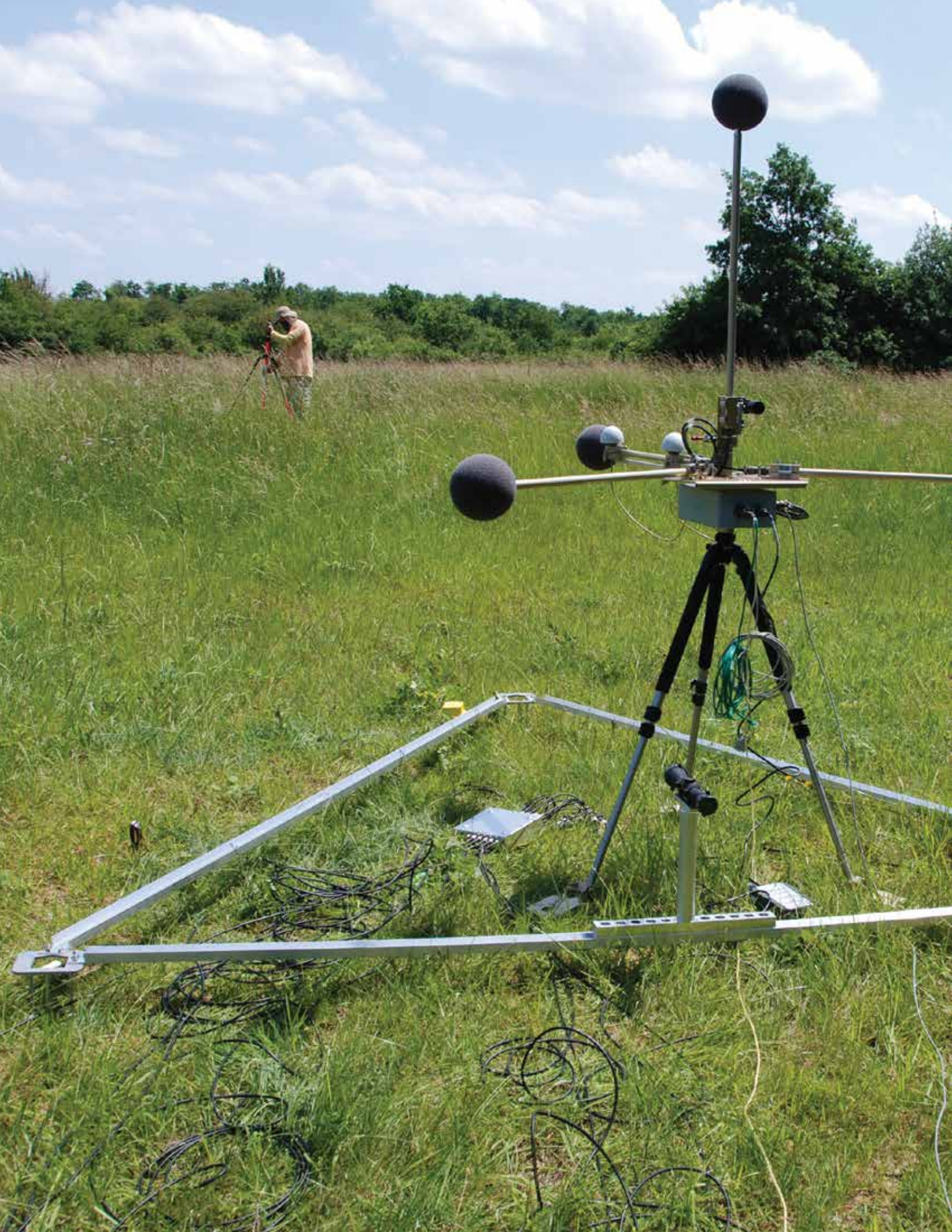
flexible substrates for making flexible supercapacitors. This technology is currently being commercialized under a new startup company out of Stevens Institute of Technology. Further advancing this technology for military applications, ARL leveraged unique high-speed supercapacitors from SBIR partner JME, Inc., in 2012 to demonstrate energy storage from a munitions-energy-harvesting system under development by ARDEC. These supercapacitors operate at a 15,000-times-higher frequency than traditional supercapacitors and are ten times smaller than traditional electrolytic capacitors. JME Inc., under a phase II SBIR is currently working to develop this technology for commercial production. These advances in ARL-developed supercapacitors enable size and weight savings for munitions electronic systems and simultaneously yield improvements in reliability and shelf life over electronic capacitors.

Affordable Precision for Indirect-Fire Systems—The GPS-guided fuze ultimately provided the "first round fire for effect" capability for artillery. It demonstrated the first use of GPS in a high-g environment and greatly increased accuracy for the 105-mm and 155-mm artillery systems. In 1989 ARL transitioned the technology to ARDEC, which developed the capability into a guided-munition system with ARL acting as the technical advisor. The first operational firing occurred

in Iraq in May 2007, and then in Afghanistan in February 2008. The system, named Excalibur M982 Block 1a–2, was eventually type classified in 2010. The Army received the R&D Achievement Award for this effort in 1995, and the Top Five DoD Program Award in 2006. In 2007 the system was recognized in the Army's Greatest Inventions Award program.

Aerodynamics Modeling Breakthrough—In 2000 a state-of-the-art numerical capability using Chimera overset approach was developed by the ARL Computational Fluid Dynamics (CFD) team to compute aerodynamics of complex configurations and multiple bodies in relative motion. This approach for the first time made the complex physics and fluid dynamics of aerodynamic interference for multibody problems uniquely identified. It was a major breakthrough for time-dependent problems and established a readily available new technology for the U.S. Army.

A Simplified Model for Blast/Impulse of Buried Explosives—ARL released a model in 2012 for understanding the blast and impulse response of buried explosives and potentially for vulnerability–lethality analysis. By incorporating tailored modeling assumptions, along with analytical-modeling constructs, the underlying model exhibits a size, structure, and performance much closer to an analytical model than a full-fledged, general-purpose numerical code. Unlike many blast codes currently employed, the current model can separate out the contributions of both delivered soil impulse and residual high-explosive blast. Initially conceived in 2009, the model is used to carry out a variety of parametric studies of the buried-explosive event, to include the effects of burial depth, explosive variation, and soil condition. Currently, the model continues to be improved.



Awards

ARL has been honored throughout the defense and S&E communities for its research contributions to the nation. The lab has been recognized twice—in 2004 and 2006—as the Department of the Army Research and Development Laboratory (RDL) of the Year for large research laboratories. This honor is testimony to ARL's success in providing innovative science, technology, and analysis to enable full-spectrum operations. The award is based on a number of criteria including excellence of staff, strategic management of human capital, status of facilities, world-class nature of ARL research and analysis, significant research accomplishments, and support to the Global War on Terrorism. Over the past several years, ARL has also been recognized with numerous collaboration awards under this program.

ARL Annual Honorary Awards

Each year, the Army Research Laboratory community comes together to celebrate the achievements of select scientists, engineers, and staff at its annual Honorary Awards Ceremony. The ceremony was instituted in 1995 under the direction of then-ARL Director John Lyons. The program was developed to recognize the highest levels of performance and/or achievement throughout the laboratory. These awards are unique to ARL and provide the ARL Director with the opportunity to personally recognize and thank members of the ARL team for their high levels of performance.

Given ARL's excellent reputation for fulfilling the Army's needs as its corporate laboratory, the selection process for these awards is highly competitive. Directorates are encouraged to nominate one candidate (a "candidate" may designate an individual or group of individuals involved in a team project) in each of the categories. Directorates complete a detailed nomination package, and recommendations on the winners are made by the ARL Corporate Awards Panel to the ARL Director. If no nominees are worthy of the high standards established for each of these awards, the Panel may recommend to the ARL Director that no award be given in that particular category.

The awards ceremony is held in the autumn and alternates location between Aberdeen Proving Ground and Adelphi Laboratory Center. The program is presided over by the Director of ARL, who delivers welcoming remarks and assists in presentation of the awards. Other prominent honors, such as the annual Research and Development Achievement awards and Lab of the Year, are also recognized at the ceremony. The achievements of these members of our working community speak to the continued excellent reputation of the Army Research Laboratory.

Individual ARL research projects and achievements have also been highly recognized within the DoD community. From 2004 to 2013 the lab took home a total of 86 Army Research and Development Achievement Awards. This award was established to recognize outstanding S&E achievements and technical leadership throughout the Army's commands, laboratories, and RDECs. In 2011 one ARL employee received the Army Modeling and Simulation Award. In addition, during this period, nine ARL employees were recognized with the prestigious AMC Personnel of the Year award, one employee in 2012 and one in 2013 were awarded the Presidential Early Career Award for Scientists and Engineers, and one employee in 2013 received the Special Recognition Award for Black Engineer of the Year.

2006 Army's Greatest Inventions Program—OmniSense

ARL has also been highly successful in the competitive Army's Greatest Inventions Program, which is dedicated to recognizing the best technology

solutions for Soldiers. Soldiers from three active-duty divisions selected ten winning programs based upon their inventiveness, their potential benefit outside the Army, and their impact on Army capabilities from the Warfighter perspective. From 2003 to 2008 (when that award program ended), ARL was recognized with a total of 11 of these awards for the following inventions:

2003

- Agentase Nerve Agent Sensor

2004

- Armor Survivability Kit for the HMMWV
- IED Countermeasure Equipment
- UTAMS Mortar, Rocket, Explosion Locator

2005

- Persistent Threat Detection System
- Fido Explosives Detector

In 2003 crewmembers of the Landing Craft, Air Cushioned (LCAC) 57 offloaded M998 High Mobility Multipurpose Wheeled Vehicles (HMMWVs) on the Inner Apra harbor on Guam during the exercise Tandem Thrust. (U.S. Marine Corps photo by Staff Sgt. Michael R. Picklo/Released)

2006

- OmniSense
- Constant Hawk
- Interim Fragment Kit 5
- 'Blow Torch' Counter-IED System

2008

- MRAP Armor Weight Reduction Spiral Program

A New Beginning and New Vision for ARL

Mr. Miller's retirement in June 2012 signaled the end of one era at ARL and the dawning of another. In 2013 Dr. Thomas P. Russell took over as director of ARL, bringing with him a fresh vision for the future. Over the course of his government career, Russell's talents took him into progressively broader leadership roles, enabling him to gain significant expertise at the helm of military-research organizations.

Dr. Thomas P. Russell

Russell's government career began as a research scientist at the Naval Surface Warfare Center–White Oak, Md. He later joined the Naval Research Laboratory, serving as a research scientist and head of the High-Energy Materials Section within the Chemistry Division. During his five-year tenure at the Naval Surface Warfare Center, he held positions of director of the Chemistry and Detonics Division, Research Department; department head, Research and Technology Department; and acting technical operations manager.

As director of the Aerospace and Material Sciences Directorate in 2006, he oversaw the Air Force's basic-research program in aerospace, chemical, and material sciences. In 2010 he was tapped to become director of the Air Force Office of Scientific Research (AFOSR). There he oversaw the management of the entire basic-research investment for the Air Force—leading 200 scientists, engineers, and administrators in Arlington, Va., and foreign technology offices in London, Tokyo, and Santiago, Chile.

Russell has been a visiting scientist at the National Institute of Standards and Technology, an adjunct professor at the Washington State University Shock Dynamics Laboratory, and a part-time faculty member at Montgomery College in Maryland.

Dr. Russell is also well known as an accomplished scholar and inventor, accounting for more than 100 publications and inventions. His principal fields of interest are energetic materials, decomposition–combustion chemistry, detonation physics/chemistry, high-pressure chemistry/physics, and spectroscopy. In 2006 he was appointed to the Senior Executive Service.

Changing Demands in an Evolving Global Environment

During this period of 2013 to the present, ARL leadership became increasingly aware of changes in the global environment that would impact the many roles and missions of the Army of the future. It was clear this evolving environment and the changing pace of science and technology required ARL to become a more flexible, dynamic, collaborative organization. Fresh strategies were needed to define a new way of conducting defense research within this new environment.

To that end ARL developed an overarching, research management and leadership strategy envisioned to strengthen the whole organization by energizing and enabling the workforce for success. Leadership began to foster a culture of true collaboration among academia, government, and industry, with strategic technical objectives designed to support strategic land-power dominance for the Army of 2050 and beyond.

Developing organizational business savvy became paramount in enabling efficient and effective laboratory operations. The theme statement of ARL's mission remained "Discover, innovate, and transition science and technology to ensure dominant strategic land power"—but greatly improved methodologies, techniques, and materials were being implemented to achieve it.

ARL leadership now identified six goals essential to strengthening the Army's research program:

- **Provide scientific leadership** for a collaborative research enterprise

- **Attract the Nation's best S&E personnel** who would contribute to and lead Army research
- **Ensure coherence and balance** in the ARL research portfolio
- **Foster connections** between Army researchers and the Army community
- **Maximize the discovery and innovation potential** in the ARL research environment
- **Identify and execute opportunities to transition technologies** for the Future Force

Russell joined ARL at a critical turning point in its evolution; his vision articulates a new strategic framework for how ARL will conduct defense research. His Research Management and Leadership Strategy (RMLS) encapsulated a high-level overview of the research management and leadership landscape that best positions ARL to develop as the nation's premier laboratory for land forces.

Russell's RMLS is built on four pillars that define new thinking, initiatives, and approaches:

1. **People First**
2. **Open Campus**
3. **Technical Strategy**
4. **Business Acumen**

ARL's Open Campus Business Model

ARL leadership has become increasingly aware of the changes in the global environment and how those changes impact the roles and missions of the Army of the future. This evolving environment and the changing pace of science and technology mean ARL must become a more flexible, dynamic, and collaborative organization.

Through the vision and guidance of ARL Director Dr. Russell, leadership has introduced a new business model that empowers ARL to create a dynamic, cooperative S&T ecosystem linking government assets with the global research community. Open Campus is a new initiative introducing more adaptive and responsive modes better suited to meet 21st-century challenges in national security and far into the future. ARL launched this new initiative to cooperatively advance scientific breakthroughs with visionary, ambitious scientists and technologists from academia, private-sector businesses, institutes, and others across the global research community. Russell and ARL leadership recognized the need to modify policies and procedures that were blocking open interaction between private- and public-sector researchers, even going as far as removing physical barriers such as walls and fences. The Open Campus initiative also creates flexibility in government career paths, allowing employees to diversify their work experience through assignments in academia and industry while remaining a government employee.

Already underway, Open Campus has begun constructing a laboratory system with a continuous flow of people and ideas. Open Campus partners work side-by-side with ARL research scientists and engineers, share ARL's specialized research facilities, bring ARL researchers to their institutions to communicate a perspective on research conducted in federal laboratories, and extend the broader DoD network. New ARL facilities will be constructed in the future to host partners, with laboratory and office space to serve academia and small businesses, and to incubate entrepreneurial startups.

ARL's Open Campus initiative is a collaborative endeavor, with the goal of building a science and technology ecosystem that will encourage groundbreaking advances in basic and applied research areas of relevance to the Army.

Dr. Russell particpates in a People First meeting.

The **People First** initiative is creating a premier organization staffed with diverse team members who are excited, dedicated, and focused on achieving ARL's mission. By fostering an environment that encourages and enables employees to take ownership and stewardship, employees feel more of an investment in ARL and its mission.

Leadership understood that ARL's internal programs must support work–life balance; promote an exciting and interesting workplace; reward service, teamwork, and collaboration; and provide opportunities for advancement and learning for employees at all levels. This whole process helps employees see their contributions as worthwhile, resulting in employees personally invested in the organization's success. Success in this initiative further allows ARL to continue to attract, develop, and retain highly productive scientists, engineers, technicians, and administrative support personnel focused on expanding the limits of science to provide innovative solutions to support the Warfighter.

Open Campus introduces a fundamentally new business model that empowers ARL to create a dynamic, cooperative S&T "ecosystem" linking government assets with the global research community. Open Campus introduces more adaptive and responsive modes better suited to meet the national-security challenges of the 21st century and beyond. ARL launched this new initiative to cooperatively advance scientific breakthroughs with visionary, ambitious scientists and technologists from academia, private-sector businesses, and institutes across the global research community. Russell and other ARL leaders recognized the need to modify policies and procedures that previously blocked open interaction between private- and public-sector researchers—even going as far as removing physical barriers such as walls and fences. With multiple disciplines of scientists and engineers coming together, this integrated, flexible work environment extends across academia, industry, and government to fuel innovation through onsite R&D collaboration. The Open Campus initiative also creates flexibility in government career paths, allowing employees to diversify their work experience through assignments in academia and industry while remaining a government employee.

Already underway, Open Campus has begun constructing a laboratory system with a continuous flow of people and ideas to successfully execute ARL's Technical Strategy. Open Campus partners work side by side with ARL research scientists and engineers; they share ARL's specialized research facilities, bring ARL researchers to their institutions to communicate a perspective

on research conducted in federal laboratories, and extend the broader DoD network. Leadership envisions future construction of new facilities to host partners with laboratory and office space to serve academia and small businesses and to incubate entrepreneurial startups.

Technical Strategy defines scientific, technical, and analytical areas ARL believes are vitally important. These were translated into focused campaigns that act in concert with cross-cutting campaigns to provide a robust S&T framework geared toward overcoming the technological challenges to the future Army's strategic land-power dominance.

The eight S&T campaigns are *Extramural Basic Research, Computational Sciences, Materials Research, Sciences for Maneuver, Information Sciences, Sciences for Lethality and Protection, Human Sciences,* and *Assessment and Analysis.* Each S&T campaign creates a new focus on important elements in a scientific area. In each campaign, ARL will be a scientific leader, a major collaborator with industry and/or academia, or an observer closely following "thought leaders" in that area. Leadership puts these S&T campaigns into effect as ARL's long-term scientific agenda, encouraging more cross-directorate research and collaboration across the organization, academia, and industry.

The fourth pillar, **Business Acumen**, is essential to building an agile and responsive research laboratory. Russell and ARL leadership foresee that as the Open Campus initiative allows ARL to form partnerships with industry, ARL builds business acumen by leveraging models of efficiency and lessons learned from our industry partners. This translates to more efficient laboratory management at ARL. Russell recognized that all levels of ARL must engage in executive-level thinking to build business acumen. It became essential for all ARL employees to have a big-picture understanding of how their roles were impacted by the ARL Technical Strategy. Leadership began to implement key drivers of business acumen, including:

- a command climate promoting open and collaborative research across traditional organizational and disciplinary boundaries;
- expanded mechanisms for collaborating and partnering with the private sector (including joint use of research space);
- active awareness of Army doctrine and Soldier lessons learned, and;
- streamlined business processes and practices across the laboratory enterprise.

From a historical perspective, Russell's vision represented a paradigm shift across many levels of the organization. ARL's old ways of thinking and of doing business were giving way to much more dynamic approaches made necessary by the evolving global environment. Both Russell and ARL leadership predict this new strategic framework will open up tremendous and far-reaching opportunities. Leadership foresees an enormous payoff, with these initiatives spurring significant S&T advances to accomplish power-projection superiority, information supremacy, lethality and protection superiority, and Soldier performance augmentation—all essential to the future Army's strategic land-power dominance. Leadership is implementing strategies reaching decades into the future so that today's Army is ideally positioned to become the Army of 2050—streamlined into an agile, adaptable, lethal, and resilient force with a greatly reduced "tooth-to-tail" structure possessing capabilities far superior to today's forces.

Dr. Philip Perconti

Transition of Leadership: Enabling the Deep Future

In 2016, Dr. Thomas Russell was reassigned to the position of Deputy Assistant Secretary of the Army for Research and Technology. This unforeseen departure led to Dr. Philip Perconti taking the reins as acting director of ARL and subsequently named permanent ARL director in June of 2017. Dr. Perconti expanded upon the vision and direction set forth by Dr. Russell through the Research Management and Leadership Strategy, by establishing Essential Research Areas (ERAs) to focus ARL's resources on the Army's highest scientific research priorities. The ERAs were designed to enable the Army to dominate the theater of operations, project national power robustly, and execute combined arms maneuver in air, land, maritime, space, and cyberspace domains. Executing the ERAs required the implementation of a cumulative, converged, linked research programing of ARL's on-going activities. Thereby driving an ARL corporate strategy to ensure the Army's future force maintains decisive overmatch in an ever increasingly complex global environment.

Prior to becoming the Director of ARL, Dr. Perconti was the director of ARL's SEDD Director where he was responsible for leading and transitioning the Army's primary basic and applied research programs in sensors, electronics, signal processing, and power and energy component technologies. Prior to joining ARL in January 2013, Dr. Perconti was the director of the Science and Technology Division of CERDEC's Night Vision and Electronic Sensors Directorate for 12 years.

Dr. Perconti received his bachelor's degree in electrical and computer engineering from George Mason University, a master's degree in electrical and computer engineering from The Johns Hopkins University, and a doctorate in electrical and computer engineering from The George Washington University. He is a Fellow of the Military Sensing Symposium, a member of the Eta Kappa Nu Electrical Engineering Honor Society of the Institute of Electrical and Electronics Engineers, the Army Acquisition Corps, the Technical Cooperative Program Sensors Multi-Sensor Integration Panel and the Institute of Electrical Engineers, and serves as chairman for the Military Sensing Program, Passive Sensors Committee.

Focusing the S&T Paradigm: Essential Research Areas

ARL investment strategy focuses on addressing the Chief of Staff of the Army's (CSA) priorities and preparing the Army of the future to fight and win in a complex world. Under Perconti's leadership, ARL identified nine ERAs that are critical to reducing technology uncertainty, addressing knowledge gaps, and identifying technology risk associated with delivering new capabilities. While the ERAs do not encompass the entire breadth of the ARL S&T portfolio, they embody the S&T the Army deems essential to delivering advanced capabilities to the future Warfighter. The nine ERAs are Human-Agent Teaming, Artificial Intelligence and Machine Learning, Accelerated Learning for a Ready and Responsive Force, Cyber and Electromagnetic Technologies for Complex Environments, Distributed and Cooperative Engagement in Contested Environments, Manipulating Physics of Failure for Robust Performance of Materials, Tactical Unit Energy Independence, Science of Manufacturing at the Point of Need and Discovery.

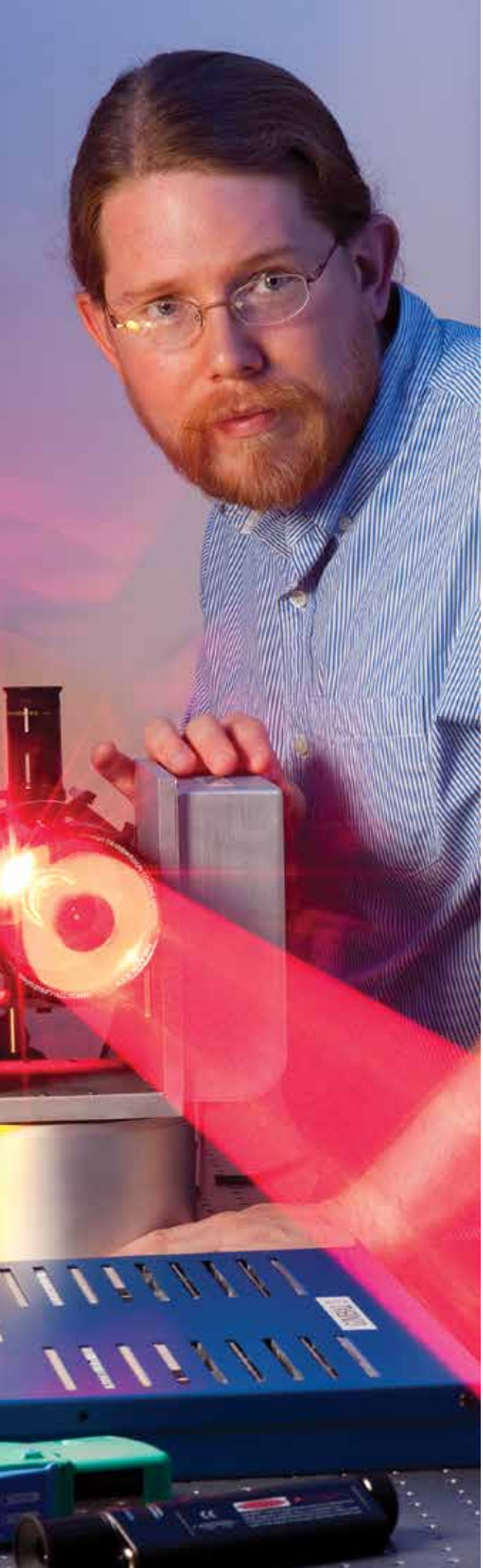
The ERAs have been developed with the understanding that

Diagram depicting Essential Research Areas.

future warfare will be fought across all five domains—land, air, space, cyberspace, and maritime—and among three realms: the physical, the domain of activities defined in space and time by the laws of physics; the informational or virtual, the domain of activities defined by thought and perception; and cultural (or human), the domain of activities defined by the interaction of people and societies. In each ERA, technical gaps with Army outcomes have been identified that are critical in the path of progress in these ERAs.

Upon his assumption of responsibilities as ARL's newest director, Perconti published the Executive Summary to the ARL Technical Strategy, which outlines the lab's future S&T portfolio strategy that keeps the S&T campaigns intact while establishing a critical path to ensure ARL's ERAs were woven into ARL's long-term strategy. Perconti realized that ARL's S&T portfolio must be strategically balanced to enable future technological overmatch. This strategy is shaped through the priorities of ARL's higher headquarters, the Army Materiel Command and the Research, Development, and Engineering Command, with the intent of operationalizing S&T for the Army. ARL's S&T program is grounded in a vision of the future that provides Army leadership with the knowledge and understanding to inform decisions on options for disruptive Warfighting capabilities with reduced uncertainty and calculated risk. Given its best assessment of the future threat environment, ARL aligns and synchronizes research to address the CSA's priorities and fill Training and Doctrine Command (TRADOC) gaps for emerging concepts.

In development of the ERAs, Perconti set strategic goals in areas deemed essential to enable the CSA's priorities and shape how the future Army will fight and win in a complex world. Through its S&T Campaigns, ARL defines specific technical goal to address not just its ERAs, but also its foundational mission program to discover, innovate, and transition. Progress toward these technical goals are assessed annually and the assessments are used to determine the near-term execution plan and outline a path toward becoming the Nation's premier laboratory for land forces.



Glossary of Acronyms and Abbreviations

AAN Army After Next

ACIS Advanced Computational and Information Sciences

ADPA American Defense Preparedness Association

AFATDS Advanced Field Artillery Tactical Data System

AFOSR Air Force Office of Scientific Research

AHPCRC Army High-Performance Computing Research Center

AIMTB Artificial Intelligence Module Test Bed

ALBE Air-Land Battlefield Environment

ALC Adelphi Laboratory Center

AMARC Army Materiel Acquisition Review Committee

AMC Army Materiel Command

AMMRC Army Materials and Mechanics Research Center

AMRA Army Materials Research Agency

AMUS Aerostat-Mounted UTAMS System

APG Aberdeen Proving Ground

ARDEC Armament Research, Development and Engineering Center

ARL Army Research Laboratory

ARO Army Research Office

ASA (RDA) Assistant Secretary of the Army for Research, Development and Acquisition

ASHPC Advanced Simulation and High-Performance Computing

ASK Armor Survivability Kit

ASL Atmospheric Sciences Laboratory

ASU Arizona State University

ATACMS Army Tactical Missile System

AVP Aerial Vehicle Pilots

BAA Broad Agency Announcement

BBI Brain-to-brain Interface

BED Battlefield Environment Directorate

BIDS Biological Integrated Detection System

BiLAT Bilateral Negotiation Simulation

BLUEFOR Representing U.S. Forces

BMI Brain–machine Interface

BRAC Base Realignment and Closure

BRL Ballistic Research Laboratory

BRLESC Ballistic Research Laboratory's Electronic Scientific Computer

BVLD Ballistic Vulnerability/ Lethality Division

C2V Command and Control Vehicle

CA Cooperative Agreement

CAD Chemical Agent Disclosure

CASEL Cognitive Assessment, Simulation, and Engineering Laboratory

CB Conex Box

CECOM Communications–Electronics Command

CENTCOM U.S. Central Command

CERDEC Communications-Electronics Research, Development and Engineering Center

CFD Computational Fluid Dynamics

CH Constant Hawk

CICC Corporate Information and Computing Center

CIMP Center for Intrusion Monitoring and Protection

CISD Computational and Information Sciences Directorate

CIWS Close-in Weapons System

CKEM Compact Kinetic-Energy Missile

CMRL Combat Materiel Research Laboratory

CONUS Contiguous United States

C-QWIP Corrugated-Quantum Well Infrared Photodetector

CRADA Cooperative Research and Development Agreement

CSA Chief of Staff of the Army

CTPS Combat Trauma Patient Simulation

CTA Collaborative Technology Alliance

DA Department of the Army

DARPA Defense Advanced Research Projects Agency

DASA Defense Atomic Support Agency

DCL Director of Corporate Laboratories

DCGS-A Distributed Common Ground System-Army

DCSTPM Deputy Chief of Staff for Technology Planning and Management

DIA Defense Intelligence Agency

DICE Distributed Incident Collaborative Environment

DLWPS Doppler LiDAR Wind Profiling System

DMR Defense Management Review

DNA Defense Nuclear Agency

DoD Department of Defense

DOE Department of Energy

DOFL Diamond Ordnance Fuze Laboratories

DRI Director's Research Initiative

DSI Director's Strategic Initiative

DSP Detector Special Purpose

EAR Environment for Auditory Research

ECH Enhanced Combat Helmet

ECOM Electronics Command

EDVAC Electronic Discrete Variable Automatic Computer

EEG Electroencephalography

EFP Explosively Formed Projectile

EM Electromagnetic

EMP Electromagnetic pulses

EMVAF Electromagnetic Vulnerability Assessment Facility

ENIAC Electronic Numerical Integrator and Computer

EPR Enhanced Performance Round

EPS Electromagnetic Protection System

EPSD Electronic and Power Sources Directorate

ERA Essential Research Area

ERADCOM Electronics Research and Development Command

ERDC-CRREL Engineer Research and Development Center Cold Regions Research and Engineering Laboratory

ETC Electrothermal Chemical

ETDL Electronics Technology and Devices Laboratory

ETT Embedded Training Team

FAA Functional Area Analysis

FALCon Forward Area Language Converter

FAST Field Assistance in Science and Technology

FCS Future Combat Systems

FDC Flexible Display Center

FedLab Federated Laboratory

FIRST For Inspiration and Recognition of Science and Technology

FK6 Fragment Kit 6

FLIR Forward-Looking Infrared

FMTV Family of Medium Tactical Vehicles

FPA Focal-Plane Array

Frag Fragment

FY Fiscal Year

GCS Ground Combat Systems

GEMS Gains in the Education of Mathematics and Science

GOCO Government-Owned, Contractor-Operated

GPRA Government Performance and Results Act of 1993

GPR Ground-Penetrating Radar

GPS Global Positioning System

HBCU/MI Historically Black Colleges and Universities/ Minority Institutions

HDDC Harry Diamond Development Center

HDL Harry Diamond Lab

HEL Human Engineering Laboratory

HERO Hazards of Electromagnetic Radiation to Ordnance

HMMWV High-Mobility, Multipurpose Wheeled Vehicle

HPC High-Performance Computing

HPCMP High-Performance Computing Modernization Program

HRED Human Research and Engineering Directorate

ICBM Intercontinental Ballistic Missile

ICE IED Countermeasure Equipment

IED Improvised Explosive Device

IEWTPT Intelligence Electronic Warfare Tactical Proficiency Trainer

IFAK Improved First Aid Kit

IMETS Integrated Meteorological System

IMPRINT Improved Performance Research Integration Tool

INSCOM U.S. Army Intelligence and Security Command

IR Infrared

IRCM Infrared Countermeasure

ISI Improved Sensor Integration

IST Information, Science and Technology

IT Information Technology

JERRV Joint EOD Rapid Response Vehicle

JIEDDO Joint IED Defeat Organization

JPO Joint Program Office

JSHS Junior Science and Humanities Symposium

JTAPIC Joint Trauma Analysis and Prevention of Injury in Combat

JTRS Joint Tactical Radio System

JUONS Joint Urgent Operational Need Statement

LABCOM U.S. Army Laboratory Command

LANL Los Alamos National Laboratory

LCP Lithium Cobalt Phosphate

LEAD Letterkenny Army Depot

LFT&E Live Fire Test and Evaluation

Li Lithium

LLNL Lawrence Livermore National Laboratory

LOSAT Line-Of-Sight Antitank Missile

LTAS Long Term Armor Strategy

LVSR Logistics Vehicle System Replacement

LWIR Long-Wave Infrared

M1A1 Abrams Tank

MANPRINT Manpower and Personnel Integration

MASINT Measurement and Signals Intelligence

MAST Micro Autonomous Systems and Technology

MASTOR Multilingual Automatic Speech-to-Speech Translator System

MATT Multi-Amputation Trauma Trainer

MAV Micro Air Vehicle

MAWRS MRAP Armor Weight Reduction Spiral

MCIT Mobile Counter-IED Interactive Trainer

MEMS Microelectromechanical Systems

METCM Meteorological Computer Message (artillery)

METB3 Ballistic Meteorological Message for Surface to Surface Fires

MI Military Intelligence

MIT Massachusetts Institute of Technology

MLRS Multiple Launch Rocket System

MMBL Mounted Maneuver Battlespace Laboratory

MRAP Mine Resistant Ambush Protected

MRDEC Missile Research, Development, and Engineering Center

MSC Major Subordinate Command

MSRC Major Shared Resource Center

MTL Materials Technology Laboratory

MTVR Medium Tactical Vehicle Replacement

MWARS MRAP Armor Weight Reduction Spiral

MyWIDA My Weather Impacts Decision Aid

NASA National Aeronautics and Space Administration

NBC Nuclear, Biological, and Chemical

NBS National Bureau of Standards

NIST National Institute of Standards and Technology

NLOS Non-Line of Sight

NSRDEC U.S. Army Natick Soldier RD&E Center

NVESD Night Vision and Electronic Sensors Directorate

OCO Overseas Contingency Operations

OEF Operation Enduring Freedom

OIF Operation Iraqi Freedom

OP Outreach Program

OPFOR Opposing Forces

ORDVAC Ordnance Discrete Variable Automatic Computer

OSUS Open Standards for Unattended Ground Sensors

PED Processing, Exploitation and Dissemination

PEO Program Executive Office

PIF Prototyping and Integration Facility

PM Program Manager

PM CEH Project Manager Counter Explosive Hazard

PM RUS Project Manager Robotics and Unmanned Sensors

PSD Physical Sciences Directorate

PTDS Persistent Threat Detection System

QE Quantum Efficiency

QRI Quick Reaction Initiative

RCTA Robotics Collaborative Technology Alliance

R&D Research and Development

RDEC Research, Development, and Engineering Center

RDECOM Research, Development and Engineering Command

RDL Research and Development Laboratory

REF Rapid Equipping Force

RF Radio Frequency

RFAST-C RDECOM Field Assistance in Science and Technology Center

RMLS Research Management and Leadership Strategy

RPDA Ruggedized Personal Digital Assistant

RPG Rocket-Propelled Grenade

R-QWIP Resonator-Quantum Well Infrared Photodetector

RTP Research Triangle Park

RWS Remote Weapons Station

S3I Signatures, Sensors, Signal and Information Processing Directorate

S&E Science and Engineering

S&T Science and Technology

SBIR Small Business Innovative Research

SEDD Sensors and Electron Devices Directorate

SETAF Southern European Task Force

SEMASC Specialty Electronic Materials and Sensors Cleanroom

SEN Sensors Directorate

SLAD Survivability/Lethality Analysis Directorate

SLV Survivability, Lethality, and Vulnerability

SOCOM Special Operations Command

SOFC Solid Oxide Fuel Cell

SoS System-of-Systems

SPEAR Soldier Performance and Equipment Advanced Research

SRI Strategic Research Initiative

SS-RICS Symbolic Sub-symbolic Robotics Intelligence Control System

ST Senior Research Scientist

STACA Science and Technology Acquisition Corps Advisor

STARS Science and Technology Academic Recognition System

STAT Science and Technology Assistance Team

STEED Statistical Translation Engine for English-to-Dari

STRI Simulation, Training and Instrumentation

STTR Small Business Technology Transfer

TAB Technical Advisory Board

TAIS Army Tactical Airspace Integration System

TAP Tactical Advanced Power

TARDEC Tank Automotive Research, Development, and Engineering Center

TC3 Tactical Combat Casualty Care

TERM Tank Extended-Range Munition

TFT Thin-film Transistor

THAAD Theater High-Altitude Area Defense

TMS Transcranial Magnetic Stimulation

TOPS Thrown Object Protection System

TPW Technology Planning Workshop

TRADOC Training and Doctrine Command

TREE Transient Radiation Effects on Electronics

UARC University Affiliated Research Center

UAS Unmanned Aircraft System

UGS Unattended Ground Sensors

UGV Unmanned Ground Vehicle

UHMWPE Ultra-High Molecular Weight Polyethylene

USAICS U.S. Army Intelligence Center and School

USAMRMC U.S. Army Medical Research and Materiel Command

USARAF United States Army Africa

UTAMS Unattended Transient Acoustic MASINT Sensor

UV Ultraviolet

V Volt

VA U.S. Department of Veterans Affairs

VAL Vulnerability Assessment Laboratory

VMEBus Versa Modular Eurocard bus

VTC Vehicle Technology Center

VTD Vehicle Technology Directorate

WES Waterways Experiment Station

WIAMan Warrior Injury Assessment Manikin

WMRD Weapons and Materials Research Directorate

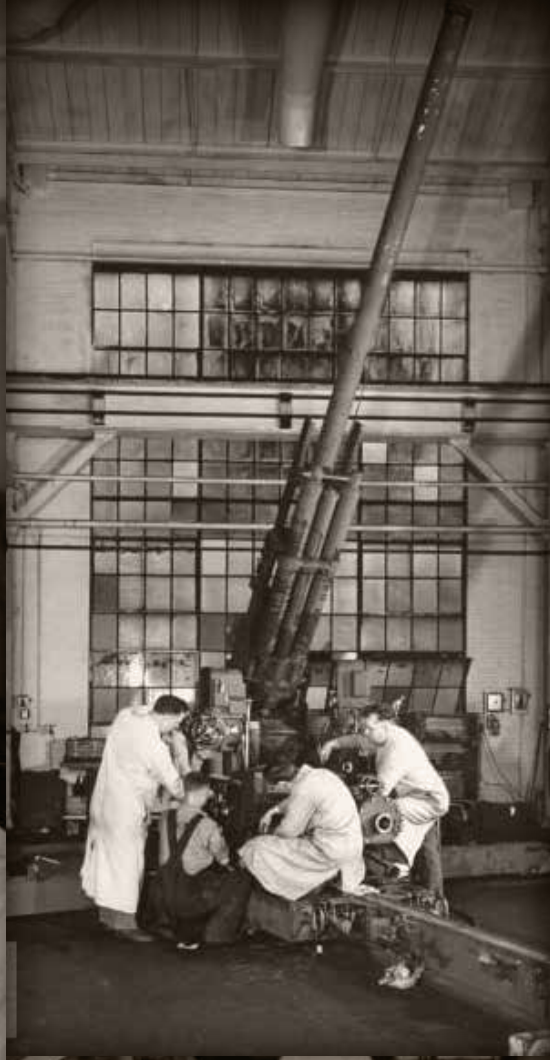
WRAIR Walter Reed Army Institute of Research

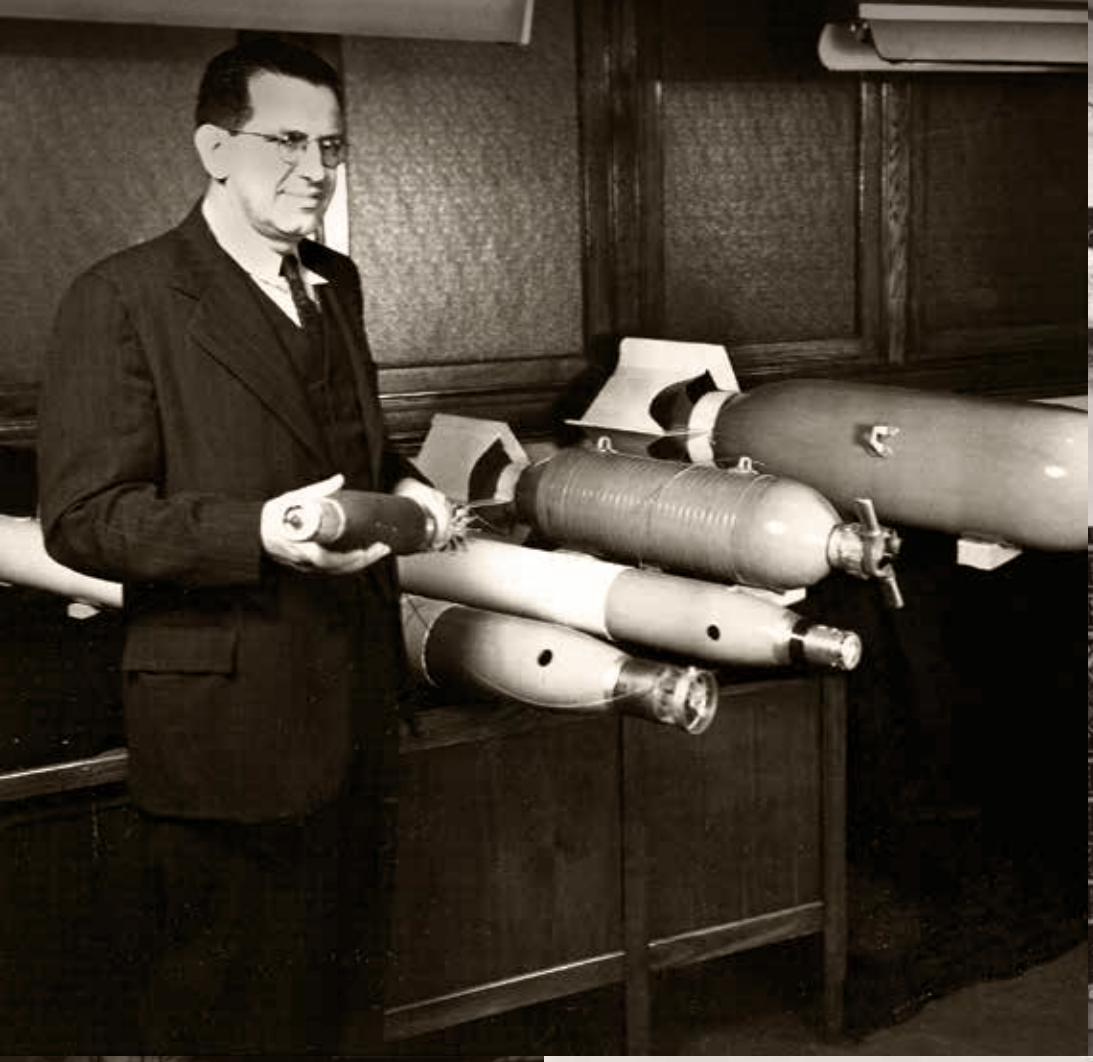
WRE–N Weather Running Estimate–Nowcast

WSMR White Sands Missile Range

XUV Experimental Unmanned Vehicle

WIPERS





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