Army Basic Research

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"The vastness of return is illustrated by the fact that the total cost of all basic research, from Archimedes to the present, is less than the value of 10 days of the world's present production."

Victor Weisskopf
Physics Today, August 1969

Basic research is a process that seeks to discover certainty in an uncertain world. This is achieved through the integrated application of systemic observations, theories, experimental methods and models of natural phenomena and instrumentation to make precise measurements of fundamental phenomena. An important outcome of basic research is the understanding of, and the ability to reliably predict, natural phenomena. When exploited through human imagination, this knowledge creates a future rich in innovative technologies for both military and commercial applications. Basic research's fundamental role has been demonstrated numerous times throughout human history and accounts for the vast majority of technologies and capabilities we enjoy today.

Three ARL scientists work on a II-VI Molecular Beam Epitaxy (MBE) machine that is used at ARL to create thin layers of mercury cadmium telluride for infrared sensors. (Photo courtesy of ARL.)

Below are some examples of Army-funded basic research that resulted in entirely new discoveries and enabled revolutionary capabilities:

- The principles for the maser and laser by Dr. Charles Townes (Columbia University), 1964 Nobel Prize winner in physics; and development of non-linear optics and laser spectroscopy by Drs. Nicolaas Bloembergen (Harvard University) and Arthur Schawlow (Stanford University and Bell Labs), who shared the 1981 Nobel Prize in physics for this work. These three scientists' efforts have made the laser ubiquitous in weapon systems across the battlefield and in commercial applications throughout the world.
- Fundamental work on atomic beams, including work that provides the basis for modern timekeeping, conducted by Dr. Gerald Zacharias. Another Army-supported researcher, Dr. Hans Dehmelt, who won the 1989 Nobel Prize in physics, developed some of the early ideas for laser cooling, which have now led to super-precise ion clocks. Dr. Steven Chu, 2001 Nobel laureate in physics, also supported by the Army, developed Zacharias' fountain clock concept into a reality using laser cooling ideas. This is currently the most accurate time standard in the world (used by the National Institute of Standards and Technology and DOD). Ultra-precise time is the foundation for the Global Positioning System, essential for today's navigation and precision-guided munitions.

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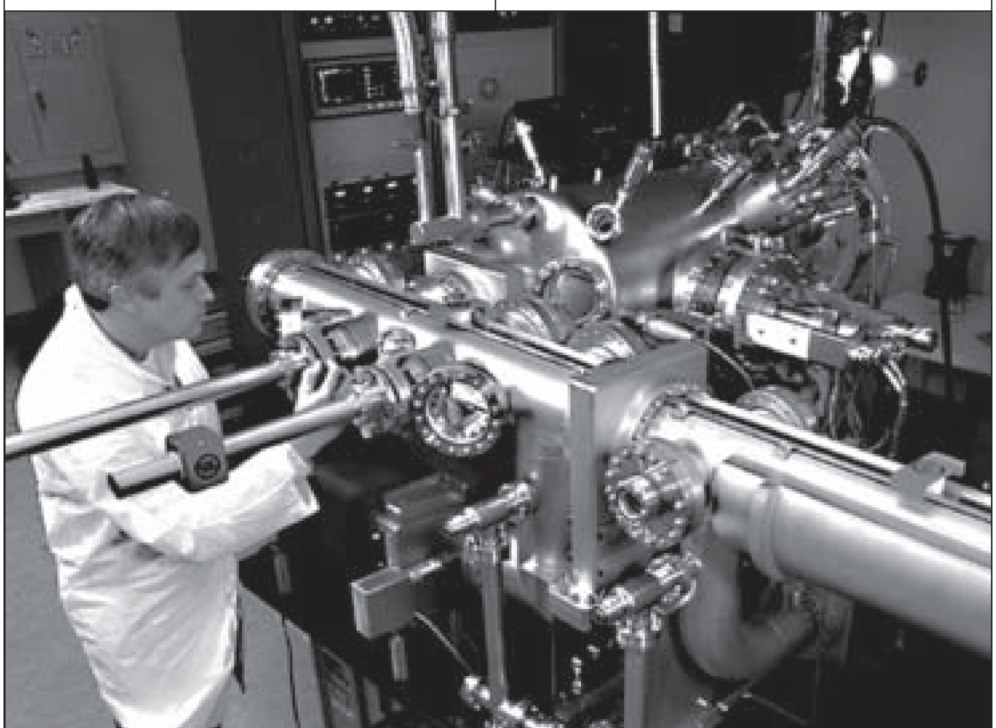
- Development of the universal Computer Aided Design of integrated circuits (IC) and the IC process modeling tools by Drs. Donald Pederson and Robert Dutton; and the development of semi-conductor heterostructures used in all modern semiconductor high-speed electronics, detectors and light emitters by Herbert Kroemer (University of California-Santa Barbara), who won the 2000 Nobel Prize in physics for this work. The combination of integrated circuits with semiconductor heterostructure devices has revolutionized all DOD electronic and optoelectronic systems, providing compact, ruggedized Army communication and sensor systems with increased functionality at lower cost.

Army basic research's goal is to ensure that the Army has overwhelming land-warfighting capabilities unmatched by any future adversaries. This goal's achievement will be accomplished through the investment in talented and knowledgeable people, state-of-the-art equipment and facilities and basic research areas judged relevant to the Army's mission. This strategy ensures that the Army is at the forefront of knowledge exploitation essential to its land-warfare mission. A wide range of investments supporting this strategy involve numerous academic, industrial and Army in-house organizations that are involved in the discovery and maturation of new knowledge for the purpose of advancing Soldier capabilities.

Army Educational Outreach Program (AEOP)

The Army's investment in people begins with programs geared to spark the interest of middle and high school students in the areas of science, mathematics and technology (SMT). AEOP



An ARL scientist works on a III-V MBE machine, one of four at ARL. The III-V MBE machines are used to create several kinds of semiconductor materials and structures, including gallium arsenide-based materials for Quantum-Well Infrared Photodetectors, gallium antimonide/indium arsenide for Type II Superlattice detectors and semiconductor lasers and gallium nitride-based materials for ultraviolet sources and detectors. (Photo courtesy of ARL.)

encourages young people to engage in Army-sponsored SMT competitions and provides opportunities for them to work with researchers at Army-funded universities. The AEOP includes programs that provide interaction between students and researchers at Army laboratories to become familiar with the pioneering research work performed by Army scientists and engineers in support of our Nation's defense.

Outreach to Academia and Industry

Approximately 60 percent of the Army's basic research funding is "extramural," directed mainly toward academia and industry. The Army funds basic research activities in academia through its Single Investigator Program (SIP), Army University Affiliated Research Centers (UARCs), University Research Initiatives (URIs) program and Army Centers of Excellence (COEs). Each of these investments emphasizes various aspects of fundamental basic research, education and training. For the next generation of scientists and engineers, the Army supports graduate education and training programs at scores of U.S. universities and colleges. Graduate students trained in the disciplines of basic research generally go on to work in industry, Army labs or leading universities.

SIP

The SIP involves support of focused research challenges within Army-relevant research disciplines led by senior faculty members at universities. Typically, these investigations involve a small team of supervised graduate and postdoctoral students seeking to advance knowledge on the frontier of Army-relevant disciplines, while achieving their goal of furthering their scientific training. These efforts are modestly funded and long-term, involving multiyear research grants in relatively focused areas of research.

UARCs

Occasionally, opportunities arise to advance a major new capability through a sustained long-term multidisciplinary effort. To exploit these opportunities, the Army has created UARCs in the areas of Soldier protection, hypervelocity lethality, simulation and training and full-spectrum dominance. Each center brings together a collection of specific basic research disciplines to focus on significant technical challenges involving a sustained effort over time. The centers partner with industry and Army labs to transition new knowledge and novel technology concepts for further development. The centers also take advantage of knowledge and expertise that reside within Army labs and industry to further advance their research work.

> Another example of Army-unique research is the work conducted at the Medical Research and Materiel Command, the lead DOD organization for infectious disease research and combat casualty care.

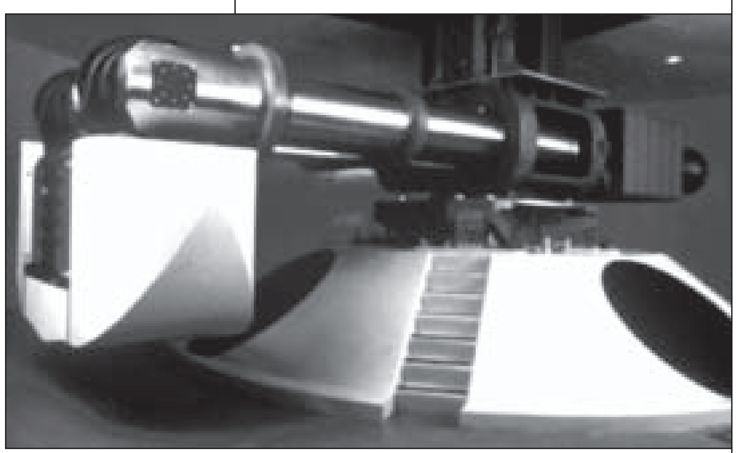
URIs

Through the Army's URIs, virtual centers are created to address more focused research challenges involving shorter term multidisciplinary efforts. These research efforts cut across a number of universities with faculty members who are experts in specific disciplines. They are modestly funded and typically involve 5-year efforts.

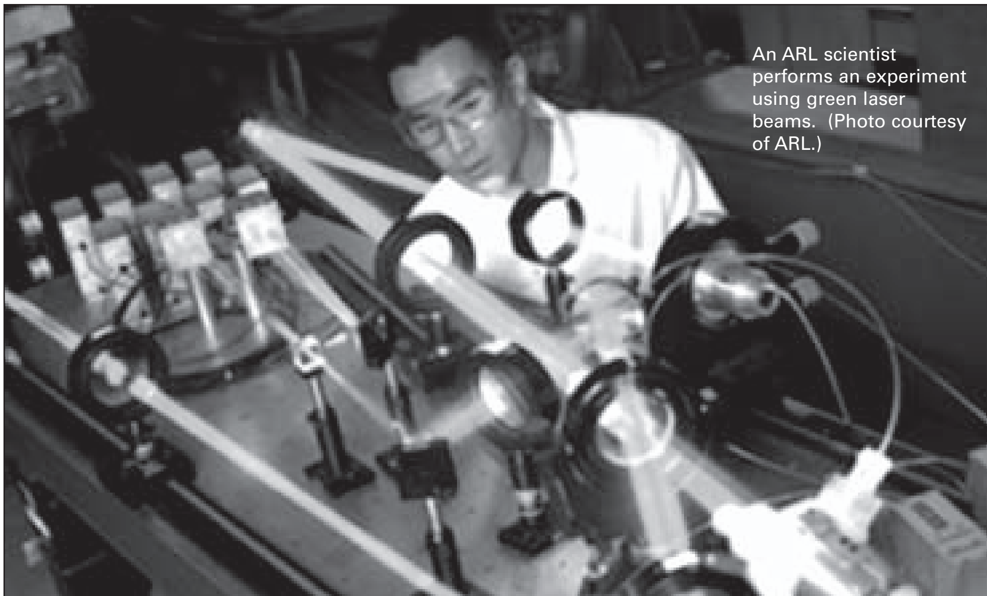
COEs

While creating new technological opportunities is important in realizing new capabilities, there are technology areas for which the Army has enduring needs, such as rotorcraft, automotive, microelectronics, materials and information sciences. Graduate student training is critical to maintaining state-of-the-art capabilities in these areas. For this reason, the Army has created COEs that focus research efforts on expanding knowledge frontiers in these enduring areas.

Some basic research areas, while of great interest to the Army, involve relatively large investments from the commercial sector. These key areas include networks and communications, robotics, power and energy, sensors and decision aids. To leverage these large investments, the Army has created Collaborative Technology Alliances that involve partnerships between industry, academia and the Army Research Laboratory (ARL). This strategy incorporates the practicality of industry, knowledge expansion in these areas by our universities and Army scientists and engineers, who interpret, shape, mature and transition this research to Army programs.



This USACE centrifuge has a 6.5-meter radius and has been tested to its maximum payload of 8,000 kilograms at 143 g's of acceleration. It is the largest centrifuge in the world and greatly reduces the elapsed time required to conduct environmental science experiments. (Photo courtesy of USACE.)



An ARL scientist performs an experiment using green laser beams. (Photo courtesy of ARL.)

Approximately 40 percent of the Army's basic research program is conducted in-house in Army labs. The overwhelming majority of this work is Army-unique research conducted at labs with specialty facilities. For example, the U.S. Army Corps of Engineers (USACE) has the world's largest centrifuge that is used to reduce the time required to perform experiments in environmental science for which USACE is the lead DOD organization. USACE also has unique testing and research facilities in the areas of force protection, situational awareness and mobility assurance. For example, force protection facilities are used to experiment with new materials for various aspects of construction, with cumulative work conducted at these facilities over the years having played a critical role in the Pentagon's renovation that resulted in lives saved on Sept. 11, 2001.

Additionally, USACE's diverse fundamental and applied research business portfolio supports battlespace environments, military engineering, environmental quality and installations and civil works.

Another example of Army-unique research is the work conducted at the Medical Research and Materiel Command (MRMC), the lead DOD organization for infectious disease research and combat casualty care. At Fort Detrick, MD, MRMC has the only Level 4 containment facility in the Nation that is used to handle life-threatening microorganisms for which there are no vaccines or treatments. These facilities were used to expeditiously identify the anthrax bacterium strain disseminated in envelopes after 9/11. MRMC also performs basic research that supports our Soldiers throughout their life cycle, from entry into the Army to discharge, as well as their health care needs thereafter.

ARL

The largest component to the Army basic research program is performed at ARL, which conducts fundamental and applied research in the areas of weapons, materials, sensors and electronic devices, computational information sciences, man-machine interfaces and vehicle technology. ARL also conducts experiments in the ballistics area at its unique testing and research facilities. This research involves improving vehicle protection against landmines, the development of new forms of armor for combat vehicles and the individual Soldier and novel penetrators to combat emerging threats. It also uses these testing and research facilities to develop unique approaches to defeating penetrators, which threaten the survivability of Army combat systems.

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ARL is also developing an understanding of insensitive propellants and explosives that are insensitive to detonation but maintain their desired energetic characteristics. While it has a substantial in-house program, ARL constantly reaches out to the broader research community to ensure that it has the latest knowledge in critical areas as well as the most advanced research tools available today. ARL also provides technical and analytical products to its extended research community, which includes the Army Research, Development and Engineering Centers and the Army acquisition community.

The most important warfighting system in the Army is the individual Soldier. In addition to the equipment a Soldier relies upon when going into battle, the Soldier's preparation through training is extremely important. Soldiers today are expected to be multi-skilled and ready to conduct missions spanning major theater wars and small-scale contingencies, as well as stability and support operations.

ARI

The U.S. Army Research Institute (ARI) for the Behavioral and Social Sciences' role is to conduct basic

An ARL scientist performs X-ray analysis. (Photo courtesy of ARL.)

research that provides the foundation for selecting, training and developing our Soldiers and leaders. In addition, the program is developing human performance models that capture human behavior under a wide range of anticipated battlefield conditions. Because the Army is such a human-intensive organization, understanding human behavior through the work conducted at ARI is fundamental and critical to Army readiness and mission success.

To ensure the constant pool of innovative ideas in the pipeline of technology development, the Army basic research program funds In-house Laboratory Independent Research (ILIR). ILIR is used by Army labs to perform high-risk research and to attract eager young minds with state-of-the-art research knowledge and tools to work with senior Army scientists and engineers to stimulate innovation in the technology development process.

Prioritizing Basic Research

The key to success in basic research is selecting the right research challenges, choosing the right people to do the work and providing the right level of resources to maximize the likelihood of success. There are many factors that go into making judgments with respect to these issues. Prioritizing basic research challenges in terms of investment depends upon both internal and external factors. Research challenges are driven by questions that are significant to the particular field of investigation. The answers to these questions provide the next major advancement in knowledge that could significantly increase understanding within a scientific discipline or sub-discipline. The challenge is choosing questions that can be answered in one's lifetime. One is often reminded of the famous statement by Max Born, Nobel laureate in physics, "I know when I am doing research — when I don't know what I am doing." Uncertainty is a fact of life for those who perform

Past Army Basic Research investments provide the weapons, communication systems and protective body and vehicle armor Soldiers need today. Here, SPC Graig Harmeling, 940th Military Police Co., patrols the streets of Dawanyah, Iraq, March 31, 2005. (U.S. Army photo by SGT Arthur Hamilton.)

basic research, regardless of the context and scope of their expertise. Additionally, external factors play a significant role in deciding on investing in basic research.

Metrics

Likewise, metrics play an important role in measuring progress in basic research. Metrics typically involve quality, productivity, leadership and relevance — both to the field of investigation and to the organization performing the work. The reliability of basic research knowledge depends upon its openness to public scrutiny and criticism. This factor plays a very important role in assessing the quality of basic research work. It manifests itself in various forms of recognition after the work has been published through citations, invited talks, keynote speeches and awards.

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The National Academies have looked at this issue many times and its Committee on Science, Engineering and Public Policy has published metrics that provide the appropriate measurements of quality. Quality of research before the work is undertaken is decided through peer review involving leading professionals in the appropriate disciplines and subdisciplines. Such peer reviews also address relevance to the field of investigation.

Productivity

Productivity is often one of the most contentious issues because of the pressures to justify investments through results in the near term. It's a fundamental fact of life that basic research is an inefficient process by its very nature. The odds of success are overwhelming against those who perform basic research, because there are vastly more ways to imagine how nature works versus the actual way it does. Trying to tinker with making basic research investigations more efficient is more likely to impair the progress of discovery than improve it. Nevertheless, return on investment (ROI) is extraordinarily high, even given this "inefficiency."

Productivity can be measured by the number of papers published in professional journals, number of graduate students produced and number of conference proceedings published, among others. The open availability of basic research results to public scrutiny and criticism account for its great strength over human history. Over the long term, ROI can be judged, and studies indicate that ROI is greater than 25 percent — even taking into account failures.

The relevance of basic research is decided by knowledgeable project/product managers who are connected to the broader research community and their customers for the work performed. Basic research customers are the materiel developers who perform the more downstream aspects of research and development. The vast majority of basic research results have relatively broad application across technology areas, and this accounts for the great leverage derived from the investment.

Unlike other professions, those people involved in basic research tend to thrive on uncertainty because it fuels their intellectual curiosity. Richard Feynman, Nobel laureate in physics, once told a group of students attending his lectures, "Maybe some of you would like to join us on the greatest adventure the human mind has ever begun." For the Army, there is another very important reason for basic research. Our basic research investments will enable us to overcome the many technical challenges associated with Army transformation but, more importantly, will ensure that when our Soldiers are called upon to defend freedom and liberty anywhere in the world, they will come home safe and victorious.

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