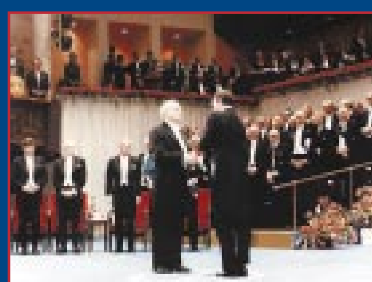
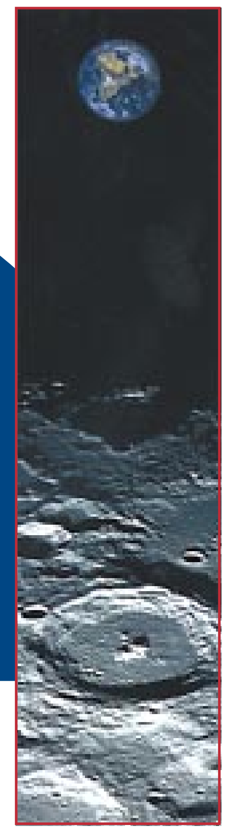
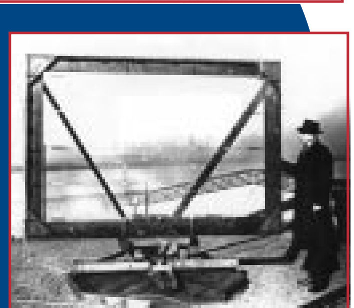
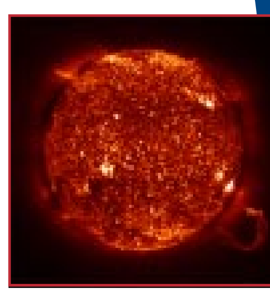
75th Anniversary
AWARDS FOR INNOVATION

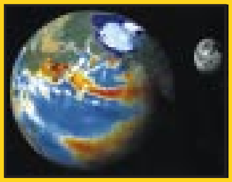





75 Years

NAVAL RESEARCH LABORATORY



This plot shows the deviation of Pacific Ocean sea surface temperatures in 1992-1993 from the mean values of the previous seven years. Remarkably, the warm anomaly extending from Japan to North America at 40° N can be traced back to anomalies caused in the tropics a decade earlier by the 1982-1983 El Niño climate event.

Launch of NRL's Vanguard rocket from Cape Canaveral. NRL was chosen in 1955 to develop and launch the United States' first space satellite, in conjunction with the International Geophysical Year. Vanguard (TV-4) was successfully launched on March 17, 1958, after two earlier attempts to reach orbit failed during the preceding December and February.

The Robert J. Collier Trophy, established in 1912, is given annually, "for the greatest achievement in aeronautics or astronautics in America." The 1992 Trophy was presented to the Global Positioning System (GPS) Team, composed of researchers from the Naval Research Laboratory, the U.S. Air Force, the Aerospace Corporation, Rockwell International Corporation, and IBM Federal Systems.

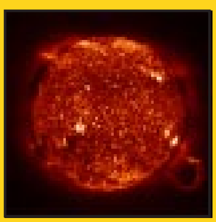
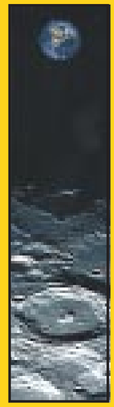
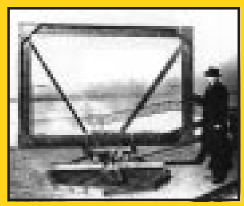


Image of the Sun in Helium II at 304 Å from the Extreme Ultraviolet Imaging Telescope on the SOHO satellite; bright active regions on the disk and a prominence off the southwest limb are visible.

Dr. Jerome Karle receives the 1985 Nobel Prize in Chemistry from King Carl Gustav XVI of Sweden. Dr. Karle and his colleague, Dr. Herbert Hauptman, shared the prize for their path-breaking work in crystal structure analysis.



This colorized image shows the full Earth over the lunar north pole as *Clementine* completes mapping orbit 102 on March 13, 1994. It is a clear day over Africa and the Arabian Peninsula. The angular separation between lunar horizon and Earth has been reduced for illustration purposes. The large crater at the bottom of the image is Plaskett at 180° west, 82° north.



Radar researcher and later Director of Research, Dr. Robert Page, standing on the roof of Building 1 with an antenna developed for performance comparison with the experimental 200 MHz radar installed on the USS *Leary*. The USS *Leary* served as a test platform for radar before its general introduction into the Fleet.

75 Years
NAVAL RESEARCH LABORATORY

Logo of NRL's Diamond Jubilee celebration, symbolizing the scope of science and technology development that has resulted from 75 years of research at the Laboratory—from the sea to the stars

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Celebrating 75 Years of Science and Technology Development for the Navy and the Nation

Naval Research Laboratory
1923-1998

CONTENTS

NRL Mission

To conduct a broadly based multidisciplinary program of scientific research and advanced technological development directed toward maritime applications of new and improved materials, techniques, equipment, systems, and ocean, atmospheric, and space sciences and related technologies.

The Naval Research Laboratory provides

- Primary in-house research for the physical, engineering, space, and environmental sciences
- Broadly based exploratory and advanced development programs in response to identified and anticipated Navy needs
- Broad multidisciplinary support to the Naval Warfare Centers
- Space and space systems technology, development, and support.

PREFACE

To commemorate the 75th anniversary of the Naval Research Laboratory (NRL), 75 innovations were formally recognized in a ceremony held on June 19, 1998 in Washington, D.C. These innovations were selected to reflect the breadth and the sustained impact of the Laboratory's program. They include some of NRL's most important contributions to science, technology, national security, and society. They are, however, not to be interpreted as the "Top 75." While a few are scientific in nature, such as the Nobel Prize-winning work in chemistry, most are technological innovations that have found use in military and/or industrial applications. All are unclassified. Therefore, some major contributions, in areas such as space systems and electronic warfare, could not be publicly recognized.

To avoid an overwhelming document, the "histories" of the 75 were written to be brief. Such brevity means that much of the fascinating story behind each innovation unfortunately remains untold. However, together these 75 histories tell a fascinating story of a 75 year-old laboratory through their simple and individual differences.

- Some innovations were achieved quickly. In order to meet the national goal of orbiting a scientific satellite during the International Geophysical Year, Project Vanguard pioneered the development of a three-stage rocket, tracking system, and satellite in the unprecedented time of 2-1/2 years.

  Others required many years to bring to fruition. The development of the first U.S. radar spanned the better part of two decades and was fielded in time for duty in the critical Pacific naval battles of World War II.

- Some were forged in times of war. A massive engineering effort, made in the midst of world conflict, resulted in a new uranium separation process that contributed to the Manhattan Project's success.

  Others were born in times of peace. During America's demobilization after World War II, synthetic lubricants were developed for new high-performance jet aircraft that would later prowl and own the Korean skies of the early 1950s.

- Some journeyed far beyond to test new technologies for defense missions. The deep space probe *Clementine* marked America's return to the Moon, imaging the entire lunar surface in unprecedented clarity, and setting new standards for "faster, better, and cheaper" satellite development.

  Others journeyed far beneath for answers to ill-fated missions. Deep sea search technologies were developed and used by expeditions to find the Navy's lost submarines, USS *Thresher* and USS *Scorpion*, which lay silent and broken on the dark ocean bottom.

- Some looked outward to decipher the cycle of creation and destruction within Nature's handiworks. A long-running series of solar studies were conducted to explain the Sun's effects on the Earth and, in turn, on military systems.

  Others looked inward to decipher that cycle within Man's handiworks. The principles of fracture mechanics were pioneered to understand how all structures, both military and civilian, are created with, or will contain, flaws that govern their eventual failure.

- Some revealed more about the world in which we live. The discovery of El Niño's long-term impacts promise a greater understanding of how decadal oceanic effects may influence North America's weather.

  Others revealed more about how we live in our world. New airport security technology was invented to detect explosives and narcotics, and may someday be used to detect landmines in countries afflicted with their presence long after hostilities have passed.

- Some served national interests in visible ways. The TIMATION concept led to invention and development of the first satellite prototypes of the NAVSTAR GPS, the revolutionary navigation system that played a critical role in the Gulf War and continues to shape our day-to-day lives with commercial applications.

  Others served in invisible ways. The development of the first satellite for electronic intelligence collection, previously highly classified, provided a revolutionary capability that shaped the very conduct of military operations in America's "long twilight struggle" with communism.

Together, the 75 histories demonstrate that NRL has made a profound difference, in times of war and in times of peace, through the creative work of scientists and engineers who serve in the nation's interest. The record shows that since 1923 NRL has helped make the U.S. Fleet the most formidable naval fighting force in the world, and by doing so, helped safeguard democracy throughout the titanic conflicts with fascism and communism.

The 75 histories are presented in chronological order, from NRL's beginnings to the present day. Many of the earlier histories required varying degrees of research, and some detective work, because the sands of time had partially obscured both the work and its supporting documentation. For those histories I thank the NRL Historian, Dr. David van Keuren, for his pursuit of reference material ranging from Laboratory files to the Library of Congress, and, for the later histories, I thank the many scientists and engineers who provided much useful information. I also wish to thank the Laboratory's Director of Research, Dr. Timothy Coffey, whose questions, comments, and advice enhanced the technical integrity of this document.

Finally, there are faded histories, some representing the fruit of a career's labor, that have receded irretrievably into the past. Regrettably, these could not be selected. Existing only as anecdotal stories now, they can no longer be linked unambiguously to NRL. Lost histories are avoidable only through constant efforts to document both the work and its impact. What Shakespeare called "the inaudible and noiseless foot of Time" should compel us to continuously make those efforts as the Laboratory moves forward and into the next millennium.

Don J. DeYoung
Executive Assistant to the Director of Research
June 1998

Gamma-Ray Radiography

Achievement

NRL's development of gamma-ray radiography was an important contribution to the nondestructive testing (NDT) of metal castings and welds. The method, devised by R.F. Mehl in the 1920s, entailed the use of gamma-ray radiation as a shadowgraphic technique to detect flaws in cast or welded steels.

This technique was first used to ascertain the extent of suspected flaws in the sternpost castings of the U.S. Navy's new 10,000-ton heavy cruisers.[1] The integrity of these post castings was vital to the successful operation of the vessels. Upon examination, the sternpost castings of these vessels were found to be faulty, and all 10 cruisers of the affected class subsequently had to be repaired to avoid operational failure. During the five-year period before World War II, this NDT technique facilitated the development of improved steel casting processes. By trial and nondestructive examination, the methods used in all stages of the molding, casting, and testing of steel were improved.

Impact

Mehl's work on the Navy's cruiser sternpost castings established gamma-ray radiography as an NDT technique in this country.[2] It also contributed to American seapower by improving the production of high-quality steel for armor, ship frames, and fittings.

In 1941, the American Society for Nondestructive Testing originated the biannual Mehl Honor Lecture series to honor R.F. Mehl for his pioneering work in gamma-ray radiography. The selected speaker is chosen for having made an outstanding contribution to the field of NDT.[3]

Primary Reference Documents

- Mehl, R.F., Doan, G.E., and Barrett, C.S., "Radiography by the Use of Gamma Rays," *Transactions of the American Society for Steel Treating*, Chicago, 1930.
- Barrett, C.S., Gezelius, R.A., and Mehl, R.F., "The Technique of Radiography by Gamma Rays," *Metals and Alloys*, December 1930.
- Mehl, R.F., "Report on Use of Gamma Rays for Radiographic Inspection of Sternpost and Keel Knuckle Casting," NRL Report, June 30, 1931.
- Mehl, R.F., "Radiography Inspection with Gamma Rays," *American Machinist*, Vol. 75, 278-80 (1931).

Individual(s) Being Recognized

R.F. Mehl

[1] Taylor, A.H., *The First Twenty-Five Years of the Naval Research Laboratory* (NAVEXOS P-549), April 1948, p. 26.

[2] *Materials Science and Technology Division History*, NRL/PU-6300-93-240 (May 1993), p. 91.

[3] Lambert, R.H., VADM, "A Tribute to Robert F. Mehl," *Materials Evaluation*, March 1972, p. 15.

First Operational Fathometer

Achievement

One of NRL's first accomplishments was the development of the Sonic Depth Finder. Today this device is called a fathometer. The depth finder used two transducers (U.S. Navy MV type hydrophones), one for transmissions in the frequency range near 1,000 Hz, and the second as a receiver. The method of measuring the transit time from the ship to the sea bottom and return was provided by a calibrated time delay between the outgoing and received signal. The repetition rate of the transmitted pulse was adjusted by the time delay control to make the received signal exactly coincide with the next transmitted pulse. The delay or depth was then read from the calibrated control.

This was the first acoustic depth finder to be placed in the U.S. Fleet for routine service. The depth finder was installed in the destroyer USS *Stewart* just prior to its departure for Manila via Gibraltar and the Suez Canal. Throughout the trip, soundings were taken at least every 20 minutes and at times as often as every minute. The depths encountered were up to 3,200 fathoms (5,900 m). In 1923 and 1924, depth finders were installed in the destroyers *USS Hull* and *USS Corey* which proceeded to make a 35,000 square mile survey off the coast of California. This was followed by installation of the equipment in several more Navy ships.[1] In 1934, improved depth-finding equipment using the QB transducer was installed in the Fleet.[2]

Impact

The device developed by H.C. Hayes was the first depth finder to be placed in the Fleet for routine service, greatly enhancing both surface and subsurface navigation.

Primary Reference Documents

- Hayes, H.C., "The Sonic Depth Finder," *Proceedings of the American Philosophical Society*, Vol. LXIII, No. 1 (1924).
- Stephenson, E.B., "Instructions for Echo Detection Equipment Model XQB," NRL Report RA55A227, August 1934.

Individual(s) Being Recognized

H.C. Hayes

[1] Hayes, H.C., "The Sonic Depth Finder," *Proceedings of the American Philosophical Society*, Vol. LXIII, No. 1 (1924).

[2] Stephenson, E.B., "Instructions for Echo Detection Equipment Model XQB," NRL Report RA55A227, August 1934.

Development of High-Frequency Radio Equipment

Achievement

In addition to NRL's pioneering work in radio propagation, the Laboratory's development of radio equipment, such as quartz-crystal frequency control, high-power transmitters, and receivers, led to the adoption and extensive utilization of high frequency (HF) by the Navy. Many of these NRL developments were adopted Navy-wide. For example, the quartz crystal oscillator circuit became the Navy standard oscillator circuit (1924),[1] and the Model RG receiver was the first to reach the Fleet in large numbers, becoming the Navy's principal receiver (1925) for over a decade and continuing in service during World War II.[2] NRL's HF radio equipment enabled the following achievements that, in turn, facilitated Navy-wide adoption of HF communications.

- An important factor in the Navy's adoption of HF was the performance of the NRL-developed HF transmitter and receiver carried by the Navy's dirigible USS *Shenandoah* during its transcontinental trip in 1924. This equipment accomplished the unusual feat of remaining in communication with NRL throughout the entire trip.[3]

- An NRL HF crystal-controlled transmitter communicated directly with the flagship USS *Seattle* during the cruise of the Fleet to Australia in 1925, a demonstration that contributed importantly to the Navy's adoption of HF.

- NRL maintained regular communications with the Antarctic base and support ships of Commander R.E. Byrd's expedition to the South Pole in 1929. The base and ships were equipped with NRL-designed and fabricated radio gear.[4]

Impact

NRL's advances in radio equipment made possible the Navy's adoption of that part of the radio-frequency spectrum known as the HF band (2 to 30 MHz). That technological advance had a profound effect on naval communications for the next 50 to 60 years during times of peace and war.

Primary Reference Documents

- Crossley, A., "Piezo-Electric Crystal-Controlled Transmitters," *Institute of Radio Engineers*, January 1927.

- Model RG Receiver, *Naval Radio and Sound Reports*, Project V-6E-26 (1925) and Project V-6E-27 (1927 and 1933).

- "Report of the Shenandoah Flight," *Naval Radio and Sound Reports*, December 1924.

Individual(s) Being Recognized

A.H. Taylor, L.C. Young, and L.A. Gebhard

[1] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 51.

[2] *Ibid.*, p. 60.

[3] *Ibid.*, p. 46.

[4] Taylor, A.H., *Radio Reminiscences: A Half Century* (NRL, Washington, DC, 1948), pp. 134-135.

Radio Propagation and the "Skip-Distance" Effect

Achievement

In 1925, NRL discovered the principles governing the "skip-distance" effect, which could not at the time be explained by the prevailing wave-propagation theory. The effect refers to radio signals that disappear after the "ground wave" dissipates but reappear at a considerable distance, varying with frequency, time of day, and season. Building upon the work of Sir Joseph Larmor, NRL's A. Hoyt Taylor and E.O. Hulburt jointly published in 1926 a modification of the theory that adequately explained the high-frequency "skip-distance" effect and that agreed with the experimental data.[1] In connection with this high-frequency-propagation work, NRL was the first to determine the frequency above which radio waves would penetrate the Earth's atmosphere and propagate through outer space, making radio communication in space possible.[2] NRL would later develop the world's first satellite communication system using the Moon as a relay.

NRL's work in this area further demonstrated that around-the-world HF transmissions could be obtained through successive reflections from the Earth's ionosphere with the proper choice of frequency, time of day, and season. Encirclement of the globe as many as three times in the same transmission and in both directions was observed in 1926. At the same time, reflections of the pulsed HF transmissions from Earth surface prominences, currently called "backscatter," were first observed. These HF "backscatter" observations generated the first concept of detecting and ranging on targets over very long distances.[3] This concept led to the later development of over-the-horizon radar by NRL.

Impact

NRL's seminal work in the field of radio propagation laid the foundation for modern HF wave-propagation theory; led to the Navy's acceptance of HF radio frequencies which had a profound effect upon naval communications for the next 50 to 60 years; led to NRL's development of the world's first satellite communication system; and led to the Laboratory's development of over-the-horizon radar.

Primary Reference Documents

- Taylor, A.H. and Hulburt, E.O., "Wave Propagation Phenomena at High Frequencies," *Naval Radio and Sound Reports*, September 1925.
- Taylor, A.H., "An Investigation of Transmission on the Higher Radio Frequencies," *Institute of Radio Engineers*, December 1925.
- Taylor, A.H. and Hulburt, E.O., "The Propagation of Radio Waves Over the Earth," *Physical Review*, Vol. 27, February 1926.

Individual(s) Being Recognized

E.O. Hulburt and A.H. Taylor

[1] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, pp. 43-45.

[2] *Ibid.*, p. 115.

[3] *Ibid.*, p. 44.

Invention of U.S. Radar

Achievement

Prior to the development of radar, Navy ships could track other ships or aircraft only by using optical techniques, sound ranging, or primitive radio direction finding. New methods of detection and ranging were necessary. In 1922,[1] while working on radio direction finders for aircraft, A.H. Taylor and L.C. Young noted a distortion of "phase shift" in radio signals reflected from a steamer on the Potomac River. In short, NRL had detected a moving ship by radio waves and had, as a result, discovered the radar principle. Eight years after the initial discovery of the radar principle, NRL scientists observed that reflections of radio waves from an airplane could also be detected.

From 1930 to 1940, NRL explored the use of radio for detection and ranging. In 1933, the use of a pulse technique to detect aircraft and ships was proposed by Young. R.M. Page made major advances over the next few years in the area of transmitters and receivers, eventually developing the highly important "duplexer" in 1936. The duplexer permitted the use of the same antenna for both transmitting and receiving. The pulse technique combined with the duplexer did away with the separate receiving and transmitting antennas that most of the other early radar developers employed. Page and Young received the patents for the duplexer, an invention that dramatically changed the nature of radar in the U.S. and abroad.

Impact

NRL invented and developed the first modern U.S. radar. The Laboratory developed the first operational radar, the XAF, and installed it on the battleship USS *New York* in 1939. It was rapidly transferred to industry for production. By the time of the attack on Pearl Harbor, there were 20 radar units in operation. Radar of this type contributed to the victories of the Coral Sea, Midway, and Guadalcanal.[2]

The invention of radar and the developments that flowed from it (e.g., monopulse radar and over-the-horizon radar) are among the foundations of modern military power. And, as a sensor for navigation and surveillance, radar plays a major role in the operation of civilian transportation systems, weather forecasting, astronomy, and automation, among other uses.

Primary Reference Documents

- U.S. Patents: No. 1,981,884 to Taylor, A.H., Hyland, L., Young L.C., "System for Detecting Objects by Radio," 1934; No. 2,512,673 to Page, R.M., "Radio Pulse Duplexing System," 1950; No. 2,688,746 to Page, R.M. and Young, L.C., "Impedance Control Coupling and Decoupling Systems," 1954.
- R.M. Page, Laboratory Notebook 171, Vol. III, March 1934; letter from NRL to the Bureau of Engineering, June 11, 1936, in File S-S67-5 #1, National Archives Building.

Individual(s) Being Recognized

R.M. Page, A.H. Taylor, and L.C. Young

[1] The discovery was made by researchers working for NRL's predecessor organization, the Naval Aircraft Radio Laboratory (NARL). When the facilities of the new Laboratory became available, the personnel and activities of NARL were transferred to become the major component of NRL's Radio Division.

[2] King, E.J., ADM, *U. S. Navy at War: 1941-1945* (Navy Department, Washington, DC, 1946), p. 226.

First Operational U.S. Sonar

Achievement

Underwater acoustic research was started by the U.S. Navy in 1917 with a small group at the U.S. Experiment Station in New London, Connecticut, investigating the use of underwater sound in World War I. This group, headed by H.C. Hayes, was eventually moved to NRL on its opening in 1923.

Hayes and his colleagues decided that the passive sonic devices used in World War I were seriously limited in the detection of enemy submarines. It was their belief that an *active* echo-ranging sonar operating in the 20 to 50 kHz frequency range would provide the best antisubmarine warfare system for surface ships. This approach was taken from the start of the new Sound Division at NRL, where practically all of the U.S. Navy's R&D in sonar prior to World War II was carried out.[1]

NRL's first effort was to develop an improved quartz-steel transducer. Extensive effort was placed on each of the components of the new sonar system, from the transducers and signal processing to the mechanical mounting and housing functions. Of particular significance was the development of the streamlined sonar dome to house the transducer. The dome enabled surface ships to make attacks at speeds up to 15 knots. In 1927, a number of U.S. naval vessels conducted tests with the NRL quartz-steel echo-ranging sonar. This was the first practical sonar based on the 1918 demonstration by P. Langevin, a French physicist, of the possibility of echo-ranging or "pinging" at supersonic frequencies.[2]

A later system, the Echo Detection Equipment Model QB, became the first operating sonar used by the U.S. Navy.[3]

Impact

Sonar transformed naval warfare by improving the ability of surface ships and submarines to detect and track enemy submarines.

Primary Reference Documents

- U.S. Patent No. 2,005,741 to Hayes, H., "Magnetostrictive Sound Generator," June 25, 1935.
- Klein, E., "Notes on Underwater Sound Research and Applications Before 1939," ONR Report ACR-135, September 1967.

Individual(s) Being Recognized

H.C. Hayes

[1] "Sonar Systems," NRL Achievements File (1982). This source cites as references: Sonar Detector, OPNAV P413-104, Navy Department, Chief of Naval Operations, Washington, DC, 1946; and "Notes on Underwater Sound Research and Applications Before 1939," by E. Klein, ONR Report ACR-135, September 1967.

[2] Baxter, III, J.P., *Scientists Against Time* (Little, Brown & Co., Boston, 1946), p. 171. This book is the brief official wartime history of the Office of Scientific Research and Development.

[3] Stephenson E.B., "Instructions for Echo Detection Equipment Model XQB," NRL Report RA55A227, August 1934.

Liquid Thermal Diffusion Process

Achievement

NRL was the first research center that General Leslie Groves visited when he took charge of the Manhattan Project in September 1942. The Laboratory at that time had the distinction of being the first U.S. government agency to support uranium research in 1939.[1] One result of that support was the first successful separation of uranium isotopes by the *liquid thermal diffusion process*.

The liquid thermal diffusion process was one of the three methods that the Manhattan Project used to obtain the enriched uranium necessary to form the first atomic bombs. In its early stages, the project employed two enrichment methods, but in 1944 the project hit a technical impasse. When the project's technical director, Dr. Robert Oppenheimer, became aware of NRL's research in using liquid thermal diffusion as a method of separating uranium isotopes, he ensured its use in the Manhattan Project.[2] In June 1944, the blueprints of NRL's liquid thermal diffusion plant were sent to Oak Ridge, Tennessee, and within three months the first columns of the Oak Ridge uranium separation plant were in operation. In the spring of 1945, Oak Ridge was producing uranium-235 for the Hiroshima weapon.[3]

The Laboratory's contribution was accomplished by a team led by P. Abelson at NRL's main site and later at a larger pilot plant built at the Philadelphia Naval Shipyard in 1943.[4] Abelson had invented the process earlier with NRL funding while he was employed by the Carnegie Institution of Washington. But, by 1941 he had become an NRL employee hired to investigate the scale-up of the process. Abelson also invented the first practical method for making uranium hexafluoride, a key material needed for the process of U-235 separation.[5]

Impact

The liquid thermal diffusion process was a significant contribution to the success of the Manhattan Project.

Primary Reference Documents

- Ruskin, R.E., "Separation of Isotopes," *NRL Progress Report* (September 1947).
- NRL memorandum, Subj. "Early History of Uranium Power for Submarines," May 1, 1946.

Individual(s) Being Recognized

P. Abelson

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[1] Hewlett, R.G. and Duncan, F., *Nuclear Navy:1946-1962* (University of Chicago Press, Chicago, 1974), p. 17; Bowen, H.G. VADM, *Ships, Machinery, and Mossbacks*, (Princeton University Press, 1954), p. 187.

[2] Rhodes, R., *The Making of the Atomic Bomb* (Simon & Schuster, Inc., New York, 1988), pp. 551-553.

[3] Hewlett and Duncan, p. 21.

[4] Smyth, H.D. "Atomic Energy for Military Purposes," cited in R.E. Ruskin, "Separation of Isotopes," *NRL Progress Report*, September 1947.

[5] Rhodes, p. 550.

Aircraft Radio Homing System

Achievement

When the first aircraft carriers—the USS *Langley* (CV-1) in 1922, and the USS *Lexington* (CV-2) and USS *Saratoga* (CV-3) in 1928—became available, there was need for a suitable means of navigating carrier-based planes to and from carriers and air facilities ashore.[1]

To solve this problem, NRL developed an aircraft radio homing system which was installed on all Navy aircraft carriers and their aircraft and which provided the primary means for aircraft to navigate back to their carriers during World War II. NRL's experimental model was installed on the carrier USS *Saratoga*, the flagship of the Commander, Aircraft Battle Force, then ADM E.J. King in May 1938. After witnessing its performance, ADM King, in a letter to the Navy Department dated August 29, 1938, recommended, "Adopt the (Model YE) system for primary means of homing radio aircraft." As a result, the system was installed on all aircraft carriers and used extensively in the Pacific during World War II.[2]

The homing system had a dual frequency which confused the Japanese admirals, who realized that U.S. aircraft were successful in returning to their carriers but did not understand how this was accomplished. In one reported incident during a battle in the Marianas, in the waning hours of daylight, when American planes followed the stricken enemy nearly to the limit their fuel would permit, most of the planes and their pilots were saved by homing back to their carriers in the dark with this equipment.[3]

Impact

This system had a major impact upon Pacific combat operations during World War II. The many glowing reports received from combat units and individual pilots whose lives were saved under trying circumstances attested to the importance and value of this NRL development. The British also eventually adopted this system for their carrier aircraft. The system continued in use until it was replaced by the Tacan system in 1960.[4]

Primary Reference Documents

- "Homing Devices for Aircraft," NRL File F42-1/25, 1935-1938.
- "Aircraft Homing Devices," NRL File F42-1/69H, National Archives; NRL CRMO.

Individual(s) Being Recognized

A.H. Taylor, R.B. Meyer, and M.H. Schrenk

[1] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 271.

[2] *Ibid*., p. 273.

[3] *Ibid*., p. 274; Taylor, A.H., *Radio Reminiscences: A Half Century* (Naval Research Laboratory, Washington, DC, 1948), p. 171.

[4] Gebhard, p. 274.

Proposal of a Nuclear Submarine

Achievement

The use of nuclear power to propel submarines under water was first proposed by an NRL physicist, R. Gunn, soon after fission was discovered in 1939.[1] In March 1939, Navy officials, one of which was Gunn, met with several civilian scientists who felt the military should be made aware of the vast possibilities of nuclear fission. Among the civilian scientists was Enrico Fermi. While most of the Navy personnel present at the meeting concentrated their attention on a nuclear weapon, Gunn was conceiving the idea of using nuclear power to drive the world's first nuclear submarine.[2]

Within a few days after this historic meeting, Gunn had requested and received $2,000 for preliminary work on the possibility of developing nuclear power for ship propulsion.[3] Later, in June 1939, in a memo to the NRL Director, Gunn stated:

> "Under certain special circumstances of bombardment by neutrons, the heavy element uranium dissociates into two other elements with the evolution of tremendous amounts of energy which may be converted directly into heat and used in a flash boiler steam plant. Such a source of energy does not depend on the oxidation of organic material and therefore does not require that oxygen be carried down in the submarine if uranium is used as a power source. This is a tremendous military advantage and would enormously increase the range and military effectiveness of a submarine."

In April 1946, NRL forwarded a report to the Bureau of Ships entitled "The Atomic Energy Submarine," which concluded that it was considered feasible to construct atomic power plants of a size and output suitable for ship propulsion. This report also marks the first interest in liquid metal coolants for reactors.[4]

Impact

NRL was first to conceive, propose, and investigate the use of nuclear power in submarine propulsion, and through subsequent efforts the Laboratory contributed to the planning and development of the world's first atomic-powered submarine, the USS *Nautilus*. The nuclear submarine is one of the most formidable weapons systems ever developed.

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- Abelson, P.H., Ruskin, R.E., and Raseman, C.J., NRL Memorandum to Director, Subj. "Atomic Energy Submarine," March 28, 1946.

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R. Gunn

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[2] Hewlett, R.G. and Duncan, F., *Nuclear Navy:1946-1962* (University of Chicago Press, Chicago, 1974), p. 16.

[3] NRL Memorandum, "Early History of Uranium Power for Submarines," May 1, 1946.

[4] Address by Honorable James H. Wakelin, Jr., Assistant Secretary of the Navy for Research and Development, before the 22nd Annual Meeting of the American Power Conference in Chicago, Illinois, March 29, 1960, p. 9.

Plan-Position Indicator

Achievement

When NRL demonstrated the first U.S. radar, the XAF, during Fleet exercises in 1939, it was observed that the radar's use could be facilitated by a display presenting a polar-coordinate map. Such a map would indicate the range and bearing of all objects "visible" to the radar.

To provide a polar-coordinate map-like display of targets, NRL originated the radar plan-position indicator (PPI) — the well-known radar scope with the round face and the sweeping hand — between 1939 and 1940.[1] It was developed independently in England and in the U.S. when neither country knew of the work in the other country.[2]

NRL's PPI was first utilized by incorporation in the experimental model of the SG radar, which was installed and demonstrated on the destroyer USS *Semmes* in April 1941. The Model SG (developed by The Radiation Lab and Raytheon) became the Fleet's first radar to be equipped with the NRL-developed PPI type of presentation. Nearly 1,000 Model SG radars were produced during World War II and many remained in service for nearly two decades.[3] The PPI would become particularly useful when "combat information centers" were established aboard command vessels in the Fleet.[4]

Impact

The PPI is now universally used by military and commercial interests of the world for the display of radar information for such functions as air and surface detection, navigation, aircraft traffic control, air intercept, and object identification.

Primary Reference Documents

- "Report of Progress Problem W5-2S," NRL letter to Bureau of Engineering, S-S67/36, ser. 135, February 26, 1940.
- U.S. Patent No. 2,779,939 to Page, R.M., "Indicating Systems," January 1957.

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R.M. Page

[1] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 193.

[2] Page, R.M., *The Origin of Radar* (Doubleday & Company, Inc, New York, 1962), p. 156.

[3] Gebhard, p. 187.

[4] Taylor, A.H., *The First Twenty-Five Years of the Naval Research Laboratory* (NAVEXOS P-549), p. 68.

Identification Friend-or-Foe Systems

Achievement

In the 1930s, neither the Army nor the Navy had a device that could adequately identify targets on the ground, sea, or in the air, particularly in overcast weather and at night. Identifying friendly planes returning to carriers under poor visibility was an especially serious problem. To solve the problem, NRL sought a solution through the use of radio waves.

NRL developed the first U.S. radio recognition identification friend-or-foe (IFF) system, the Model XAE, in 1937. This system provided coded transmissions from aircraft, which were received for identification aboard ship, and transmitted back to aircraft for verification. In 1939, NRL devised the first U.S. IFF system in which radar pulses received by a target ship or aircraft were repeated back to the radar and displayed as a pulse associated with the echo pulse on the scope. As part of this system, NRL's R.M. Page developed the first U.S. pulse transponder, basic to pulse IFF systems and pulse beacon systems.[1]

The Mark X IFF was a later radar beacon system developed by NRL. It was essential to the military because it reduced fratricide when utilizing beyond-visual-range weapons. By 1958 the FAA had established the Air Traffic Control Radar Beacon System (ATCRBS), essentially the civil version of the Mark X. The International Civil Air Organization later adopted the ATCRBS, making the Mark X the basis of the world's air traffic control system.

In 1948, NRL began research seeking a high-security IFF system. NRL's work, as well as the work of institutions such as the Air Force Cambridge Laboratory, led to the Mark XII IFF system in 1960.[2] It was the first IFF system to use cryptographic techniques to prevent deception where an enemy appears as a friend by using a captured transponder (the device giving the "yes" answer to interrogations), which had been experienced in World War II.

Impact

The first U.S. IFF system, NRL's Model XAE, met an urgent operational requirement to allow discrimination of friendly units from enemy units. In subsequent developments, the Mark X impacted U.S. and allied armed forces, as well as national and world civil airways, and the cryptographic Mark XII essentially nullified the threat of deception by an enemy using captured IFF transponders.

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- Cleeton, C.E., "Proposed System of Electronic Recognition," NRL P-3131, June 1947.
- Cleeton, C.E., "Coding and Security of Electronic Recognition and Identification Systems," NRL Report 2972, September 12, 1946.

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R. M. Page and C. Cleeton

[1] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 251.

[2] *Ibid.*, p. 259.

Monopulse Radar

Achievement

To overcome the angular limitations of existing radars, NRL developed the first monopulse radar in 1943. The monopulse technique makes angular determinations simultaneously on each individual received pulse. This new type of radar provided a tenfold improvement in angular accuracy over previous fire and missile control radars at the longer ranges.[1] The monopulse radar is now the basis for all modern tracking and missile control radars. Although monopulse radar was developed independently in other countries that often treated the work as classified, the Laboratory's R.M. Page holds the U.S. patent on this technique.

The monopulse technique was first applied to the Nike-Ajax missile system, which was the nation's U.S. continental air defense system. The radar of this system was patterned after NRL's experimental model. After additional improvements to provide a more compact and efficient monopulse antenna feed and lobe comparison waveguide circuitry, monopulse tracking radar became the generally accepted tracking radar system for the military and civilian agencies, such as NASA and the FAA. In fact, NRL's work eventually led to the AN/FPS16, developed jointly by NRL and RCA, which was the first radar designed especially for missile ranges. It was used to guide the launchings of the first U.S. space satellites, *Explorer I* and *Vanguard I*, at Cape Canaveral in 1958.[2]

Impact

The invention of monopulse (simultaneous lobing) tracking radar was a breakthrough in precision target tracking. Monopulse radar performance is critical to gunfire control, missile guidance, missile-range precision launch, and range safety, space vehicle tracking, FAA civil aircraft landing systems, Navy aircraft carrier landing systems, and target recognition.

Primary Reference Documents

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R.M. Page

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[2] *Ibid*., p. 200.

First American Airborne Radar

Achievement

Prior to the entry of the U.S. into World War II, and in anticipation of having to contend with the German submarine menace, NRL developed the first American airborne radar, the Model ASB, in 1941. During the war, it was known as the radar that fought the war from the air in the Pacific.[1]

It was the first operational U.S. airborne radar widely used for bombing, detection of ships and surfaced submarines, and airborne intercept. The Model ASB was the first radar to be used in carrier-based aircraft, employed in attacking and destroying Japanese ship convoys in the Pacific. It was also very effective against submarines because it tremendously widened the area that could be covered by patrol planes.[2]

Experience with this type of radar led to NRL's involvement in the UHF E2 Airborne Early Warning Radar, microwave intercept radar, and antisubmarine warfare periscope detection radars.

Impact

This radar saw extensive use during World War II, not just by the U.S. Navy and Army Air Corps, but also by the British military. It was installed almost universally in U.S. naval aircraft and became known as the "workhorse of Naval Aviation." Over 26,000 units were procured (from 1942 to 1944), the largest procurement of any model radar during the war.[3]

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A.H. Taylor, R.M. Page, and R.C. Guthrie

[1] Page, R.M., *The Origin of Radar* (Doubleday & Company, Inc, New York, 1962), p. 173.

[2] Taylor, A.H., *The First Twenty-Five Years of the Naval Research Laboratory* (NAVEXOS P-549), p. 215.

[3] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 201.

First Far-Ultraviolet Spectrum of the Sun

Achievement

In 1946, using a captured German V-2 rocket, NRL scientists led by R. Tousey obtained the first far-ultraviolet spectrum of the Sun from beyond the atmospheric boundary. NRL was not alone in the early attempts to measure the solar ultraviolet spectrum as Johns Hopkins University's Applied Physics Laboratory obtained excellent results only 6 months after NRL.[1]

The successful flight of October 10, 1946 carried cosmic ray detectors, pressure and temperature gauges, radio transmitters, and antennae to measure propagation through the ionosphere, as well as Tousey's spectrograph.[2] Although earlier flights had returned scientific data revealing cosmic-ray counts and pressure and temperature information, the successful retrieval of an ultraviolet spectrum of the Sun captured the attention of both the scientific and popular press. The *Washington Post* heralded the discovery of the "new ultraviolet" and reproduced samples of two spectra on page 1. The *New York Times*, *Times Herald*, and *Washington Star* all followed suit.[3]

Impact

Scientifically, NRL had extended the known spectrum of the Sun, but more significantly, this achievement marked the birth of both space-based astronomy and the U.S. Navy's space program.

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R. Tousey

[1] Friedman, H., "Reminiscences of 30 Years of Space Research," NRL Report 8113, August 1977.

[2] Newell, H.E. and Siry, J.W., eds., "Upper Atmosphere Research Report No. II," NRL Report R-3030, December 30, 1946.

[3] DeVorkin, D.H., *Science with a Vengeance* (Springer-Verlag, New York, 1992), pp. 143-144.

First Detection of X Rays From the Sun

Achievement

With the launch of an experiment aboard a V-2 rocket on September 29, 1949, NRL directly confirmed that X rays from the Sun are a principal cause of ionization in the E region of the Earth's ionosphere.[1] Additional experiments, aboard a Viking rocket flight and two Aerobee firings, later indicated that the solar X-ray spectrum is adequate to account for all of E-layer ionization.[2] This pioneering research opened the field of solar X-ray astronomy that the Laboratory explored so extensively in the 1950s and thus contributed profoundly to the understanding of the physical processes in the solar atmosphere. A practical benefit of this research includes the improved understanding of the effects of solar disturbances on radio communication and an improved ability to predict the influence of solar particle emissions on the radiation environment of manned space flight.

NRL's H. Friedman led the Laboratory's pioneering efforts in X-ray astronomy. In 1969, he received the National Medal of Science, the U.S.'s highest honor for scientific achievement, for "pioneering work in rocket and satellite astronomy and in particular for his contributions to X-ray astronomy." More recently, in honor of this work he received the coveted Wolf Foundation Prize for Physics in 1987. The Wolf Prize committee recognized Friedman and the other two co-recipients of the award:

> "as the principal founders of X-ray astrophysics, a new field of astronomical science which has proven to be a prolific source of fundamental discoveries and deeper physical understanding about high-energy processes in the universe. Their work has profoundly influenced every area of astronomical research. All agencies engaged in space science are now developing major orbiting facilities for X-ray observations, which will play a vital role in the future of astronomical science."

Impact

Solar X-ray emission is used to predict the state of the ionosphere and its effect on radio frequency transmission, especially at the HF frequencies. This was of major importance to Naval communications. The knowledge gained from the first detection of X rays from the Sun was a major milestone in a continuing endeavor by NRL that began with E.O. Hulburt's theoretical efforts[3] in the 1930s and continued through the SOLRAD satellite series, as well as other space satellite research programs.

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H. Friedman

[1] DeVorkin, D.H., *Science with a Vengeance* (Springer-Verlag, New York, 1992), p. 240.

[2] Hevly, B.W., *Basic Research Within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-Ray Astronomy* (Johns Hopkins University, 1987), p. 224.

[3] Hulburt, E.O., "Ionization in the Upper Atmosphere of the Earth," *Physical Review*, Vol. 31, 1018 (1928).

The Principles of Fracture Mechanics

Achievement

Fracture mechanics is a field that recognizes that all structures are manufactured with, or will ultimately contain, flaws that govern the eventual failure of the structure. The study of the stresses caused by the flaws, and the material's resistance to failure from them, forms the basis for the field of fracture mechanics. Fracture mechanics permitted, for the first time, the capability to calculate the strength of structures containing defects, which inevitably occur in fabrication or during service operation. The net result of these new design principles increased the reliability of structures due to improved design capability and an improved predictive capability of in-service damage.

NRL's G.R. Irwin is recognized as the pioneer of modern fracture mechanics.[1] He developed the scientific principles for understanding the relationships between applied stresses and cracks or other defects in metallic materials. Irwin developed, around 1947, the concept that fracture toughness should be measured in terms of resistance to crack propagation. Critical values of the stress intensity describing the onset of fracture, the onset of environmental cracking, and the rate of fatigue crack growth were established later.

As a consequence of Irwin's scientific work, fracture mechanics is now taught in many graduate schools and remains an active field of R&D today.

Impact

Using these fracture-safe design principles, NRL assisted in the solution of many important military and commercial problems, for example, by solving the catastrophic failures in commercial jet aircraft in 1953, and the fracture problems experienced by the Polaris and Minuteman missile programs in 1957.[2] Fracture mechanics has been applied throughout the world for the design of any structures where sudden, catastrophic failure would cause loss of life or other serious consequences. Examples include nuclear reactor pressure vessels, submarines, aircraft and missiles, and tanks for storage of toxic or flammable materials, etc.

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G.R. Irwin

[1] Rossmanith, H.P., "George Rankin Irwin - The Father of Fracture Mechanics," presented at the George R. Irwin Symposium on Cleavage Fracture, *The Minerals, Metals & Materials Society*, 1997.

[2] *Ibid*., 19-20; and Irwin, G.R., "Fracture Mechanics," *Report of NRL Progress*, NRL (1973), p. 36.

Molecular Structure Analysis and the Nobel Prize

Achievement

NRL has produced two Nobel Laureates, J. Karle and H. Hauptman, who each received the Nobel Prize for Chemistry in 1985 for devising direct methods employing X-ray diffraction analysis in the determination of crystal structures. The seminal research paper, "The Phases and Magnitudes of the Structure Factors," was published in 1950. The major events leading to these new methods were: quantitative molecular structure analysis in 1948; foundation mathematics for the X-ray phase problem in 1949; and the first general procedure for solving crystal structure problems in 1963.[1] As experience with applications developed, I. Karle made a major contribution to the development of analytical techniques of broad applicability to all types of crystals, whether they had a center of symmetry or not. It was a considerable step to bridging the gap between theory and practical application.

X-ray diffraction analysis involves the determination of the arrangement of atoms in crystals from which the molecular formula is derived directly. Determination of the molecular structure is important in that once the structural arrangement is understood, the substance itself can then be synthesized to produce useful products. This research occupies an almost unique position in science because the information it provides is used continuously in other fields. In fact, many phenomena in the physical, chemical, metallurgical, geological, and biological sciences are interpretable in terms of the arrangements of atoms.

J. Karle and I. Karle are still conducting research at NRL after 54 and 52 years, respectively, of government service. Their research plays a large part in the Navy's energetic materials program, which focuses on making explosives and propellants that are safer, more powerful, or both.

Impact

Methodologies for determining molecular structures are major contributions to science and technology. For example, they form the basis for the computer packages used in pharmaceutical laboratories and research institutions worldwide for the analysis of more than 10,000 new substances each year. A significant portion of structural research has direct application to public health, including the identification and characterization of potent toxins found in animals and plants, antitoxins, heart drugs, antibiotics, anti-addictive substances, anticarcinogens, and antimalarials.

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J. Karle, H. Hauptman, and I. Karle

[1] Karle, I.L. and Karle, J., "Recollections and Reflections," in *Crystallography in North America*, D. McLachlan, Jr., and J.P. Glusker, eds., 1983.

The Viking Program

Achievement

In 1946, NRL directed the development of a new sounding rocket called Viking, which was designed and built by the Glenn L. Martin Company. The rocket motor was built by the Reaction Motors Company, the firm that had just constructed the motor for the Bell X-1 aircraft, in which Chuck Yeager broke the sound barrier in 1947. Viking was the first rocket designed for essentially research purposes and the first to use a gimballed motor to control the direction of flight.[1]

The first successful launch of the Viking took place at the White Sands proving ground in 1949. Later, in 1950 a rocket was launched from a ship, the USS *Norton Sound*, achieving an altitude of 106.4 miles.[2] This launching of such a large rocket from the deck of a ship had very important national security ramifications in that it was a step toward the eventual deployment of missiles at sea. In fact, *Life* magazine reported that Navy officials "had proved for the first time that big rockets, capable of carrying A-bombs several hundred miles, could be launched from the deck of a ship."[3]

In all, twelve Vikings were launched by NRL between 1949 and 1954, establishing many milestones: highest altitude of any research rocket at that time (136 miles); first measurements of temperature, pressure, and winds in the upper atmosphere; first measurements of the electron density in the ionosphere; and first high-altitude (approximately 100 miles) photographs of the Earth.

Impact

The Viking program established many scientific milestones, demonstrated the feasibility of sea-based missile systems, and took the first high-altitude picture of a hurricane in October 1954. This was the first color photograph successfully taken from such altitudes, and it initiated the interest of the weather service in high-altitude weather monitoring.[4] Finally, Viking paved the way for the historic Vanguard project, America's first satellite program.

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M.W. Rosen

[1] Caidin, M., *Vanguard!* (E.P. Dutton & Co., Inc., New York, 1957), p. 138.

[2] Glaeser, "Space: A New Dimension in Naval Warfare," *U.S. Naval Institute Proc*eedings, Vol. 113, 132 (May 1987).

[3] "Seagoing Rocket," *Life* (June 26, 1950).

[4] Krause, E.H., "The Genesis of Rocketborne Space Research," *Report of NRL Progress*, NRL (1973), p. 47; and Mitchell, P.A., "The Navy's Mission in Space," *Oceanus*, Vol. 20, No. 2, 22 (Summer 1985).

Synthetic Lubricants

Achievement

Soon after the introduction of gas turbine-powered aircraft in World War II, it became evident that new and better lubricants were required to take advantage of the potential capabilities of these engines. The new lubricants would have to retain sufficient viscosity to support bearing loading at 280° to 300° F and be oxidatively and thermally stable enough to withstand heat "soak back" temperatures of from 400° to 500° F. Because of NRL's previous success in developing synthetic lubricants for instrument bearings, the Navy Bureau of Aeronautics requested in 1947 that it undertake the development of lubricating oils for turbojet and gas turbines.

Responding to this request, W.A. Zisman, C.M. Murphy, and their colleagues conducted fundamental studies that related molecular structure to lubricating and temperature/viscosity properties. Structural guides, derived from those fundamental studies, permitted extending the useful temperature range of the oils.[1] As a result, NRL developed the first hydrocarbon ester fluids as lubricants that would perform acceptably at the high bearing operating temperatures in jet engines.

By the early 1950s, diester lubricants developed at NRL were in use in Navy turbine engine aircraft and soon were used by nearly all military and civilian turbine-powered aircraft. As turbine engine power requirements and operational temperatures increased, NRL was active in developing lubricants and lubricant additives to meet these more stringent conditions as well.

In addition to extending the high temperature range, instrument oils were also developed for service at –65° F to overcome the problem of losses due to aircraft cannon freezing at the high altitudes newly reachable by jet aircraft at the time of the Korean War.[2]

Impact

The U.S. military needed new lubricants to be able to utilize turbine aircraft at their maximum performance, especially in combat. NRL research met this requirement. Essentially all turbine engines now used by military and civilian aircraft are lubricated with ester oils whose development was based on early research and development at NRL.

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W.A. Zisman and C.M. Murphy

[1] American Chemical Society, *Langmuir*, Vol. 3, No. 3 (1987).

[2] *Ibid*.

Radar Absorbing Materials and Anechoic Chambers

Achievement

Since the end of World War II, NRL has pioneered the development and production capabilities for thin magnetic radar absorbing materials (RAM), thicker nonmagnetic RAM, and designs for radar anechoic chambers. In 1945, the "NRL Arch" apparatus was constructed to provide a means for measuring angular dependent performance of broadband RAM. The name "NRL Arch" is still used, and the apparatus is accepted worldwide by RAM manufacturers and stealth technology contractors. In 1953, NRL developed a broadband, nonmagnetic material called "DARKFLEX,"[1] the precursor to materials used in today's radar anechoic chambers. NRL initiated a pilot production plant, then transferred large-scale production to Sponge Rubber Products Company. Also in 1953, NRL assembled the first effective radar anechoic chamber. The design and elements of it are contained in most chambers today.

The fundamental mechanisms of absorption by magnetic ferrites and alloys were extensively investigated at NRL by a group headed by G. Rado. The understanding of these fundamental mechanisms (magnetic moment rotation, domain wall displacement, and spin-waves) allowed the development of broad bandwidth frequency coverage, thin magnetic RAM. This led to the NRL project "NEWBOY," initiated in 1976. Thin RAM materials from this project were extensively used by the Joint Cruise Missile Program Office and the other services as prototype stealth treatments for missile-like drones, aircraft, and ships.

Impact

For more than four decades, NRL has been a resource for RAM innovation, prototype production, and measurement tools/facilities. In fact, NRL has developed, produced, and in several instances installed materials on Navy/DoD platforms from the end of World War II through Desert Storm. Much of NRL's work preceded efforts on "stealth" technology and significantly impacted it in the areas of submarines, missiles, aircraft, ships, and land vehicles.

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R.W. Wright, G.T. Rado, W.H. Emerson, B. Faraday, and D.W. Forester

[1] Tanner, H.A., Sands, A.G., and McDowell, M.V., "DARKFLEX-A Fibrous Microwave Absorber," NRL Report 4137, April 1953.

Over-the-Horizon Radar

Achievement

During the late 1940s, NRL foresaw the need for detecting moving targets, including aircraft and missiles, at distances and altitudes beyond line-of-sight distances. Microwave radar as developed during World War II was limited in range by the curvature of the Earth. In 1950, while using the pioneering work it accomplished in 1926 (radio "skip distance" effect theory), NRL began to investigate the use of radar operating in the high-frequency (HF, or short wave) portion of the radio spectrum to extend the range beyond the horizon. This is achieved by the refraction (bending) of radar waves when traveling through the ionosphere, which is located high above the Earth's surface. Using the ionosphere to bend the radar energy back to the Earth's surface can extend the range of a radar out to 2,000 nautical miles.

By 1955, NRL was operating a low-power HF radar called MUSIC (Multiple Storage Integration Correlation) which demonstrated Earth backscatter at over-the-horizon (OTH) distances and echoes from line-of-sight targets. It also observed nuclear explosions at long range, as well as the launch of rockets.[1]

In 1961, based on the success with MUSIC, a high-power, high antenna-gain OTH radar known as MADRE (Magnetic Drum Radar Equipment) was installed at the NRL Chesapeake Bay field site. It was able to detect and track aircraft as they traveled across the Atlantic Ocean. With the NRL MADRE experimental radar, nearly all the fundamental capabilities of HF OTH radar were discovered and demonstrated: aircraft detection and track, ship detection, missile launch detection, nuclear test location, sea state determination, storm tracking, and vectoring aircraft to intercept.

Impact

NRL's development of OTH radar solved a critical military requirement where the horizon limit of conventional radar was overcome, giving an order of magnitude or more increase in useful range. This technology formed the technical base that led to the Air Force's AN/FPS-118 radar for continental air defense and the Navy's Relocatable Over-the-Horizon Radar, as well as influencing HF radar development in other countries of the world. HF OTH radar is the most cost-effective wide-area sensor available today.[2]

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High-Resolution Radar

Achievement

High-resolution radar is important in many areas of radar. It allows the recognition of targets and the exclusion of unwanted clutter echoes so that small stationary or slowly moving targets can be detected in heavy clutter. The need for high range-resolution to detect periscopes was recognized in the late 1940s.

NRL began to explore high-resolution radar for periscope detection and other applications in the mid 1950s. The first high-resolution pulse-compression radars were being developed at that time, thereby demonstrating that the energy of a long pulse could be obtained along with the resolution of a short pulse. Although not alone in this area, NRL was active in advancing the art of pulse compression. Other key contributions were made by MIT Lincoln Laboratory and Bell Labs.

In 1960, NRL embarked on a major effort to demonstrate X-band high-range resolution radar technology for periscope detection and the detection of surface effects generated by a submerged submarine. This was called Project Cutwater. NRL successfully demonstrated both surface and airborne radar for the detection of submarines. In 1965, the Naval Air Systems Command (then the Bureau of Aeronautics) initiated procurement of an anti-submarine (ASW) radar for new S-3 carrier-based aircraft that would employ the technology developed by NRL. Texas Instruments was awarded the contract for the radar that became the AN/APS-116.

Impact

NRL's work in high-resolution radar resulted in ASW radars for the U.S. Navy's S-3 and P-3 aircraft. These high-resolution radars have been the only operational U.S. radars for submarine detection for 25 years. By developing the means to detect enemy submarines, the Laboratory met a critical national security need.

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I.W. Fuller, G. Ohman, N.L. Davis, C.C. Watterson, and G.F. Myers

Vanguard Program — The Rocket

Achievement

Between 1955 and 1959, NRL conducted the first American satellite program, called Vanguard. The program was initiated to represent the U.S. in the International Geophysical Year (IGY), a cooperative international scientific effort to study the physical properties of the Earth. The nation's leaders chose to participate in the IGY by placing an artificial satellite in orbit, and a competition was held to determine which government agency would build and launch the satellite. NRL's plan was selected, due in part to its success with the Viking program. The Laboratory's pioneering task was to design, build, launch, place into Earth-orbit, and track an artificial satellite carrying a scientific experiment. The contractor for the rocket project was the Glenn L. Martin Company.

The rocket successfully met the program's objective of putting a satellite into orbit during the IGY. The *Vanguard I* satellite was launched into Earth orbit on March 17, 1958, 5 months and 13 days after the Soviet Union launched *Sputnik I*, and about 6 weeks after the launch of *Explorer I*. Successfully designing and developing a three-stage rocket, with three brand new and unproven stages, on such a timely schedule was unprecedented. Experience in the DoD at that time showed that in missile programs it took more than 5 years from the start of a program to arrive at the date of the first successful launching; the Vanguard team achieved their objective in 2 years, 6 months, and 8 days.[1] Wernher von Braun, chief architect of the Redstone, called it a miracle.[2]

Impact

The Vanguard rocket successfully met the program's objective of launching a scientific satellite into orbit during the IGY, and the rocket technology pioneered by Vanguard was used by later programs. The use of a "strapped down" gyro platform, the rotatable exhaust jets of the first-stage turbopump which ensured efficient roll control, and the C-band radar antenna beacon employed on the Thor-Able vehicle all originated with Vanguard. In fact, the Air Force used many design concepts from Vanguard's second and third stages in its Thor-Able booster. Finally, one of America's most versatile and reliable launchers, the Delta rocket, reflects much of Vanguard's design.[3]

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Vanguard Program — Minitrack and Space Surveillance

Achievement

Since a suitable satellite tracking system did not exist at the time of the Vanguard program, NRL developed the world's first satellite-tracking system (called "Minitrack") in 1956. This tracking network became the prototype for the networks used in tracking later Project Mercury missions.

Ironically, the Minitrack system first demonstrated its capabilities by tracking another nation's satellite. From October 5-26, 1957, NRL accurately predicted and tracked the orbits of the Soviet Union's *Sputnik I*. Three months later, NRL confirmed and tracked *Explorer I*, America's first orbiting satellite launched into orbit by the U.S. Army. Minitrack tracked the orbit of *Vanguard I*, launched on March 17, 1958.

After the Soviet launch of *Sputnik I*, the detection and tracking of foreign satellites orbiting over the U.S. became a major national security issue. As a result, the Navy Space Surveillance System (NAVSPASUR) was developed by NRL on a "crash basis" for the Advanced Research Projects Agency from 1958 to 1964 in order to detect and track such satellites. NRL was selected to develop this system primarily because of Minitrack's success. But unlike Minitrack, NAVSPASUR was designed to track satellites that transmitted signals and those that were "quiet." NAVSPASUR now consists of nine radar sites stretching between southern California and Georgia and comprises a radar "fence" capable of detecting basketball-sized objects in orbit as high as 7,500 miles above the Earth.[1] The information gathered is used to warn the U.S. naval units of periods when they would be vulnerable to detection. By 1983, NAVSPASUR was a critical element in the North American Air Defense Command's Space Detection and Tracking System and was tracking more than 4,966 objects every day.

Impact

As the world's first satellite tracking system, the impact of Minitrack was significant, not only to the primary task of tracking the orbit of the Vanguard satellites, but also in tracking the orbits of the Sputnik and Explorer satellites. Later, the concept was employed by NRL in the design and development of NAVSPASUR, the primary system for maintaining surveillance of space objects and for warning U.S. Fleet units of periods of vulnerability to foreign surveillance satellites.

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Vanguard Program — The Satellites and the Science

Achievement

The *Vanguard I* satellite was successfully launched into Earth orbit on March 17, 1958. Although it was not the first U.S. satellite successfully launched, *Vanguard I* met the program's original objective of putting a satellite into orbit during the International Geophysical Year (IGY), a cooperative international scientific effort to study the physical properties of the Earth. *Vanguard I* achieved the highest altitude of any man-made vehicle to that time and established beyond doubt geologists' suspicions that the Earth is pear-shaped.[1]

A significant innovation in *Vanguard I* was the use of miniaturized circuits. It carried two radios and a temperature sensor and was the first satellite ever to use solar cells as a power source.[2] The solar cells developed by the Signal Engineering Laboratories, placed by Vanguard engineers on the satellite shell so as not to interfere with the functioning of the internal instrumentation, set a new standard of efficiency and account for the long operating life of the satellite.[3] *Vanguard I* orbits the Earth today as the oldest man-made satellite and it will remain in orbit well into the 22nd Century.

Vanguard II was placed in orbit on February 17, 1959, and was the first satellite designed to observe and record the cloud cover of the Earth. As such, *Vanguard II* was the forerunner of future meteorological satellites.[4]

Impact

The Vanguard program established landmark scientific achievements. Scientists at the National Academy of Science and NASA acknowledge the program as a progenitor of American space exploration. According to a National Academy of Science panel in 1958, "The overall scientific program developed for use with the Vanguard launching system has made possible the total program of space vehicle instrumentation, observation, and data reduction carried out under IGY auspices. Additionally, it has provided the original basis of the present expanding program of scientific experiments for space research for the U.S."[5]

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H.E. Newell, R. Easton, and M. Votaw

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First Operational Satellite Communication System — "Communication Moon Relay"

Achievement

While conducting its original high-frequency-propagation work in the 1920s, NRL was the first to determine the frequency above which radio waves would penetrate the Earth's atmosphere and propagate through outer space, making radio communication in space possible. Years later, in 1951, NRL was the first to demonstrate that radio energy reflected from the Moon was much more coherent than predicted. As a consequence, a Moon circuit could be used to transmit data at a rate and fidelity adequate for radio communication. NRL then developed the key transmitter and receiver technologies that allowed for effective communication through a passive Moon circuit.

In 1954, NRL was the first to transmit and return the human voice through outer space.[1] NRL first demonstrated transcontinental satellite communication, from Washington, DC to San Diego, California, in 1955.[2] The first official message to be transmitted via a satellite was sent over this circuit. The system was then designated "Communication Moon Relay," or CMR. It should be noted that CMR was a spin-off of a classified NRL project, known as "Passive Moon Relay," which used the Moon as a means to intercept reflecting Soviet radar signals.

In 1959, the world's first operational satellite communication system, allowing communications from Washington, DC, to Oahu, Hawaii, was placed into operation. The public demonstration of this system took place on January 28, 1960 with the exchange of messages between the Chief of Naval Operations and the Commander-in-Chief, Pacific Fleet. Also in 1960, NRL transmitted the first pictures (facsimile) over a satellite communications system (the CMR), and the first "space mail" using the man-made passive satellite *Echo I*.[3]

Impact

While the CMR never became a routine communications system, NRL ushered in the age of satellite communications by developing key technologies needed for viable artificial satellite communications. This was of critical value because the U.S. is a global maritime power with naval forces deployed worldwide. Communication with far-flung and constantly mobile forces is critical to American seapower. With the use of satellite communications, a task force commander can stay in contact without relying on vulnerable land lines, undersea cables, and radio relay stations, which are often on foreign soil.

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J.H. Trexler

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X-Ray Astronomy

Achievement

NRL's X-ray astronomy program, led by H. Friedman, dates back to the launch of an X-ray detector on a V-2 rocket on September 29, 1949. That launch was the first of a series of rocket and satellite-based experiments that determined that solar X rays are the cause of ionization in the E-layer of the Earth's ionosphere. Following the initial report of significant cosmic X-ray emission in 1962, the NRL team expanded their attention to include detection of X rays from nonsolar astronomical sources.

Over a period of three years, NRL conducted a series of sounding rocket experiments that demonstrated the discrete nature of the X-ray sources and their association with the Milky Way.[1] They showed that the diffuse X-ray background was cosmic in origin.[2] Subsequently, they detected the first extragalactic X-ray source.[3] In one of the most significant rocket experiments flown, NRL researchers observed the Crab Nebula during a lunar occultation of the object and demonstrated that the X-ray emission was emerging from the nebula.[4] This single experiment was the first positive identification of a source of cosmic X rays with a known object and provided the first observational evidence for the X-ray production mechanism.

NRL produced a sky map of galactic and extragalactic emitters using observations made by an array of large aperture X-ray detectors on NASA's High Energy Astronomical Observatory (HEAO-1). The resulting *HEAO A-1 X-Ray Source Catalog* included 842 discrete X-ray sources and became a standard reference source for galactic and extragalactic X-ray emitters.

Impact

The work by NRL researchers was critical to X-ray astronomy, contributing to the development of a new and important research specialty. X-ray research made important contributions to the advance of cosmology and astrophysics. *The HEAO A-1 X-Ray Source Catalog* became an important reference source in X-ray astronomy.

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High-Frequency Direction Finding

Achievement

During the 1950s and 1960s, NRL demonstrated technology that permitted a radical improvement in the performance of high-frequency direction finding (HFDF) networks and oversaw the deployment of this technology in Project Boresight and Project Bulls Eye.

The first of three innovations that underlay this work was *retrospective direction finding*. Previously, all stations in an HFDF network were required to measure characteristics of the same signal while transmission was still occurring; after-the-fact measurements were needed. Previous attempts at NRL[1] and elsewhere were limited by storage bandwidth and recorder instabilities. Recording significant fractions of the HF spectrum and using a digital method for overcoming recorder instabilities[2] enabled retrospective DF. This was the basis of the 1960 quick-reaction Project Boresight that deployed the AN/FLR-7 and AN/FRA-44 worldwide.

The second innovation was the use of *circularly disposed wide-aperture direction finding arrays*,[3] which significantly increased HFDF location accuracy and signal collection. In the 1950s, NRL constructed a 400-ft diameter electronically steerable array and perfected the underlying technology. During Project Bulls Eye, scaled-up versions of this prototype were deployed worldwide by the Navy as the AN/FRD-10.

The third innovation was the use of computers for control of the HFDF network and for the prompt triangulation of target locations.[4] To achieve high computer reliability in the pre-integrated-circuit era, a novel architecture of closely coupled shared-memory multiprocessors was reduced to practice and was deployed as the AN/GYK-3.

Impact

Project Boresight's crucial contribution to national defense was recognized by the awarding of the Distinguished Civilian Service Award to NRL's R.D. Misner and M.J. Sheets. The more ambitious Project Bulls Eye deployed the second and third innovations and improved the first with the AN/FRA-54 and the AN/FSH-6, thereby making HFDF a principal means of global ocean surveillance, with special capabilities against critical targets.

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R.D. Misner, M.J. Sheets, and B. Wald

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SOLRAD I

Achievement

The SOLRAD (SOLar RADiation) program was conceived in the late 1950s as an improved means of studying the Sun's effects on the Earth, particularly during periods of heightened solar activity. Of prime interest were the effects of solar radiation on the ionosphere, which had critical importance to Naval communications. It was NRL's and the nation's longest continuing series of satellite projects dedicated to a specific research program. *SOLRAD I* was launched in June 1960, and ten more SOLRADs were fabricated by NRL and flown through 1976.

SOLRAD I was unique for many reasons: it determined that radio fade-outs were caused by solar X-ray emissions, verifying a theory of NRL's H. Friedman; it was one of the two satellites launched during the world's first multiple satellite launching; it was the world's first orbiting astronomical observatory; and it was the first satellite to be successfully commanded to shut off. On August 6, 1960, *SOLRAD I* recorded 6 of 18 minutes of the first solar flare recorded by an orbiting satellite and telemetered the information to a NASA tracking station. The data recorded throughout *SOLRAD I*'s active life shed new light on the relationships among sunspot activity, solar X-ray emission, and radio wave propagation.

Subsequent SOLRADs served as solar radiation monitors circling the Earth, on guard for any unusual solar disturbances that could have endangered the astronauts during the Apollo missions. Special SOLRAD operations for the *Apollo* 8 moon mission began at the request of NASA in December 1968 when astronauts first circled the Moon and returned to Earth. Later, during July 1969, solar flare forecasts derived from data furnished by *SOLRAD* 9 were used to safeguard *Apollo 11* astronauts and their communications systems during the historic first lunar landing mission. NRL furnished solar radiation data to the Space Disturbance Forecast Center of the Environmental Science Services Administration (now NOAA), which had the responsibility for determining the status of radiation hazards to the Apollo astronauts. *SOLRADs 9* and *10* provided this data throughout the Apollo and SKYLAB programs.[1]

Impact

NRL's SOLRAD series of satellites yielded important new scientific information on the Sun's effects upon the Earth's atmosphere. The new knowledge gained by the program also yielded practical, and in some cases critical, benefits to Naval communication and the U.S. manned space program.

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America's First Operational Intelligence Satellite

Achievement

The now unclassified *Galactic Radiation and Background I* (*GRAB I*) payload, an acknowledged co-flyer with the publicly recognized *Solar Radiation I* (*SOLRAD I*) scientific payload, was America's first operational intelligence satellite. In June 1960, fifty-two days after a U-2 aircraft was lost on a reconnaissance mission over Soviet territory, the *GRAB I* satellite soared into orbit and began transponding space-intercepted electronic intelligence signals to Earth-bound signals intelligence stations.

GRAB I was the unique application of many emerging technologies. NRL's M.J. Votaw, previously with Project Vanguard, brought the technical experience and resources necessary to design, build, launch, and operate a satellite in space. R.D. Mayo supervised the design and development of the S-band antenna with crystal video receiver and ground receive equipment to collect signals from Soviet air defense radar. H.O. Lorenzen provided the overall technical direction, obtained intelligence community sponsorship, and led transfer of the technology into operational deployment. The notion of operating the antenna/detector reconnaissance technology in an orbiting satellite and collecting its transponded signal on magnetic tape was a breakthrough answer to CNO Admiral Arleigh Burke's request for naval material bureaus and laboratories to consider how they could use space in their design ideas for the Navy.

With mission sponsorship by the Office of Naval Intelligence, NRL completed development of the satellite and its network of overseas ground collection sites. President Eisenhower approved the electronic intelligence (ELINT) program and its SOLRAD scientific experiment cover. The GRAB/SOLRAD payloads shared a ride into space with the Navy's third *Transit* navigation satellite as part of the world's first multiple-satellite launching. Field sites recorded *GRAB I* signals on magnetic tapes, which were couriered to NRL for evaluation and duplication. The National Security Agency (NSA) and the Strategic Air Command exploited the tapes for technical ELINT data and to support the Single Integrated Operations Plan.

Impact

The GRAB project provided proof-of-concept for satellite-collected ELINT. This was accomplished by demonstrating that a platform in outer space could collect as much as all other sea, air, and land-based reconnaissance platforms operating within the satellite's field of view, at a fraction of their cost, and at no risk to personnel. The output, initially overwhelming, stimulated invention by NRL and NSA of machine processing of digitized data using commercial computers. In searching the tapes for new and unusual signals, NSA found the Soviets were already operating a radar that supported a capability to destroy ballistic missiles. Such information could not be obtained by airborne reconnaissance, nor without enormous risk to human sources. The intelligence information gained from *GRAB I* had a profound impact on national security decision-making and on deterrence of nuclear war with the Soviet Union.

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H.O. Lorenzen, R.D. Mayo, and M.J. Votaw

High-Power Neodymium Glass Lasers

Achievement

In the 1960s, prior work in France had created Nd:glass lasers with single-pulse energies of about 100 joules in a pulse duration of several nanoseconds. NRL addressed bridging the gap between hundreds of joules and the tens of kilojoules or more needed for meaningful laser fusion experiments. Specifically, NRL recognized how output energy or power density of a disc laser scales with size; recognized the trade-off between laser gain, self-focusing, and spatial beam quality; developed a high-gain module and the pulsed power necessary to operate it safely; and developed, built, and demonstrated a laser system composed of such modules that produced a terawatt of peak power per beam. The success of this effort led to the adoption of this technology for the 10 kJ Shiva laser by the Laser Fusion program at Lawrence Livermore National Laboratory (LLNL).

In the later 1970s, the scaling issue became one of how to develop laser designs capable of scaling, not to kilojoules per pulse, but to megajoules per pulse. One factor in scaling was the linear and nonlinear optical properties of the host laser glass. Another was the laser performance of the neodymium ion in the particular host glass matrix. A higher gain laser could function with less glass end-to-end and hence could tolerate a higher intensity. NRL advocated the use of phosphate laser glasses. The Department of Energy (DoE) supported a test of this scaling, which culminated in the successful operation of NRL's Pharos II laser with phosphate laser glass in 1980 at over 1,000 joules. Ultimately, LLNL and DoE chose to reconfigure the large Nova laser using the phosphate laser glasses.

Impact

Between 1966 and 1982, NRL determined how to scale up high peak-power glass lasers to conditions necessary to perform realistic experiments exploring the potential of inertial confinement fusion. This effort had a major impact on the U.S. laser fusion program. Specifically, it significantly influenced the design of DoE's 10 kJ Shiva laser, the reconfiguration of DoE's Nova laser, and the design of the National Ignition Facility.

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J.M. McMahon, J.L. Emmett, J.B. Trenholme, J.L. Holzrichter, T.H. DeRieux, R.P. Burns, and R.H. Lehmberg

Improved Aircraft Canopy and Window Materials

Achievement

NRL's interest in aircraft windows originated with the blow-out failures of combat aircraft canopies. These failures resulted from the inability of the canopy material to halt the propagation of cracks caused by impacts of sharp objects or by missile penetration.[1] In 1953, J. Kies applied NRL's pioneering research in fracture mechanics for the first time to a practical problem — the failure of combat aircraft canopies.[2]

Experiments by I. Wolock, then at the National Bureau of Standards and later with NRL, showed that craze cracking of acrylic could be eliminated by hot stretching, a result which led Kies to the idea that hot stretching could add to the toughness of aircraft windows. Kies worked with commercial manufacturers of acrylic material (e.g., Rohm and Haas) and used fracture mechanics to ascertain the toughness of the material. In the course of the work, NRL shattered hundreds of aircraft canopies by projectile impact, and then carefully reassembled them to allow crack paths to be traced.[3] Kies pointed out that the critical stress for a given crack size depended only on the product $G_c E$, which could be directly computed from the applied stress and crack size for the test.

The response of aircraft engineers concerned with testing stretch-toughened glazing materials was to express their fracture test results in values they termed K (K for Kies).[4] Kies' work is also incorporated in design criteria for aircraft plastic glazing materials issues jointly by the Departments of Commerce, Navy, and Air Force.

Impact

NRL worked cooperatively with the Air Force and with commercial manufacturers to introduce stretched acrylic plastic for military canopies with increased toughness, reduced weight, and prolonged service life. This material is now employed in military and civilian aircraft, thereby reducing a once significant source of fatal accidents.

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J.A. Kies and I. Wolock

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Purple-K-Powder

Achievement

Prior to the development of potassium bicarbonate dry chemical extinguishing agent, or "Purple-K-Powder" (PKP), hydrocarbon fires were extinguished using either sodium bicarbonate dry chemical powder or protein foam. The dry chemical was effective on three-dimensional and "hidden" fires (e.g., debris from aircraft crash), but provided no protection against reflash. Protein foams were used to extinguish fuel spill or in-depth liquid pool fires. The thick foam blanket provided reflash protection by excluding oxygen from the fuel surface, but foams were ineffective on 3-D and hidden fires. The agents could not be used in combination because the foam bubbles were chemically attacked and destroyed by commercially available dry chemicals. The first step in developing an optimum approach was to develop a superior, foam-compatible dry chemical.

In 1959, a series of investigations by NRL in the area of chemical flame extinction gave birth to Purple-K-Powder. Powdered bicarbonate of soda as a flame-halting agent had been employed for many years, but its action had never been satisfactorily explained. Working with other investigators, NRL conducted fire tests with many powdered substances, which helped to clarify the chemical actions involved. This work came to the conclusion that the substitution of the potassium ion for sodium extended the flame-quenching efficiencies of the chemical powders by a factor of two.[1] This meant PKP extinguished a fuel fire in half the time or extinguished twice as much fire as before. Ensuing industry efforts resulted in production of surface coatings which allowed PKP to be compatible with foams.

Impact

The development of Purple-K-Powder represented a major advancement in the state of the art for flammable liquid fire protection. PKP became used throughout the Navy and in U.S. municipal and industrial fire protection operations, and thereafter throughout the world. It is the only dry chemical agent recognized by the National Fire Protection Association for airport crash rescue firefighting.

Primary Reference Documents

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- Peterson, H.B., Tuve, R.L., Neill, R.R., Burnett, J.C., and Jablonski, E.J., "The Development of New Foam-Compatible Dry Chemical Fire Extinguishing Powders," NRL Report 4986, September 5, 1957.
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R.L. Tuve and E.J. Jablonski

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Quantitative X-Ray Fluorescence Analysis

Achievement

NRL introduced many of the developments which have made X-ray Fluorescence Analysis (XRF) the quantitative method that it is today. In 1948, H. Friedman and L.S. Birks first outfitted an XRF spectrometer with a Geiger counter, ushering in the era of electronic detection for XRF.

Under the leadership of Birks, NRL brought XRF to maturity by pioneering the use of new instruments such as the electron microprobe,[1] curved crystal spectrographs, and multichannel energy analyzers, and by devising novel analytical methods and computer codes that implement them. Beginning with a calculation of X-ray production in the microprobe, where microscopic standards could not be realized, the codes evolved into a comprehensive software package for quantitative chemical analysis using XRF, incorporating both fundamental parameters and empirical coefficients into a single flexible program. It has been estimated that over a thousand laboratories worldwide have used the NRL software (NRLXRF), or similar programs employing the fundamental parameter approach developed at NRL.[2]

Impact

Virtually every X-ray chemical analysis system produced today incorporates one or more of NRL's seminal advances in instrumentation and analysis. NRL's research in XRF resulted in industrial applications in mining, manufacturing, and metals recycling. This legacy continues with the development of technologies for environmental cleanup and for wear monitoring of high value machinery.[3] L.S. Birks has been honored with a recurring award established in his name by the Microbeam Analysis Society. In addition, the biennial Birks Award in X-Ray Spectrometry is given by the Denver X-Ray Conference.

Primary Reference Documents

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Individual(s) Being Recognized

L.S. Birks, D.B. Brown, J.W. Criss, H. Friedman, and J.V. Gilfrich.

[1] The NRL microprobe is held by the Navy Museum.

[2] NRLXRF was made available to the public through COSMIC, an agency of the NASA/DOD Technology Transfer Network. The COSMIC version of the program was designed for mainframe computers, and from 1977 to 1990, two hundred copies were distributed. Personal computers widened the distribution of this software.

[3] Gilfrich, J.V., "X-Ray Fluorescence Analysis at the Naval Research Laboratory: 1948-1997," NRL Memorandum Report 6685--98-8120, March 19, 1998.

Improved Boilerwater Treatment

Achievement

Naval 1200 psig steam propulsion boilers are subject to the damaging effects of corrosion and scale formation on the watersides if a proper boilerwater treatment is not applied. Tube failures due to acid corrosion and scale formation are two major concerns that in the past were satisfactorily controlled by a low phosphate/free caustic treatment. However, accumulations of suspended solids required mechanical and chemical cleaning. Both types of cleaning require ships' boilers to be out of service and increase the crew's workload.

NRL and the Naval Ship System Engineering Station (NAVSSES) started investigations into new water treatments to clean, in situ, Naval high pressure boilers in the late 1960s. NRL investigated the thermal stability chemistry of ethylenediaminetetraacetate (EDTA) salts as possible active components of a boilerwater treatment for high pressure boilers. Nuclear magnetic resonance was used to study the chemistry of EDTA salts and free acid under various thermal conditions. The reported kinetics of the chemical reactions indicated the amount of EDTA to add to the boiler on a continuous basis. This research was the guide that R.L. Dausuel, Jr., NAVSSES, used to introduce EDTA into operating Navy boilers.[1]

This group effort led to a final treatment that included the addition of hydrazine to stabilize the EDTA solutions upon their addition to the boilers. After excellent results from four trial ships, the chief engineer of the Naval Sea Systems Command directed the implementation of a boilerwater treatment based on an Na_4EDTA and hydrazine process. Results of shipboard testing demonstrated that use of the Na_4EDTA to clean, in situ, high-pressure steam boilers could extend the normal 1,800 hours of operation between cleanings to 15,000 to 20,000 hours. In addition, the passivated surfaces within the steam systems treated with Na_4EDTA would be beneficial when boilers were shut down for long periods of time.

Impact

NRL's basic research was instrumental to keeping Navy ship boilers in service for much longer periods and in reducing the costs associated with frequent cleanings. In addition, industrial water treatment plants find promise in the Navy's approach.[2]

Primary Reference Documents

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Individual(s) Being Recognized

W.B. Moniz and D.L. Venezky

[1] "Boiler Water/Feedwater Test and Treatment," *Naval Ship's Technical Manual*, S9086-GX-STM-020, Chap. 220, Vol. 2, December 15, 1995 (Seventh Revision).

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Fracture Test Technology

Achievement

While NRL's G. Irwin was concerned primarily with the basic science of fracture, his colleague W.S. Pellini established methods for prevention of fracture based on experimental methods. Pellini developed engineering approaches for design and material selection in structures based on metallurgical principles. His work solved the mystery of brittle fractures of World War II *Liberty* ships, in which entire ships sometimes fractured in calm water at dockside, and is still relevant in the age of high-performance ships, aircraft, and missiles.

The test methods developed by NRL are the Dynamic Tear Test; the Drop-Weight Nil-Ductility Transition Temperature Test (DWT-NDT, standardized by the ASTM in 1963 and used along with the Fracture Analysis Diagram for design of steel structures worldwide); the Explosion Bulge Test; and the Explosion Tear Test. Such tests were incorporated into materials procurement and fabrication specifications for construction of critical submarine and surface ship components.[1] A prominent example is the selection of materials for submarine pressure hulls that had to withstand local deformations from explosive attack, without crack extension. NRL worked with the Navy's ship and submarine materials and design codes to develop methods for evaluating materials, weldments, and welding processes. These methods, based on modeling, established the requirements for qualifying welds, welders, and new companies for the construction of submarine pressure hull structures.

The DWT-NDT proved the fracture resistance of HY-80 steel was superior to conventional steels, and the fully plastic performance of welded HY-80 plates in the Explosion Bulge Test convinced the Navy that HY-80 should be used for submarine hulls and for any other critical application.[2] In addition, two Deep Submergence Rescue Vehicles that were built with pressure hull material certified to be reliable as measured by fracture mechanics methods were put into the Fleet.

Impact

For more than 20 years, NRL was recognized as the leading international center for the development of structural integrity technology. During this time, the Navy relied upon NRL's expertise to assure the structural integrity of aircraft, ships, and submarines, and in doing so, to safeguard their crew members. These techniques also increased the performance of Naval vehicles, providing such payoffs as reliable deployment of deeper running submarines.

Primary Reference Documents

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Individual(s) Being Recognized

W.S. Pellini

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Deep Ocean Search

Achievement

On April 10, 1963, the nuclear submarine USS *Thresher* (SSN 593) was lost in deep water 260 miles east of Boston, Massachusetts, with all 129 crew members aboard. The loss of the submarine and its crew was a deep shock to the Navy and to the country.

In an effort to determine the reasons for the loss, NRL applied deep-towing technology, developed years earlier for underwater acoustic research, to the deep seafloor search for the *Thresher*. However, the search was terminated in September 1963 with the onset of bad weather. On May 18, 1964, the task group began new search operations. To augment its search capability, NRL had acquired the USNS *Mizar*, a retired cargo ship suited for launching and towing the deep-towed instrument vehicle, or "fish" as it was called. NRL's "fish" included a set of three cameras to photograph the wreckage, a side-scanning sonar to probe beyond camera range, two strobe lights, a magnetometer to locate the *Thresher* pressure hull, a transponder, a sonar pinger to measure the "fish's" altitude, and a telemetry system. This unmanned vehicle, towed by *Mizar*, made the initial detection of the *Thresher* hull after only eight hours of bottom operations. NRL's photographs were later assembled into a photomosaic of most of the major parts of the sunken submarine.[1]

After NRL's success in locating the *Thresher*, the Laboratory was called upon to locate and recover a lost H-bomb off the coast of Spain in 1966, locate and photograph the lost submarine USS *Scorpion* (SSN 589) in 1968, recover the deep submersible *Alvin* in 1969, and locate and photograph the lost French submarine *Eurydice* in 1970. NRL's emergency search mission was transferred to other Navy organizations in 1980.

Impact

NRL-developed ocean search technology now resides in other government and private organizations. According to a 1966 commendation from the Marine Technology Society, NRL was responsible for "pioneering new techniques" and had "established a methodology for future ocean engineering." Years later, after the *Titanic* was located by Dr. Ballard's team, a former Navy Supervisor of Salvage stated before Congress that "the superb work of the scientific teams from NRL...led the way for the [*Titanic*] search operation in the North Atlantic."[2]

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C.L. Buchanan

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TIMATION and NAVSTAR GPS

Achievement

The NAVSTAR Global Positioning System (GPS) is designed to provide precise navigation data to military and civilian users by means of a constellation of 24 satellites. NAVSTAR is based on NRL's TIMATION (TIMe/navigATION) research program, begun in 1964. R. Easton is recognized for conceiving the idea of the time-based navigational system, which eventually led to the GPS. NRL tested TIMATION concepts by developing and launching two small experimental satellites, *TIMATION I* and *TIMATION II*.

NRL launched the *TIMATION I* satellite on May 31, 1967 and the *TIMATION II* satellite in 1969. *TIMATION I* demonstrated that a surface vessel could be positioned to within two-tenths of a nautical mile and an aircraft to within three-tenths of a nautical mile using range measurements from a time-synchronized satellite. The TIMATION program proved that a system using a passive ranging technique, combined with highly accurate clocks, could provide the basis for a revolutionary navigation system with three-dimensional coverage (longitude, latitude, and altitude) throughout the world.

In 1973, NRL's program was merged with an Air Force program that was investigating similar techniques to form the NAVSTAR GPS program. *TIMATION III* was redesignated the *Navigation Technology Satellite One* (*NTS-1*), and was launched in 1974 in connection with the new NAVSTAR effort. *NTS-1* had the distinction of carrying the first atomic clock into orbit. *NTS-2* was launched in June 1977 as the first NAVSTAR satellite.[1]

Impact

NAVSTAR's military and commercial applications are revolutionary and too numerous to enumerate here. In 1993, the National Aeronautic Association selected the GPS Team composed of NRL, the U.S. Air Force, Aerospace Corp., Rockwell International, and IBM Federal Systems Co. as winners of the 1992 Robert J. Collier Trophy, the most prestigious of all aviation awards in the U.S. The citation accompanying the trophy honors the GPS Team "for the most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago."

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Individual(s) Being Recognized

R.L. Easton

[1] Mitchell, P. A., "The Navy's Mission in Space," *Oceanus*, Vol. 20, No. 2, 24 (Summer 1985); Glaeser, F., "Space: A New Dimension in Naval Warfare," *U.S. Naval Institute Proceedings*, Vol. 113, 134 (May 1987).

Aqueous Film-Forming Foam

Achievement

NRL, beginning in the early 1960s, conducted research on fire suppression that eventually led to one of the most far-reaching benefits to worldwide aviation safety — the development of Aqueous Film-Forming Foam (AFFF). AFFF achieves rapid extinguishment of hydrocarbon fuel fires and has the additional property of forming an aqueous film on the fuel surface that prevents evaporation and, hence, reignition of the fuel once it has been extinguished by the foam. The film also has a unique, self-healing capability whereby scars in the film layer caused by falling debris or firefighting activities are rapidly resealed.

The initial concepts for AFFF came from NRL's R.L. Tuve and E.J. Jablonski, who patented the first formulation for use in a twinned agent firefighting apparatus that combined Purple-K-Powder and AFFF. Although NRL was responsible for the original concepts and formulations, it was necessary to elicit the aid of the chemical industry to synthesize the fluorinated intermediates and agents to achieve improvements in formulations. The Minnesota Mining and Manufacturing Co., now 3 M, contributed considerably to the success of the development of AFFF.

In honor of his work in developing AFFF, the Society of Fire Protection Engineers International awarded (posthumously) the Arthur B. Guise Medal to E.J. Jablonski in 1990 for "eminent achievement in the advancement of the science and technology of fire protection engineering."

Impact

Following the destructive fires aboard the aircraft carriers USS *Forrestal* and USS *Enterprise*, the Navy sought more effective firefighting agents. NRL met this Fleet requirement with the development of AFFF. In the military, AFFF firefighting foam is now on all Navy aircraft carriers, and is used by all branches of the U.S. armed forces and NATO members. The agent is also recognized by international standards organizations for the protection of civilian airfields, refineries, and fuel tank farms, where potentially catastrophic fuel fires can occur. AFFF is in the inventory of almost all fire departments in the United States and in many fire departments throughout the world.

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Individual(s) Being Recognized

R.L. Tuve and E.J. Jablonski

Radiation Dosimeters

Achievement

The need for appropriate dosimetry was recognized soon after the discovery of ionizing radiation. Experience with X rays made it apparent that ionizing radiation has a deleterious effect on the human body. It was not only the radiation hazard involved in the use of ionizing radiation, but its controlled use in biology, industry, medicine, research, and military applications that required measurement of the radiation energy absorbed.

In response to the critical need for accurate and convenient dosimetry, NRL's J.H. Schulman developed a radiophotoluminescent glass dosimeter in 1951. This dosimeter, the DT-60/PD, was accepted as a standard radiation monitor in the 1950s. Later, in the 1960s, Schulman and his colleagues developed the main features of the thermoluminescent method of dosimetry by developing a successful thermoluminescent dosimeter. In thermoluminescence dosimetry, the sensitive element is a luminescent solid that stores part of the energy received from the radiation. This storage is generally due to the trapping of electrons, which have been freed by the radiation, at imperfections in the solid. When the phosphor is heated, the stored energy is emitted as luminescent light, and the amount of this light is proportional to the dose.

Until NRL's thermoluminescent dosimeter, no such device had been considered a suitable replacement for the photographic film badge for health physics monitoring. Monitoring required the capability to accurately detect a lower level of radiation. Although the photographic film badge was capable in that respect, it was an uneconomical and inconvenient method that prevented rapid estimations of dose. The thermoluminescent dosimeter satisfied the detection range necessary without the disadvantages of the photographic film badge.[1]

Impact

Credit for the popularity of luminescent methods in dosimetry belongs, above all, to NRL's J.H. Schulman.[2] NRL's radiation dosimeters were used to provide the military with an effective, convenient, and economical diagnostic tool for radiation exposure. They also served medical uses in areas such as clinical radiology and cancer treatment.

Primary Reference Documents

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Individual(s) Being Recognized

J.H. Schulman

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Nuclear Reactor Safety

Achievement

A major application of NRL's fracture-test technology was the Laboratory's participation in the Heavy-Section Steel Technology Program conducted by the Nuclear Regulatory Commission. The technical issue was to determine the safety of nuclear reactor pressure vessels fabricated from 12-inch thick steel, as a function of the thickness and temperatures. NRL's W.S. Pellini and F.J. Loss built the apparatus and conducted experiments on full-thickness specimens to demonstrate the safety of the vessels. The program lasted several years and attracted international attention. The ASME Code rules for the operation of nuclear pressure vessels are based on the results of that program.[1]

In the early 1960s, NRL demonstrated the potentially severe embrittlement of nuclear reactor steels to be a function of neutron exposure and irradiation (service) temperatures. While emphasizing light-water reactor pressure containment steels and their modes of failure after neutron exposure, the properties of other reactor component alloys were studied as well. Broad interest in NRL's work led to support by the Atomic Energy Commission and the Army. This work is believed by most nuclear safety authorities to be a primary basis for assurance against catastrophic failure of radiation containment. In 1975, a definitive book by NRL's L.E. Steele, *Neutron Irradiation Embrittlement of Reactor Pressure Vessel Steels*, was published and became a landmark guide for specialists worldwide.[2]

Impact

All military and civilian power reactors that feature a steel pressure shell are designed or operated, or both, on the fracture principles developed by NRL.[3] And, the Laboratory's work in radiation embrittlement in reactor pressure vessel steels led to the production of radiation-resistant steels, which are applied in new reactors throughout the world, and in the assurance of reactor containment safety in older reactors.

Primary Reference Documents

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W.S. Pellini, L.E. Steele, and F.J. Loss

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Ultraviolet Remote Sensing of the Upper Atmosphere

Achievement

The concept of ultraviolet (UV) remote sensing and the Special Sensor Ultraviolet Limb Imager (SSULI) operational sensors are examples of Navy research culminating in the transition of technology. The observation of spectral lines in the altitude range from about 120 to several hundred kilometers with instruments developed by NRL's P. Mange during the 1960s and flown on NASA's Orbiting Geophysical Observatories, enabled Chandra et al.[1] to recognize the correspondence between UV emission lines from oxygen and local electron density in the ionosphere. The dramatic UV images of the Earth taken with the NRL camera built by G. Carruthers for the *Apollo 16* lunar mission demonstrated the observability of the ionosphere on a global scale, and research by R. Meier[2] in the 1970s provided a firm theoretical basis for this correspondence.

Beginning in the 1980s, work by R.R. Meier and R. McCoy[3] led to new insights and to the design of space instruments for recording the appropriate atmospheric data and converting them into parameters of interest to the DoD, in particular, the electron density and neutral density. In 1985, NRL initiated the Atmospheric and Ionospheric Remote Sensing Program, which developed the UV remote sensing concept. It not only provided the basis for the operational concepts but supported the hardware technology for the Remote Atmospheric and Ionospheric Detection System, the forerunner of the SSULI sensor. During the 1980s, the DoD Space Forecast Center and the Defense Meteorological Satellite Program recognized that requirements for global atmospheric space weather data were not being met. NRL's SSULI sensors were developed to meet the operational requirements.

Impact

Global remote sensing of the upper atmosphere is now the accepted technology for producing global maps of electron density and neutral density. This mapping capability provides the basis for a new kind of forecasting of upper atmospheric and "space weather" characteristics, much as global measurements of cloud cover led to greatly improved tropospheric weather forecasting.

Primary Reference Documents

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Individual(s) Being Recognized

P. Mange, G. Carruthers, R. McCoy, and R. Meier

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Linear Predictive Coder

Achievement

The Linear Predictive Coder (LPC) is a means to represent the speech spectrum efficiently. In the LPC representation of speech, the speech spectral envelope is represented by an all-pole spectrum. In 1973, NRL's G.S. Kang developed the world's first LPC prototype capable of operating in real time to encode speech at low data rates. NRL's efforts generated an impetus to modernize DoD tactical secure voice communication equipment. Subsequently, NRL incorporated the LPC concept into the DoD Advanced Narrowband Digital Voice Terminal (ANDVT) that was under development at the time. Later, Kang incorporated the ANDVT voice encoding algorithm in Federal Standard 1015.

The computational steps required to execute LPC processing were enormous for 1970-technology standards. In fact, it was doubted that LPC could be implemented as a voice communication device.[1] But, in 1973, NRL was successful in implementing a real-time LPC telephone operating at 2400, 3600, and 4800 bits per second because the Laboratory had developed a computationally efficient iterative solution to the LPC analysis.

Impact

NRL's development of the LPC brought a complete upgrading of military tactical secure voice communication equipment in the 1970s. The new LPC-based ANDVT replaced the old channel vocoders. Currently 20,000 ANDVTs have been deployed by the Navy and others to support tactical secure voice communication.

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G.S. Kang

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Submarine Habitability

Achievement

In the 1950s, as the age of the nuclear submarine emerged, the requirement grew for extending the capabilities of closed-cycle atmospheres for periods up to 90 days. The need for new atmosphere habitability capabilities was evident when NRL participated in a scientific cruise of the first nuclear submarine, USS *Nautilus*, in 1956. Its atmosphere was found to be "loaded" with pollutants, such as carbon dioxide, carbon monoxide, hydrogen, and hydrocarbons. NRL formed a team to solve the problem. In the 1950s and 1960s, this effort led to the CO/H_2 Hopcalite burner, the monoethanol amine CO_2 scrubber, and the adsorbent carbon bed. The major source of the hydrocarbons was paint thinners. As a result, painting was prohibited prior to submergence and during deployment.

It was also apparent that an analytical instrument was needed to monitor contaminants.[1] In the 1970s, NRL convinced the Navy that mass spectrometry was the technique of choice for atmosphere analysis onboard nuclear submarines. NRL evaluated prototype systems that became the basis of the Central Atmosphere Monitoring System Mark-I (CAMS-I). These systems were installed onboard all nuclear submarines, replacing previous poorly performing analyzers. Later, NRL's research capabilities in mass spectrometry were used to formulate the design of the next-generation analyzer, the CAMS-II. NRL directed the development, laboratory testing, and at-sea trials of the prototype. The CAMS-II is installed in Trident and Seawolf class submarines. NRL was also successful in transferring this technology to industry and in convincing the British Navy to use the CAMS-II aboard Royal Navy submarines.

Impact

Several NRL technologies led to the purification of submarine atmospheres. CAMS replaced atmosphere analyzers that were always on the "top ten" problem list of submarines. Combined, these technologies enable the Navy to operate its submarine fleet on extended deployments and at the same time be assured as to the safety of their atmospheres. The commercial version of CAMS, developed by Perkin Elmer for IBM,[2] has been used in semiconductor processing facilities to provide continuous monitoring of a variety of hazardous materials. The advantages of CAMS are its ability to measure many different atmosphere constituents, from part-per-billion to one hundred percent levels, and its reliability.

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H. Carhart and F.E. Saalfeld

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Flux-Corrected Transport

Achievement

In the late 1960s, NRL conducted theoretical and computational investigations of high-altitude nuclear effects (HANE) for the Defense Nuclear Agency. During 1970 and 1971, in the process of performing this work, NRL developed an entirely new technique for solving fluid dynamic continuity equations on a computer.

The technique, flux-corrected transport (FCT), made possible accurate calculations of shock and steep gradient phenomena by eliminating the oscillations, ripples, and numerical diffusion that had plagued all other techniques for decades. In addition to the HANE research, FCT has been employed in missile silo design, naval oceanography, nonacoustic antisubmarine warfare, and atmospheric communications research. Other applications include facilitating research in civil hydrodynamics and water resources, mine safety, atmospheric pollution transport, supernova explosions, solar weather prediction, laser and ion-beam fusion, and aerodynamics.

Impact

With 250 citations, the original paper on FCT was NRL's most cited publication during the period between 1973 and 1988. This technique has been adopted by over 500 computational laboratories, universities, and companies dealing with fluid flow problems that impact military operations, civil projects, and public health and safety.

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Individual(s) Being Recognized

J.P. Boris and D.L. Book

High-Power, High-Current Pulsed Power Generators

Achievement

In the 1960s, high-power, pulsed-power research was driven by the need to produce intense sources of radiation in the laboratory to simulate the effects of nuclear weapons on commercial and military systems. The U.K. and U.S. were exploring ways to generate 1 MA at 1 MV for 50 ns (5×10^{-8} s). In 1968, NRL designed and built the Gamble I pulsed power generator (750 kV, 500 kA, 50 ns). It was the first high-power, low-impedance facility to use demineralized water as a dielectric-energy-storage medium at high voltage. Ten years earlier, NRL had pioneered the use of water as a dielectric in a lower power, lower voltage water capacitor used to drive an exploding wire. The advantages of water as a capacitive-energy-storage medium are that it has a high dielectric constant, is self-healing to electrical breakdowns, and acts as a good insulator for high-voltage pulses of 10^{-5} s duration or less. J. Martin and I. Smith in England performed water breakdown measurements in 1965 that provided the critical design data for Gamble I.

The success of Gamble I led NRL to build the Gamble II generator that was, when completed in 1970, the largest pulsed-power generator of its kind in the world, capable of delivering 1 MV across a 1-ohm load for 50 ns. The 1 TW output power was more than the entire electrical power capacity of the U.S. At that time, the primary purpose for this capability was to provide an intense radiation source for simulating nuclear-weapon effects in the laboratory to supplement the U.S. underground simulation effects testing program. Military electronics were exposed to this radiation to assess their survivability in a real nuclear environment.

Impact

Gamble I and II were prototypes for all modern high-power, low-impedance generators now in industrial laboratories, universities, DoD and DoE laboratories, and foreign laboratories. Besides the important weapon-effects simulation, pulsed-power technology based on water-dielectric capacitive energy storage has generated other areas of research on high-power electron and ion beams and soft X rays from z-pinch plasmas for inertial confinement fusion, matter at high-energy densities, directed-energy weapons, high-power microwaves, flash X-ray radiography, pumping gas lasers, and X-ray laser technology.[1]

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Marine Surface Monolayers

Achievement

Beginning in the early 1960s, NRL performed research on the nature and effects of surface-active substances at critical interfaces in the marine environment. Much of this early basic research was guided by W. Zisman. This research led to three applications: oil spill control, radar detectable seamarkers for search and rescue, and mosquito control.

Oil Spill Control. NRL discovered that certain invisibly thin surface films applied around oil spilled on water could compress the oil into a much smaller area and maintain the oil in a thick layer, thereby enhancing the efficiency of oil-recovery operations. While developing the technique, NRL worked with JBF Scientific Corp., a manufacturer of oil recovery vessels. Following EPA approval, the method was incorporated into Navy pollution control programs for harbors and bays. It has also been used in commercial training for oil spill control.[1]

Seamarker Development. Used in combination with the standard green dye, NRL's surface-active compound spontaneously spreads rapidly over the sea surface and makes a manyfold larger mark than the dye alone. Because of the damping effect of the compound on small capillary waves on the sea surface, the one-molecule-thick films are readily detectable both visually and by radar, with radar providing nighttime and poor weather detectability.

Mosquito Control. NRL developed a thin surface film that prevents mosquitos in the pupal and larval stages from attaching to the water's surface where they breathe and feed. This causes them to drown, thus killing by physical, not toxic, means. No pesticide is required nor is a petroleum-based solvent needed to deliver the compound. The method has proven effective against mosquito genera, which are carriers of tropical diseases, including malaria. The commercially manufactured, nontoxic compound has been licensed for application [NRL-LIC-96-016] and has been used in mosquito control districts across the U.S.

Impact

The mosquito control technique has reduced public health hazards by controlling mosquitos using a more environmentally safe method in place of toxins. The oil-spill control technique has reduced the damage to property, the fishing industry, and the environment. The new sea marker benefits the military in air-sea rescue operations.

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W.A. Zisman, W.D. Garrett, and W.R. Barger

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Windspeed Measurement Using Microwave Imaging

Achievement

NRL pioneered the use of passive microwave sensing to measure ocean surface roughness and then the use of those measurements to derive the surface windspeed. Surface waves, called capillary waves, are excited by the wind. The mechanism is that the wind must have zero speed at the surface so the drag force exerted by the wind is dissipated in these small waves. The interactions between the wind and the capillary waves result in distinct increases in the thermal microwave emission from the ocean. This increase can be measured with a microwave radiometer and the increased emission can then be used to derive ocean windspeed.

In aircraft and tower experiments from 1966 to 1977, NRL's J.P. Hollinger recognized that this phenomenon could be used to fill the Navy's need to measure ocean winds. He promoted the inclusion of the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) and set its specification by chairing the DoD specification panel in 1978. The first SSM/I was launched on DMSP F8 in 1987. Hollinger led the calibration validation effort that brought the SSM/I into operational use in 1988.

Impact

The Navy needs to measure ocean winds to provide the U.S. Fleet with the most accurate meteorological forecasts possible. Due in large measure to NRL's efforts, the SSM/I is the operational ocean surface windspeed sensor now used by both civilian and military forecasters. It also provides data as input to numerical weather prediction models of the Fleet Numerical Meteorological and Oceanographic Center, National Oceanic and Atmospheric Administration, and the European Center for Medium-range Weather Forecasting. The SSM/I is used on weather satellites, and there is an SSM/I on every DMSP satellite. An improved version, SSM/IS or imaging sounder, will enter service in 2000.

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Individual(s) Being Recognized

J.P. Hollinger

Spaceborne Solar Coronagraphs

Achievement

The study of the Sun's corona, the outermost atmosphere, has been a fundamental aspect of solar science. At first, the corona could only be seen during the brief interval of a full solar eclipse. Ground-based telescopes allowed continuing observations of the corona, but only close to the Sun's surface. But with the advent of space-based observation, it occurred to NRL scientists that the absence of atmospheric scattering made possible the routine observation of the corona out to large distances from the Sun.

The first coronagraph for this purpose was developed and flown by NRL in 1963. Its success gave birth to a new understanding of the solar atmosphere. Ensuing rocket flights showed the corona changing far more rapidly than previously supposed, and the orbiting NRL coronagraph on NASA's OSO-7 satellite discovered immense explosions in which solar plasma is thrust outward, sometimes striking Earth. A new term, coronal mass ejection (CME), was born, and the frequency of such events, along with their importance for effects on Earth, was established by NRL's SOLWIND coronagraph, which recorded more than two thousand CMEs in six and one-half years on an Air Force satellite. SOLWIND also laid a basis for the international consortium that produced the LASCO wide-field triple coronagraph, which operates aboard the ESA-NASA Solar and Heliospheric Observatory. NASA's LASCO is a $75 M investment in this technology and constitutes recognition of its importance for studying the Sun and providing a diagnostic tool for geomagnetic disturbances.

The ability to examine the region near the Sun has the potential to create a new field of solar system science that merges space plasma physics with solar coronal physics. For the first time, scientists are able to see solar emissions streaming out to form the solar wind and study the progress of ejected solar material for more than a day. It is now recognized that the spaceborne solar coronagraph is one of the key instruments for studying the Sun and its environment, and it will be an essential component in monitoring space conditions to address issues of space weather.

Impact

NRL's solar coronagraph technology demonstrated the existence of CMEs and their role in major geomagnetic storms. Coronagraphs now provide the possibility of a major change in the ability to forecast the onset of geomagnetic disturbances. This is important because CME shocks propagate to large heliocentric distances and, when directed toward Earth, they disturb the magnetosphere. This can cause major geomagnetic storms disruptive of communications, power, and military detection systems. If these storms are severe, astronauts and equipment in space can be at risk.

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Individual(s) Being Recognized

R. Tousey, M.J. Koomen, D.J. Michels, and G.E. Brueckner

Fiber-Optic Interferometric Acoustic Sensors

Achievement

In 1977, NRL demonstrated the world's first fiber-optic interferometric acoustic sensor.[1] Based on this work, NRL received the first U.S. patent awarded for an optical interferometric sensor to measure external fields. This device focused on acoustic fields. From the beginning, it was viewed as a generic device in that it would be capable of responding to other external perturbations — electric field, magnetic field, temperature, etc. — depending on the design of the fiber coating or mounting structure.

NRL's work launched Navy, DoD, and national interest in fiber-optic acoustic sensors in particular, and fiber-optic nonacoustic sensors in general. In 1978, based on the fiber acoustic sensor results, NRL conducted the first Navy/DoD program in fiber-optic sensor systems (FOSS) — the vanguard of a rapidly growing interest in fiber interferometric sensors. NRL was the leader in this technology in the late-1970s to early-1980s. Other organizations, such as the Naval Underwater Warfare Center, the Naval Surface Warfare Center, and Litton, have since joined NRL in developing systems based on these sensors.

A number of sensor system technologies based on interferometric fiber acoustic sensors have been successfully demonstrated. One such system is an all-optical towed array (AOTA) with a full complement of fiber-optic acoustic sensors. In 1986, fiber-optic acoustic sensors were first tested at sea. Based on the results, an AOTA Advanced Technology Demonstration was initiated. Successfully completed in 1990, it met all performance goals and showed that the concept was a cost-effective alternative to piezoceramic technology.

Impact

NRL's original invention, and the subsequent FOSS program, led to the now ubiquitous presence of fiber-optic sensor devices. These devices resulting from NRL's pioneering work will include numerous sensor applications, such as acoustic, magnetic, electric, thermal, vibration, and flow. These applications will have impact in the areas of military operations, medical care, and nondestructive evaluation.

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J.A. Bucaro, T.G. Giallorenzi, and A. Dandridge

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Semi-Insulating Gallium Arsenide Crystals

Achievement

In the 1970s, NRL developed a liquid-encapsulated Czochralski (LEC) method of compounding and growing high-purity single crystals of gallium arsenide (GaAs). Because of the high purity, the crystals could be ion implanted to produce microwave and millimeter wave devices and integrated circuits. This development was important because transistors and microcircuits made of silicon, the most common semiconductor material used, operate poorly at microwave frequencies. NRL performed the basic process development, demonstrated the principles for achieving the high-purity semi-insulating GaAs substrate, and was instrumental in transferring the technology to industry.

A more inexpensive method of GaAs wafer production is important because it leads to reductions in the costs of microwave and millimeter wave devices and integrated circuits vital to military systems. A 1986 Navy study estimated that this technique would save the Department of Defense $560 M between 1979 and 1989. This is all the more impressive given that the original investment in NRL's research was $528,000.[1]

Cost reduction is also important in increasing the competitiveness of U.S. companies. NRL's technology was adopted by major U.S. industrial firms, such as Rockwell International, Westinghouse, Texas Instruments, and Hughes Research.[2] In commending NRL's achievement, one U.S. company claims that in 1980 approximately 100% of the GaAs device industry was in Japan. In 1997, the GaAs integrated circuit industry will realize sales of $447 M, with American companies representing 65% of that total.[3]

Impact

NRL's technology has allowed the increased use of GaAs integrated circuits. Military systems using the technology are all combat aircraft radar, ARM, Phoenix missiles, AIM-9L, AMRAAM, and satellite communication systems. Commercial uses include radar, cellular communications, and satellite systems. The technology demonstrated audited savings to the military, for the 10-year period from 1979 to 1989, of over $560 million (in 1986 dollars).[4]

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E.S. Swiggard and H. Lessoff

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[3] Letter to H. Lessoff from J. Vaughan (Vice President for Business Development), M/A-COM, September 21, 1997.

[4] Commander, NAVAIRSYSCOM.

Super Rapid-Blooming Offboard Chaff

Achievement

NRL developed the first wide spread decoy system applied to all major Navy surface combatants. The MK-36 and MK-182 cartridge was successfully operationally evaluated in 1977. Because of the operational success of this system, a follow-on international program was established to provide the continual product improvements that result from ongoing innovation. This international program led to the successful development of the MK-214 and MK-216 cartridges, which entered the Fleet in 1987 and 1988, respectively, and which are in current use. The super rapid-blooming offboard chaff (Super RBOC) system and its family of decoys will be used by the U.S. Navy and its allies well into the next millennium.

Impact

Super RBOC and its family of decoys significantly improved the Navy's capability to conduct electronic warfare from its surface combatants. It is a major advancement in the state of the art in its ability to rapidly produce an alternate target for the protection of ships against antishipping cruise missiles. With the extensive proliferation of the cruise missile threat throughout the world, this solution was especially timely and critical to the survivability of the Fleet.

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Individual(s) Being Recognized

J. Montgomery, W. Humphries, and W.J. Schaefer

Ion-Implantation Metallurgy

Achievement

In the late 1970s, NRL researchers devised a surface modification technique to develop new materials with unique and extraordinary properties by forcibly implanting ions (electrified atoms) into ordinary materials. The new properties may be physical, chemical, electrical, optical, or mechanical. Ion implantation offers broad new areas of applications, including corrosion-resistant ball bearings.

The alloy ASA M50 and M50 NIL are the primary bearing steels used by the Navy in its turboshaft engines. Since the Navy operates over salt water, the environment is very corrosive compared to that experienced by Air Force and commercial aircraft. Refurbishment and replacement of bearings, which cost up to $3000 each, is a significant maintenance expense. Turboshaft bearings must maintain high rolling contact fatigue resistance at relatively high operating temperature, therefore stainless steel cannot be used. Protection of the bearings with an anticorrosion coating has been unsuccessful due to delamination of the coatings. NRL's research offered an answer to this problem.

Bearings were ion-implanted with Cr ions that produced a 75-nm-thick stainless steel layer on the low alloy bearing steels ASA M50 and 52100. This dramatically improved the service life and shelf life of the expensive bearings. This research stimulated a Manufacturing Technology Program for ion implantation of bearings with Cr or Cr+P ions. Results showed that the bearings could be implanted for between $70 and $170 per bearing, and that this cost was more than paid for by the average increase in the bearing service life of 2.5 times. The Navy program demonstrated to three commercial companies in the U.S. and Europe that implantation of rolling element bearings could be part of their ion implantation business operations. Presently, the primary commercial process is for instrument bearings. Motivated by the Navy program, the U.S. Army undertook a study of ion implantation of tool steels for helicopter rework. The study was successful, and as a result, the Army purchased an ion implantation facility for installation at a Corpus Christi Army helicopter rework facility.

Impact

The early NRL work established the state of the art for ion-implantation metallurgy. In one application, NRL's technology is an advance for corrosion protection of ball bearings on naval aircraft, thus providing a solution to an important Navy problem. It has also benefitted the U.S. Army and found application in commercial processes.

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G.K. Hubler, K.S. Grabowski, J.K. Hirvonen, and F.A. Smidt

Fluorinated Network Polymers

Achievement

Polyurethane coatings were introduced in the 1960s as a material to line massive fuel tanks used for long-term storage of aviation, marine, and vehicle fuels. This was done as a means of achieving longer lifetimes for the fuel tanks, cleaner fuels for aircraft and ships, and the elimination of fuel leakage through the porous welds of these large, underground, steel tanks. Each tank holds 300,000 barrels of aviation fuel and is 100 ft in diameter by 250 ft high. To give a better indication of the size of these fuel storage tanks, one tank holds enough gasoline to give a 12-gallon fill-up to 1,050,000 automobiles.

To improve the polyurethane coatings, NRL developed tank linings consisting of a fluorinated polyurethane filled with Teflon powder. The material is both hydrophobic and oleophobic and impermeable to water, gases, hydrocarbons (fuels), and other corrosive agents. Use of the lining began in 1983; by early 1986, the lining had been installed in tanks at Naval Air Station Pensacola, Florida (four tanks), Corpus Christi, Texas (two tanks), Norfolk, Virginia, and Patuxent River, Maryland, and at Naval Support Facilities at Yokosuka, Japan, Craney Island, Virginia (two tanks), Diego Garcia (two tanks), and Pearl City, Hawaii (five tanks).

In estimating the financial savings of the fluoropolyurethane topcoat, the Naval Facilities Engineering Command performed a life cycle cost analysis for a 60-year life for the tanks at Craney Island, Virginia. The Command included costs for coating installation and necessary replacement, plus periodic cleaning of the tanks. In 1993 dollars, the epoxy coating costs $60,863 per year, a conventional urethane coating costs $40,698 per year, and the fluorinated urethane coating costs $30,144 per year.[1] Based on 18 fuel tanks coated to date, the total life-cycle savings for using fluorinated urethane coatings in place of conventional urethane coatings are $11.4 M, and are more than $33 M by replacing epoxy coatings.

Impact

NRL's fluorinated polymer coating is an effective lining for the massive fuel tanks at Naval air stations and Naval support facilities. It also saves a significant amount of money over the life of the tanks. The U.S. Army mandates this lining for the same purpose,[2] and the Defense Fuel Supply Center also specifies this coating in all new tanks. Finally, a clear coating of this polyurethane was adopted in 1987 as the standard coating for BRA-22 radomes on all Los Angeles-class submarines because the water shedding characteristics of the coating provide more rapid access to stable radar when broaching the sea surface.

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J.R. Griffith

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[2] U.S. Army Corps of Engineers Guide Specification, CEES-09873.

Excimer Laser Technology

Achievement

NRL researchers S. Searles and G. Hart (then an NRL-NRC postdoctoral associate) discovered the first excimer laser in 1975. Excimer lasers operate in the ultraviolet (UV) and have short-duration pulses that allow the study of fast processes. UV lasers can be tightly focused relative to longer wavelengths in the visible range of the spectrum, and excimer lasers are more efficient relative to other UV lasers. The use of lasers with shorter wavelengths is limited because the radiation does not propagate through air.

Following the NRL discovery, other laboratories utilized the high-voltage, electron-beam generators to demonstrate excimer laser emission with other gases. The demonstration at NRL that an electrical discharge could be used to make an excimer laser with order-of-magnitude lower voltages led to commercial development. Once the commercial sector developed the technology, the excimer laser became a laboratory tool for studies of molecular excitation and material ablation. The utilization of the laser for fundamental studies increased rapidly in all fields, especially in the fields of biology and medicine. An indication of its prevalence as a research tool is that by 1998 over 10,000 articles have been published with "excimer laser" as a key word. At NRL, a "custom" excimer laser system is nearing completion for the study of laser-induced fusion reactions.

In the commercial sector, the technology has been developed for photolithography in the semiconductor business and for medical applications. In 1992, Hart and Searles were presented the Rank Prize for Opto-electronics in London, England. The award read:

> "Today's high power ultraviolet gas lasers find applications in science, industry, and medicine ranging from the production of integrated circuit chips by photolithographic techniques to a surgical procedure in which the cornea of the eye can be reshaped so as to correct for defects in vision."

Impact

NRL's discovery of the excimer laser has provided the research community with a new tool, especially for fundamental studies in biology and medicine. In the commercial realm, the laser has found applications in the production of integrated circuit chips and in corneal sculpting for vision correction. In the latter application, the market is estimated to be over a billion dollars.

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Individual(s) Being Recognized

S.K. Searles

Specific Emitter Identification

Achievement

Specific emitter identification (SEI) provides electronics intelligence (ELINT) signal collection platforms with the capability to uniquely identify a radar transmitter with such accuracy as to make it possible to assign a "fingerprint" to that particular signal. In using SEI techniques, systems with a radar transmitter can be cataloged and tracked, and the data interchangeability between SEI systems allows a signal to be collected by one system and then "handed off" to another system for tracking. For example, SEI can be used to covertly track a contraband transport whose signal of interest can be collected by an aircraft and then transmitted electronically to a ship for subsequent tracking.

On April 14, 1982, R. Goodwin was the recipient of the Navy Superior Civilian Service Award. He was cited for:

> "performing and directing the research and development efforts that led to the achievement of an important, new Navy capability in real-time pulsed-emitter characterization."

In June 1993, the National Security Agency (NSA) recognized the superior capability of NRL's SEI concept and equipment after a competition among numerous participants from industry and other service laboratories.[1] The NSA test served as an impartial means for selecting an SEI methodology for use as a national standard. As a result of the test, NSA issued a message (DTG 011440Z, June 1995) that stated in part, "Accordingly, NSA has selected the Naval Research Laboratory processor (L-MISPE) to be the standard for conducting SEI/UMOP collection operations...."

Impact

NRL's SEI technology has had major impact on the Navy, Air Force, Army, Marines, and Coast Guard. There are currently SEI systems deployed on ships, aircraft, submarines, and ground sites. These sites have been very successful at cataloging and tracking platforms of interest. In one application, a library of over 10,000 specific radar signals has been compiled. This library is shared between the sites to aid in performing tactical intelligence and surveillance tasks.

Primary Reference Documents

- Goodwin, R.L., "System for Classifying Pulsed Radio-Frequency Modulation," NRL Classified Patent Disclosure No. 772,602, February 10, 1977.[2]
- Goodwin, R.L., "Electronic Warfare Unintentional-Modulation Processors: System Definition Considerations," NRL Report 9040, June 1988.

Individual(s) Being Recognized

R. L. Goodwin, C.H. Heider, J. Edwards, and R. Oxley

[1] Christiansen, R.M., et al., "Assessment of L-MISPE Performance in Musketeer Dixie II," NRL Memorandum Report 7404-93, February 14, 1994.

[2] This is Goodwin's original patent disclosure for emitter feature extraction and use for SEI. Since the abstract was classified, no patent was pursued.

Inverse Synthetic Aperture Radar

Achievement

Inverse synthetic aperture radar (ISAR) is a coherent imaging technique for classifying ships at sea. NRL's D.W. Kerr had the concept for using the ship's irregular motions to provide the angle-aspect change necessary for imaging.

ISAR processes the radar echoes in fine range-resolution cells, resolving the incremental Doppler frequency shift between scatterers caused by the ship's angular change (roll, pitch, and yaw) during an observation interval. The Navy uses this as a mode with a scanning surveillance radar. In the scanning mode, the radar produces a plan-position indicator (PPI) map of the ocean in which detected ships appear as bright "blips." When a radar operator designates a "blip" with a cursor, the radar antenna searchlights the ship position, and a continuous series ISAR ship image appears on the screen.

The AN/APS-116 radar, which was based on earlier NRL developments, was replaced by the AN/APS-137 that has the added capability of performing recognition of ships based on NRL's ISAR technique. The APS-137 is now installed in P-3 as well as S-3 aircraft.

As an ocean surveillance tool, the Navy uses ISAR for providing ship classification and the targeting of long standoff range missiles.

Impact

ISAR is the DoD's only operational system for classifying ships. It is operational on the Navy's S-3B and P-3C aircraft, the Coast Guard's C-130 aircraft, and in full-scale development for the Navy's SH-60R (LAMPS) helicopters. It has been demonstrated on Navy and Coast Guard ships and found useful.

Primary Reference Documents

- Ringwalt, D.L., Kerr, D.W, and Hermann, G.W., "Project Profile Phase IV — Mediterranean Test Summary," NRL Memorandum Report 4008, June 29, 1979.
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- Musman, S., Kerr, D.W., and Bachmann, C., "Automatic Recognition of ISAR Ship Images," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 321, No. 4, 1392-1403 (1996).

Individual(s) Being Recognized

D.W. Kerr, G.W. Hermann, and D.L. Ringwalt

Key Distribution and Management for Cryptographic Equipment

Achievement

NRL's Navy Key Distribution System (NKDS) substantially improves the security of cryptographic key material that is distributed throughout the Navy to communications security (COMSEC) accounts. Traditionally, key material was generated and stored in a hardcopy form (e.g., paper) and distributed to COMSEC accounts as unencrypted text. As the Walker spy case demonstrated, this left the key vulnerable to compromise and to alteration. It also made rapid key generation and distribution impossible.

If NRL's NKDS key protection mechanisms had been available at the time, the Walker compromise could not have occurred. The concept, architecture, and requirements developed by NRL for NKDS changed the paradigm of key material generation, distribution, and management. The NRL requirements called for the replacement of the unencrypted paper key scheme by an electronic system in which keys are encrypted from generation until employment so that their confidentiality and integrity are ensured. NKDS also facilitates rapid planning and execution of battlegroup communication plans, resulting in an improvement in Navy operational flexibility. This approach provides the security needed to protect key material from compromise, and thus protect lives and the mission of the Fleet. NKDS went operational in September 1994.

Impact

The NRL-developed architecture and requirements have become the cornerstone of current DoD key material generation, distribution, and management systems. The most notable of the current tri-service systems employing the architecture and requirements of NKDS is the Common Tier 1, a program decreed on May 18, 1994 by E. Paige, Jr., Assistant Secretary of Defense for C^3I, as the COMSEC Material Control System for the DoD. The decree also mandated the Common Tier 1 system to support the civil agencies and provide an interface to our allies at the national level. The Electronic Key Management System (EKMS) program is currently developing the remaining technology conceptualized as part of NKDS. The ideas and concepts of NKDS, once completed as part of the EKMS program, should provide the basis for a secure, efficient, and responsive COMSEC Material Control System for the next century.

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- Chincheck, S., "System Specification for the Navy Key Distribution System (NKDS)," Type-A System Specification, November 1988.
- Chincheck, S., "Computer Security Analysis of the Navy Key Distribution System," NRL Report 9297, April 1991.
- Chincheck, S., "Detailed Operational Concept for the Navy Key Distribution System," NRL Report 9803, July 1991.

Individual(s) Being Recognized

S. Chincheck

Infrared Threat Warning

Achievement

A passive anti-aircraft missile warning system based on detection of the infrared (IR) radiation from missile plumes was demonstrated by NRL. The device is intended to detect missiles fired at aircraft and provide a warning to enable the effective use of countermeasures. The development evolved from initial concept analyses and proceeded through sensor development, measurements to verify the concept, and demonstration of a system suitable for engineering development. OPNAV has approved engineering development of the system beginning in 2001. The system will be developed for initial use on the F/A-18E/F and V-22.

Initial concept formulation and analyses were performed by NRL's A.F. Milton and E.H. Takken in 1981. By 1983, the algorithms for using spectral and temporal processing had been described. The incorporation of spatial processing into the two-color algorithm formed a powerful signal processing approach that allowed for long-range missile detection with a very low false-alarm rate. Implementation of the concept required use of high-sensitivity IR focal plane arrays, which were becoming available with in-dewar multiplexer and preamplifier in the 1980s. A data measurement sensor incorporating this focal plane array technology provided the first target and background data used to validate the algorithms. This "Fly's Eye" sensor used two coaligned 128 × 128 array sensors for fast-framing two-color measurements. It was the first warning development sensor flown on an NRL P-3 for ground scene clutter and battlefield ordnance measurements and for tracking missile firings along the rocket track at China Lake, California. A system suitable for transition to engineering development was developed under an advanced technology demonstration program through ONR. The NAVAIR Electronic Warfare Advanced Technology program has funded an effort to demonstrate operational functionality in a missile firing at a drone F-4 aircraft.

Impact

OPNAV has approved engineering development of the system beginning in the year 2001 for initial use on the F/A-18E/F and V-22 aircraft. The Army CECOM has adopted the NRL missile warning approach as the preplanned product improvement for their Common Missile Warning System. The Director for Electronic Warfare, OSD, has identified the NRL demonstrated approach as the eventual tri-service missile warning system.

Primary Reference Documents

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Individual(s) Being Recognized

A.F. Milton, E.H. Takken, M. Pauli, G. Katz, and K.A. Sarkady

Optical Fiber Gyroscope

Achievement

NRL was the first to demonstrate long-term inertial-quality performance in a fiber-optic gyroscope. This achievement was a pivotal milestone in the device's development into a practical, precision, inertial-quality navigation instrument that has stimulated intense industrial development of the device.

The fiber-optic gyroscope provides rotation sensing for inertial navigation and other positioning and directional applications, such as attitude, heading, and reference in airplanes. The device is used for air and sea navigation and satellite attitude control. Since it provides longer lifetime rotation sensors, it also leads to lower operational cost.

Before 1983, the fiber-optic gyroscope was essentially a laboratory curiosity, with little industrial activity due to limited sensitivity and large bias drifts. The sensitivity problem was solved in Germany by R. Ulrich with the introduction of the broadband source. The bias drift problem was solved at NRL by W.K. Burns and his colleagues, who built one of the first fused-fiber couplers with polarization-maintaining fiber, and used this coupler to build a fiber gyroscope with polarization-maintaining fiber. This fiber and coupler greatly reduced the polarization noise that was responsible for long-term bias drift, and performance of 0.035 deg/hr over 24 hours was demonstrated. This result led to the initiation of widespread industrial interest and development efforts, as it demonstrated that the fiber-optic gyroscope was capable of practical inertial navigation. Numerous companies market fiber gyroscopes today that directly incorporate NRL's work.

In 1995, the Institute of Navigation awarded NRL's W. K. Burns the prestigious Thurlow Award for his contributions to the development of the fiber-optic gyroscope.

Impact

NRL was the first to demonstrate long-term inertial-quality performance in a fiber-optic gyroscope. The technology is now replacing spinning mass gyroscopes with fiber optical devices without moving parts. This is a revolution in rotation-sensing technology, and will have a permanent impact due to higher reliability and longer lifetime, as well as weight, size, and cost reduction. The fiber gyroscope has impacted both military and civilian applications from use on U.S. military platforms to automobiles in Japan. The optical fiber gyroscope is in production in the U.S. as well as in Europe and Japan.

Primary Reference Documents

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- U.S. Patent No. 4,612,028 to Abebe, M., Burns, W.K., and Villarruel, C.A., "Polarization Preserving Single Mode Fiber Coupler," 1986.

Individual(s) Being Recognized

W.K. Burns, R.P. Moeller, and C.A. Villarruel

Permanent Magnet Materials

Achievement

In 1980, NRL's N.C. Koon was the first to examine the magnetic properties of rare earth-iron-boron (R_2-Fe-$_{14}$B) alloys, which showed promise for permanent magnet use. NRL scientists did the first work on these materials and hold the fundamental U.S. patents. These NRL patents have been licensed to several firms and products are being offered commercially. Since 1983, commercial alloys based on R-Fe-B have been in commercial production, and by 1985 these materials provided almost twice the magnetic energy density of the best materials previously available.

These magnetic materials are eventually expected to cost much less than the older materials because they are made from less expensive and more abundant elements. They also offer relatively good corrosion resistance and easy formability into complex shapes.

Impact

These new magnet materials have had a tremendous impact in the concept and design of devices that use a magnetic field to produce motion. Specifically, these materials promise to be useful by both the military and commercial sectors for improved microwave tubes, sensors, powerful lightweight electric motors and generators, computer peripherals, and for faster, more compact actuators.

Primary Reference Documents

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- U. S. Patent No. 4,402,770 to Koon, N.C., "Hard Magnetic Alloys of a Transition Metal and Lanthanide," September 6, 1983.
- U. S. Patent No. 4,533,408 to Koon, N.C., "Preparation of Hard Magnetic Alloys of a Transition Metal and Lanthanide," August 6, 1985.

Individual(s) Being Recognized

N.C. Koon

Navy Operational Global Atmospheric Prediction System

Achievement

NRL's Navy Operational Global Atmospheric Prediction System (NOGAPS) is DoD's unified global weather analysis/forecast system, used for operational weather prediction around the world. NOGAPS provides surface fluxes; ocean, wave, and ice prediction; tropical cyclone prediction; and ship and aircraft routing systems. Much of the atmospheric and oceanographic support for military operations has its roots in NOGAPS, whether it is the prediction of cloud cover over the strike target, estimation of environmental effects on weapons systems, the prediction of tropical cyclone formation and movement, or high seas warnings.

The transition to NOGAPS in 1988 marked a major improvement in DoD's global weather prediction ability and provided the necessary environmental forcing for numerous additional weather and oceanographic products. The Naval Meteorology and Oceanography Command estimates that use of NOGAPS in the Optimum Track Ship Routing and Optimum Path Aircraft Routing systems, in addition to increasing the safety of Fleet units, saves the Navy roughly $45 M a year in fuel costs. Accurate weather forecasts reduce sortie costs by $16 M a year, and the Atlantic Fleet saves $6 M a year in utility costs by using NOGAPS forecasts. An accurate forecast for northward recurvature of an advancing hurricane that results in a decision not to sortie the Atlantic Fleet can easily save the Navy $5 M. Improved advance warning of impending landfall and potential tropical cyclone strength also prevent loss of life and reduce property damage.

NOGAPS has had an impact on other environmental technology. For example, the NOGAPS high-resolution global reanalysis of atmospheric conditions during the Gulf War has been recognized by independent experts as the most accurate depiction of synoptic-scale weather during that period. And, boundary conditions from NOGAPS have enabled NRL's mesoscale weather prediction system to provide the most accurate assessment of mesoscale meteorology in the Persian Gulf region. These assessments have been used to estimate locations of potential troop exposure to hazardous chemical release during the Gulf War.[1]

Impact

NRL's NOGAPS has had a far-reaching impact on both military and civilian weather forecasting. U.S. military commands are the principal beneficiaries of NOGAPS. The Navy, Air Force, Army, and Coast Guard all use the NOGAPS analysis and forecast products in support of their operations. NOGAPS products are also used by the National Oceanographic and Atmospheric Administration, and the Department of Energy.

Primary Reference Documents

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- Barker, E.H., "Design of the Navy's Multivariate Optimum Interpolation Analysis System," *Weather Forecasting*, Vol. 7, 220-231 (1992).

Individual(s) Being Recognized

N.L. Baker, E.H. Barker, T.F. Hogan, and T.E. Rosmond

[1] Chang, S.W., et al., "A Meteorological Re-Analysis for the Study of Gulf War Illness," NRL/MR/534--98-7233, January 1998.

Generalized Nearfield Acoustical Holography

Achievement

In the period from 1982 to 1998, NRL developed and implemented a new measurement technique called generalized nearfield acoustical holography (GENAH). NRL's E.G. Williams performed the pioneering work that is revolutionizing the field of experimental acoustics in noise characterization and control throughout the world.

GENAH is the only experimental technique that, from a single array measurement, can provide a complete global analysis of the vibration, radiation, and scattering of structures in air and underwater. This work has provided the Navy with a powerful tool to understand the radiation and scattering of sound from submarines. The knowledge being gained far outstrips what is currently understood in Navy and non-Navy communities. The understanding of fluid-structure interaction and wave propagation gained through GENAH has been a cornerstone in the Navy's effort to study and remedy acoustic vulnerabilities in the U.S. submarine fleet. This work has changed the way the Navy views the vibration, radiation, and scattering from submarines and has been a major force in changing the thinking of Navy and non-Navy researchers in their endeavors to quiet the U.S. submarine fleet.

Because of the remarkable scientific and engineering impact of this research, NRL has inspired nearfield acoustic holography efforts throughout the world. In underwater acoustics, the French, Italian, and Japanese navies have applied GENAH to study the vibration and radiation of submarines. In architectural acoustics, the measurement technology for studying the transmission of sound through building structures has been revolutionized using GENAH principles in France, while in Japan, new techniques for the measurement of reflection coefficients have been developed. Recent transitions of NRL's work have concentrated on noise control in the automotive and aerospace industries, including studies in tire noise and interior cabin noise at laboratories in the U.S., Korea, and Japan. It has also been used to deal with moving noise sources such as cars and trains in France, Korea, and Japan.[1]

Impact

NRL's development of GENAH is revolutionizing the field of experimental acoustics in noise characterization and control throughout the world. The U.S. Navy is using NRL's work to reduce acoustic vulnerabilities in the submarine fleet. In industry, major acoustical measurement companies have marketed systems based on GENAH for use in a broad range of applications, including noise control in the automotive and aerospace industries. Research papers citing NRL's work have appeared in almost every major scientific country in the world.

Primary Reference Documents

- U.S. Patent No. 4,415,996 to Maynard, J.D. and Williams, E.G., "Nonwavelength-limited Holographic Sound Field Reconstruction," November 15, 1983.
- Williams, E.G., "Method of Measuring Structural Intensity in Vibrating Plate Radiators," U.S. Statutory Invention Registration H1330, July 5, 1994.

Individual(s) Being Recognized

E.G. Williams

[1] Bruel and Kjaer, "Vehicle Noise Investigation Using Spatial Transformation of Sound Fields," *Sound and Vibration*, April 1989.

Polar Ice Prediction System

Achievement

The Polar Ice Prediction System (PIPS) is the first operational ice nowcast/forecast system for the Arctic, as well as the first regional operational ice forecast system for the Barents and Greenland Seas. These systems were superseded in 1995 by the first operational coupled ice/ocean nowcast/forecast system encompassing all sea-ice covered regions in the northern hemisphere.

PIPS is the U.S. Navy's numerical, model-based, sea ice forecasting system. The original PIPS 1.0 became operational in 1987. It executed daily, 120-hour forecasts of ice thickness, ice drift, and ice concentration (including ice edge) for the Arctic and the Barents and Greenland Seas. Two additional regional forecast systems for the Barents and Greenland Seas became operational in July 1989 and October 1991, respectively. These models also made 120-hour forecasts of the same conditions as PIPS 1.0, but at five times the resolution. PIPS 2.0 became operational in 1995 and superseded all earlier forecasting systems. It is the first fully coupled, operational, ice-ocean nowcast/forecast system in the world. It combines the Hibler ice model technology of the earlier PIPS with a Bryan-Cox ocean model to provide more accurate 5-day ice forecasts.

PIPS' use of remotely sensed data from assimilation in ice/ocean prediction is also a first. Although satellite data have previously been used by the high-latitude scientific community for model validation and verification purposes, NRL's team is the first to make use of satellite-derived ice data (ice concentration) as part of a data assimilation technique used to initialize ice/ocean forecast systems daily. The value of this capability has been recognized by other international forecasting centers such as the U.K. Meteorology Office, in that they have requested this technique for incorporation into their own forecast systems.

Impact

Accurate ice forecasts are important to the U.S. Navy operations. NRL's PIPS (PIPS 1.0 through PIPS 2.0) provided a major advance to the state of the art in operational sea-ice assimilation and forecasting. These were the first of their kind, real-time, operational capabilities in the world and are still unequaled today. PIPS provides operational guidance to the National Ice Center (a joint Navy, National Oceanographic and Atmospheric Administration, Coast Guard organization) in its civilian and military forecasts of high-latitude ice conditions.

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Individual(s) Being Recognized

R.H. Preller

Fixed-Wing Airborne Gravimetry

Achievement

Measurement and analysis of the spatial variations in the gravity field of the Earth are useful from both geologic/geophysical and geodetic perspectives. Gravity data serve in the first case as a remote sensing probe of shallow and deep mass distributions beneath the surface of the ocean or land, an important tool for economic geology and basic geophysical research. In the second area, geodesy/gravity data are used to establish the shape and figure of the Earth. Geodetic quantities are of critical operational importance to the Navy, primarily as corrections to high-accuracy inertial navigation systems in submarines and ballistic missiles. Over the years, enormous efforts and expenditures have been devoted to shipboard and terrestrial gravity surveys to meet Navy requirements.

Airborne gravimetry had long been a desirable goal because of the lower costs, rapid collection, and access to logistically difficult areas made possible by airborne surveying techniques. However, the extremely poor signal-to-noise characteristics of airborne gravity measurements defeated numerous attempts since the 1950s by government, academic, and industry researchers to provide airborne data of useful accuracy and resolution. It was found possible to acquire data at low speeds in helicopters, however their range was too limited and their costs too high to make them preferable to traditional ship and land survey methods.

In 1979, NRL began a program in airborne gravimetry from long-range, fixed-wing aircraft capable of meeting Navy requirements. The research program required the development of extremely accurate three-dimensional aircraft positioning, specialized aircraft operational techniques, and improvements to gravimeter technology. This program resulted in the world's first successful demonstration of accurate fixed-wing-based airborne gravity measurements. The 1981 field test of the prototype measurement system achieved accuracies of 2 to 3 parts per million on several profiles over an Atlantic gravity test range at aircraft speeds of 250 knots. Development of the system and techniques continues to the present day.

Impact

The NRL long-range airborne gravity measurement system is unique and provides required data for Navy and other DoD tactical and strategic systems that cannot be acquired in any other way.[1]

Primary Reference Documents

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Individual(s) Being Recognized

H. Fleming and J.M. Brozena

[1] Salman, R.D. (Geoscience Program Manager, NIMA) letter to E. Eppert (Superintendent, Marine Geosciences Division, NRL), Subj. "DoD Utility of Fixed Wing Airborne Gravimetry," March 27, 1998; and Forsberg, R. (President, International Association of Geodesy) letter to Brozena, J. (NRL), March 30, 1998.

Acoustic Matched-Field Processing

Achievement

Hints of matched-field processing (MFP) appeared in an early paper by A. Parvulescu. The MFP concept was first discussed in an analytic format in 1976 by H. Bucker of the Naval Undersea Center in San Diego. NRL subsequently began a program to demonstrate the practical viability of MFP. In 1981, NRL began research on the MFP concept in the shallow-water propagation environment. In 1983, NRL presented simulations of the MFP concept, now known as the conventional or Bartlett processor. This processor has become the baseline and most widely used matched-field processor. A pioneering experimental demonstration of MFP was reported by NRL in 1985. This work produced the widely used adaptive or high-resolution MFP processor. The conventional and adaptive MFP processors were used as the theoretical basis for MFP shallow-water research programs conducted at the SACLANT ASW Research Centre, Italy, and at the Naval Oceanographic R&D Activity (now NRL) located at the Stennis Space Center, Mississippi. The NRL shallow-water work was expanded to the deep-water environment with the initiation of the ONT High Gain Initiative (HGI). NRL provided much of the theoretical basis and numerical simulation for the research conducted by the HGI from 1988 to 1993. The HGI results suggest that large volumetric acoustic array systems, which use MFP concepts, may be useful for long-range surveillance purposes in deep-water environments.

In a related area, the use of MFP to invert for antisubmarine warfare (ASW)-related environmental parameters has received significant attention by the naval research community. These MFP inversion methods were pioneered at NRL. They are being incorporated in research measurement programs directed toward the development or evaluation of techniques to be used for the rapid extraction of parameters that are needed to estimate naval ASW sonar performance. Research conducted at NRL included development of algorithms and the early experimental demonstrations of MFP inversions of ice and bottom properties. One of the first such inversions was for sea ice parameters in the Arctic. The use of global optimization techniques to invert for geoacoustic parameters (a common approach now) was pioneered at NRL.

Impact

NRL's early work in MFP provided much of the theoretical and experimental basis for the Navy's HGI, and will serve as the basis for the design and performance evaluation of large volumetric arrays concepts presently being considered by ONR. In addition, MFP methods pioneered at NRL have and are being incorporated into measurement programs.

Primary Reference Documents

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Individual(s) Being Recognized

R. Heitmeyer, O. Diachok, W. Kuperman, M. Porter, J. Perkins, A. Tolstoy, and M. Collins.

Magnetic Materials and Semiconductor Technology

Achievement

NRL's G.A. Prinz recognized that the developments in semiconductor materials technology in the 1970s, which permitted atomic control of crystal film growth in ultrahigh vacuum, could be exploited to fabricate new magnetic materials in thin film form. Furthermore, he saw that the close lattice match between compound semiconductors and the bcc phases of Fe, Co, and Ni would open the door to integrating these two fields of materials into common monolithic structures. He initiated molecular beam epitaxial (MBE) growth of magnetic materials on semiconductors at NRL in 1979.

NRL's J.J. Krebs carried out the characterization of these new materials. Using the powerful techniques of angularly dependent ferromagnetic resonance, along with magnetic susceptibility and X-ray fluorescence, he generated a detailed description of these new materials, including the interface and surface properties that dominated their behavior. All further work in this field has confirmed the general properties of epitaxial ferromagnetic metal films established by the Laboratory's work.

NRL's work led directly to the discovery by three other laboratories in France and Germany of the giant magnetoresistance effect using Fe/Cr multilayers epitaxially grown on GaAs. The use of magnetic metal films on semiconductors for sensors is now widespread. The largest use is in read heads for computer hard disks. They are under development for mechanical motion sensors by the automotive and machine tool industry, as well as by the military for fuses and perimeter defense. The largest impact will probably be for nonvolatile magnetic memory in computers, which is under development at several corporations within the U.S. as well as abroad in Japan, Germany, France, and the Netherlands. The industrial efforts in the U.S. are supported by the Defense Advanced Research Projects Agency.

Impact

NRL's pioneering work led to the discovery of the giant magnetoresistance effect using Fe/Cr multilayers epitaxially grown on GaAs. In the commercial arena, magnetic metal films on semiconductors, exploited for the giant magnetoresistance effect, is already generating $1 B in sales for sensors in read heads, and the introduction of magnetic computer memory will impact a market measured at $100 B annually. For military applications, this technology promises far better performance of satellites, missile guidance, and aircraft navigation.

Primary Reference Documents

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Individual(s) Being Recognized

G.A. Prinz and J.J. Krebs

On-Board Processor

Achievement

NRL developed a spaceborne computer which, at this time, is 100 times more capable than anything else flying. By doing so, the On-Board Processor (OBP) program has achieved an unparalleled advancement of the state of the art in engineering in support of military operations for multiservice and multinational tactical and strategic users. The OBP is currently on a satellite providing, for the first time, real-time situational awareness information to military units located throughout the world. Since October 1996, it has been the largest supplier of tactical data to military consumers.

The OBP is the only totally automated, real-time, non-a priori, direct reporting system providing tactical data to military units 18 hours per day, seven days per week. NRL's program included total concept development, system engineering, hardware development, algorithm development, fabrication, test, and deployment. Military units deployed anywhere in the world now have an expanded area of situational awareness not available with either organic assets or other systems.

Impact

The OBP has made a two order-of-magnitude improvement in low-power, high-performance, fully programmable spaceborne computing. The OBP is supporting U.S, U.K, Canadian, and Australian military forces deployed worldwide. The OBP broadcast is received by Navy Tactical Receive Equipment, Army Commanders Tactical Terminal and SUCCESS Radio, and Air Force/USSOCOM Multi-Mission Advanced Tactical Terminals, and is displayed or processed by tactical data processors.

Primary Reference Documents

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Individual(s) Being Recognized

A.J. Fox, D.L. Pettit, and F.B. Kuhn, Jr.

Deep Space Program Science Experiment (*Clementine*)

Achievement

The Deep Space Program Science Experiment (*Clementine*) program was a highly successful lunar mapping mission that tested new spacecraft hardware. Since the 1980s, the Ballistic Missile Defense Organization (BMDO) has developed advanced sensor, spacecraft, and component technologies for missile defense systems requiring lightweight and reliable spacecraft. In 1991, a joint NASA/DoD study concluded that a collaborative deep space mission could test these developments and provide a significant science return. The DoD's goals were to test lightweight miniature sensors and components by exposing them to a long-duration space environment while obtaining imagery of the Moon and the near-Earth asteroid, Geographos. The BMDO tasked NRL with responsibility for mission design, spacecraft engineering, spacecraft manufacture and test, launch vehicle integration, terrestrial support, and flight operations.

In 1994, NRL put a satellite, equipped with a sensor payload, into orbit around the Moon. The spacecraft successfully used much newly developed hardware, including imaging sensors provided by the Lawrence Livermore National Laboratory. A high-quality mapping mission of the lunar surface was completed with outstanding success — a complete imaging of the lunar surface (1.8 million images) in eleven discrete wavebands with coarse altimetry over most of the lunar surface.

This imaging of the Moon's surface was a great success in its scientific returns: relative positions of widely separated lunar features can be accurately determined for the first time, including those on the Moon's far side; some regions in the lunar south pole were imaged with good resolution for the first time, with some data indicating the presence of ice; and complete multispectral imaging providing information on local mineral composition over the entire lunar surface. Finally, these images will help resolve issues such as the character and evolution of the primitive lunar crust, thermal evolution of the Moon and lunar volcanism, and the impact record and redistribution of crustal and mantle materials.

Impact

With *Clementine*'s success, the U.S. returned to the Moon for the first time since the end of the Apollo lunar missions. NRL's satellite demonstrated that the goal of "faster, better, cheaper" was attainable: it was built in only 22 months (less than half the usual time) for 1/5 the usual cost for similar space probes.[1] The probe was so simple to operate that its mission control center comprised eight engineers working in a warehouse in Alexandria, Virginia.[2]

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Individual(s) Being Recognized

D.M. Horan, M.S. Johnson, P.R. Lynn, and P. Regeon

[1] Excerpt from certificate accompanying the 1995 Stellar Award to the Clementine Development Team.

[2] Excerpt from The *Discover* Magazine Award for Technological Innovation (1995).

Decadal Impact of El Niño

Achievement

El Niño events in the Pacific Ocean can have significant local effects lasting up to two years. For example, the 1982-1983 El Niño caused increases in the sea-surface height and temperature off the coasts of Ecuador and Peru, with important consequences for fish populations and local rainfall. But, until NRL's work in this area, the scientific community believed that the long-range effects of El Niño events were restricted to changes transmitted through the atmosphere, for example causing precipitation anomalies over the Sahel.

Under the leadership of G. Jacobs, NRL provided evidence from modeling and observations that planetary-scale oceanic waves, generated by reflection of equatorial shallow-water waves from the American coasts during the 1982-1983 El Niño, have crossed the North Pacific and a decade later caused a northward rerouting of the Kuroshio Extension (a strong current that normally advects large amounts of heat from the southern coast of Japan eastward into the midlatitude Pacific). This has led to significant increases in sea-surface temperature at high latitudes in the northwestern Pacific, of the same amplitude and with the same spatial extent as those seen in the tropics during important El Niño events. These changes may have influenced weather patterns over the North American continent during the past decade and demonstrate that the oceanic effects of El Niño events can be extremely long-lived.

Impact

NRL's research shows, for the first time, that the oceanic effects of El Niño events can be extremely long-lived. The scientific importance of this discovery was noted in an opinion piece by M.J. McPhaden in the same issue of *Nature* as the original Jacobs, et al. (1994) article.[1] It was similarly recognized by *Discover* magazine as one of the top 75 science stories in 1994.[2]

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Individual(s) Being Recognized

G.A. Jacobs, H.E. Hurlburt, J.L. Mitchell, and J.C. Kindle

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Optical Immunoassays and Sensors

Achievement

An ideal biosensor for monitoring a manufacturing process or contaminants in the environment is not only sensitive and specific but requires minimal sample processing and is simple to use. Detection systems requiring extensive sample extraction or highly skilled personnel are not going to gain widespread acceptance. NRL has developed biosensors for field use that are portable, relatively simple to use, and require only that the sample be a relatively nonviscous liquid. The NRL biosensors use antibodies and other biomolecules to recognize biological threat agents and environmental hazards rapidly and at extremely low concentrations.

NRL has demonstrated that the sensors are capable of detecting approximately 1 to 10 ng/ml levels of analyte (i.e, biological warfare agent or explosives). The fiber-optic-based biosensors have been used to measure biological toxins in river water and clinical samples (blood, serum, plasma) or harmless bacteria released in field exercises and collected from the air. DNA-based assays, which can be used for verification of immunoassay screens, have also been developed. In addition, the biosensors have been used to detect drugs of abuse in urine and saliva and to monitor explosives in groundwater or soil.

For the Environmental Protection Agency's use in monitoring at Superfund Cleanup sites, a smaller, simpler sensor, the FAST 2000 has been developed. This system has been tested extensively in field trials at military bases with explosives-contaminated groundwater and demonstrated results that were comparable to sophisticated laboratory analytical techniques.

Impact

NRL's portable biosensors have demonstrated in the field how antibody recognition can be integrated with state-of-the-art optical components to recognize hazardous substances in complex samples. The sensors are sensitive, automated, simple to use, and provide valuable on-site detection capabilities to both the military and environmental protection communities. The sensors are capable of detecting biological toxins in water, blood, serum, and plasma; detecting drugs of abuse in urine and saliva; and monitoring explosives in groundwater or soil.

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Individual(s) Being Recognized

F.S. Ligler, G.P. Anderson, and A.W. Kusterbeck

Dilute Aperture Imaging at Optical Wavelengths

Achievement

NRL has developed techniques to coherently combine light detected simultaneously over a broad bandpass with several independent telescopes. This overcomes the limitations imposed by atmospheric turbulence and physics on the angular resolution achieved with a single telescope or aperture. Turbulence in the Earth's atmosphere had limited the resolution of imaging systems, such as telescopes, to that achieved by an aperture 4 inches in diameter, or a spatial resolution of one arc second (10^{-5} radians). To achieve higher resolution, a larger number of spatial frequencies must be coherently sampled before temporal effects cause a change in the image. This was accomplished in two ways. First, lasers, low noise photodetectors, delay lines, and high-speed computers were used to compensate for wavefront distortions caused by the atmosphere on timescales of a millisecond. Second, to overcome the limitations imposed by the uncertainty principle, which does not allow amplification at optical wavelengths, spectral bandwidth synthesis was developed to sample sufficient spatial frequencies to form a sharp image.

The technology for array control was developed using a single two-element interferometer at Mount Wilson from 1984 to 1990. This instrument developed the technology of tracking out the atmospheric turbulence in an automated system capable of integration speeds on the millisecond scale. This allowed one-dimensional, single-point sampling of the spatial frequencies. The design and fabrication of the Navy prototype optical interferometer (NPOI) from 1989 to 1998 developed the technology of wide-bandwidth synthesis at optical wavelengths. The NPOI will be capable of imaging at spatial resolutions as high as 10^{-9} radians. It has achieved images at 10^{-8} radians resolution, easily exceeding that obtained with single aperture. This work revolutionized the technique of imaging and, in principle, allows any angular resolution to be achieved. The only limit now is the brightness/solid angle of the object itself.

Impact

NRL's development of wide-bandwidth imaging at optical wavelengths is equivalent to the invention of the telescope. Future astronomical and remote sensing systems will employ this technology at optical/IR wavelengths. It will allow military systems to see farther, allowing larger standoff distances from targets and objects of interest. It will also have a major impact on space surveillance and intelligence-gathering systems.

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Individual(s) Being Recognized

K.J. Johnston and D. Mozurkewich

Mesoscale Prediction Systems

Achievement

Two mesoscale prediction systems have been developed and transitioned to operations by NRL from 1977 to 1998: the Navy Operational Regional Atmospheric Prediction System (NORAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS).

The original NORAPS, implemented in 1982, was the first globally relocatable limited-area model of its kind. In 1985, NORAPS became the first regional model in the world to use data assimilation. NORAPS has served the operational Navy community well over the past 20 years: it has been used in support of Operation Desert Shield and Operation Desert Storm, Operation Tandem Thrust, and naval operations in Bosnia, Somalia, Korea, Taiwan, the Mediterranean, Haiti, the east Atlantic, the west Pacific, and the Indian Ocean. Since implementation, NORAPS has generated over 40,000 operational forecasts for the Navy, more than any other mesoscale model in the world.

COAMPS is now in the position to elevate the state of the art further. It allows for more accurate forecasts over areas that exhibit steep topographic features and strong convection and has the added capability to explicitly forecast water and ice clouds, as well as rain and snow. Already COAMPS has achieved significant contributions. It has been used to supply reanalyses of the atmospheric conditions during the Gulf War in support of the Gulf War Illness studies.[1] Independent expert panels have praised NRL's efforts for providing the most accurate assessment of the mesoscale meteorology during that time. It was also used to produce local analyses/forecasts aboard an aircraft carrier. This shipboard execution of a mesoscale atmospheric prediction system is a world-first accomplishment, and sets the stage for improved local environmental information being supplied directly to the warfighter afloat.

Impact

NRL's NORAPS and COAMPS are mesoscale data assimilation systems used for generating high-resolution numerical analyses and short-term (0 to 48 hour) predictions of the atmosphere for limited areas of the Earth. Weather maps produced from these systems are distributed to operational DoD commands around the world to support mission planning, ship and aircraft operations, and hazardous weather avoidance. COAMPS has also been requested for use by other organizations. For example, DoE's Lawrence Livermore National Laboratory uses the model to assist in providing transport and dispersion forecasts of hazardous material releases.

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R.M. Hodur and J.D. Doyle

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Application of Nuclear Quadrupole Resonance for Detection of Explosives and Narcotics

Achievement

NRL invented technology for the detection of explosives and narcotics by nuclear quadrupole resonance (NQR). NQR is a radio frequency (RF) spectroscopic technique, related to nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI). However, no large magnet is required in NQR. The specimen is irradiated with RF energy at specific frequencies, and the size of the return signal indicates the presence or absence of known explosives and narcotics.

NRL's A.N. Garroway and his colleagues pioneered the practical use of NQR for explosives and narcotics detection by successfully addressing the technical issues required to take NQR out of the laboratory and into the field. One key technology is a technical breakthrough that allows NQR inspection by low-power RF pulses, rather than the extremely high power required in earlier approaches. A second is a specialized RF inspection coil specifically applicable to the screening of personnel, so that minimal RF energy is deposited. A third approach minimizes some of the technical problems of acoustic ringing in metal contents of baggage and also reduces the temperature variation of the NQR signal.

This work has been funded since 1987 by the Federal Aviation Administration (FAA) and the DoD (Defense Advanced Research Projects Agency (DARPA) and the Office of Special Technologies), to advance U.S. capabilities in antiterrorism and antidrug efforts. Explosives detection systems for package and baggage scanning in airports and other fixed sites have been built by Quantum Magnetics under NRL license. One package scanner has already been sold to the FAA. More recently, DARPA has funded NRL for land mine detection, which is both a military and humanitarian requirement.

Impact

This technology provides a major advancement in the state of the art for explosives and narcotics detection, and a potential breakthrough for the detection of land mines. In 1997, the Gore Commission (White House Commission on Aviation Safety and Security) recommended that NQR systems be purchased and deployed to enhance security at U.S. airports.

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Individual(s) Being Recognized

A.N. Garroway, J.B. Miller, and J.P. Yesinowski

Tactical Receive Equipment

Achievement

In the area of tactical receive equipment, NRL developed two major items: the Multi-Mission Advanced Tactical Terminal (MATT) and the Improved Data Modem (IDM).

MATT: The MATT is a satellite communications, ultra-high-frequency, four-channel radio terminal, with a multiuser format output capability in an 8 × 8 × 19-inch frame. This self-contained unit is capable of simultaneously receiving, decrypting, and processing intelligence reports. The U.S. Special Operations Command (SOCOM) selected NRL to develop the unit. NRL successfully met SOCOM design requirements and delivered the first qualified units in 24 months. Even today, there are no other military-qualified intelligence terminals housed in such a small package. The successful evaluation of the MATT led to the milestone decision for full rate production and transfer of the technology to industry. The production contract was awarded to Allied Signal Communication Systems.

IDM: In 1990, the Air Force chose NRL to lead a multiservice, multidiscipline team in developing a high-speed digital data modem for use by F-16 aircraft to rapidly pass targeting data and situational awareness updates. NRL's successful record in space and satellite systems development made it uniquely qualified for the task of maximizing performance, reliability, and quality, while minimizing size, weight, and power. Just nine months later, NRL had developed, produced, and delivered the first five units for aircraft integration. Throughout the process, NRL designed in features to enhance reliability and simplify automated assembly and production. In 1993, the technology transfer process was completed, three months ahead of schedule and under budget, with the award of an Air Force contract to a small business using the drawing package delivered by NRL. The Air Force considers the IDM program to be one of the finest examples of acquisition streamlining.

Impact

MATT filled a need for a miniaturized multifunction radio and processor that provides near-real-time national intelligence data to field commanders or tactical fighters. In addition, MATT provides the ability to combine both intelligence and theater data in the selection of targets. The IDM program established the first digital data link capability between fighter aircraft and between fighter aircraft and ground units. The IDM provides pilots the ability to do in seconds (or less) what used to take several minutes by voice radio, thus minimizing exposure to enemy jamming and/or transmission interception. It is used on Air Force F-16s[1] and Navy carrier-based EA-6Bs serving in Bosnia and the Persian Gulf.

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