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# 1962 ANNUAL REPORT

## U.S. NAVAL RESEARCH LABORATORY

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# 1962 ANNUAL REPORT

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# PART I
# INTRODUCTION

# *NRL at a Glance*

## LOCATION:

On the east bank of the Potomac, in Washington, D. C., four miles south of the Capitol.

## MISSION:

To initiate and conduct scientific research and development in the physical sciences, directed toward new and improved materials, equipment, techniques, and systems for the Navy.

## PHYSICAL PLANT:

100 buildings on 125 acres. Field stations at Chesapeake Beach, Maryland Point, and Stump Neck, Maryland; Hybla Valley, Virginia; and Coco Solo and Miraflores, C. Z.

## PERSONNEL:

66 naval personnel, 3272 civilians, of which 1062 are scientists or engineers.

## MAJOR FIELDS OF RESEARCH:

Astrophysics, metallurgy, astronomy, mechanics, chemistry, ceramics, optics, sound, radio, applications, and atomic, nuclear, and solid-state physics.

## POSITION IN NAVY ORGANIZATION:

NRL is subordinate to the Office of Naval Research; it is a station within the Potomac River Naval Command.

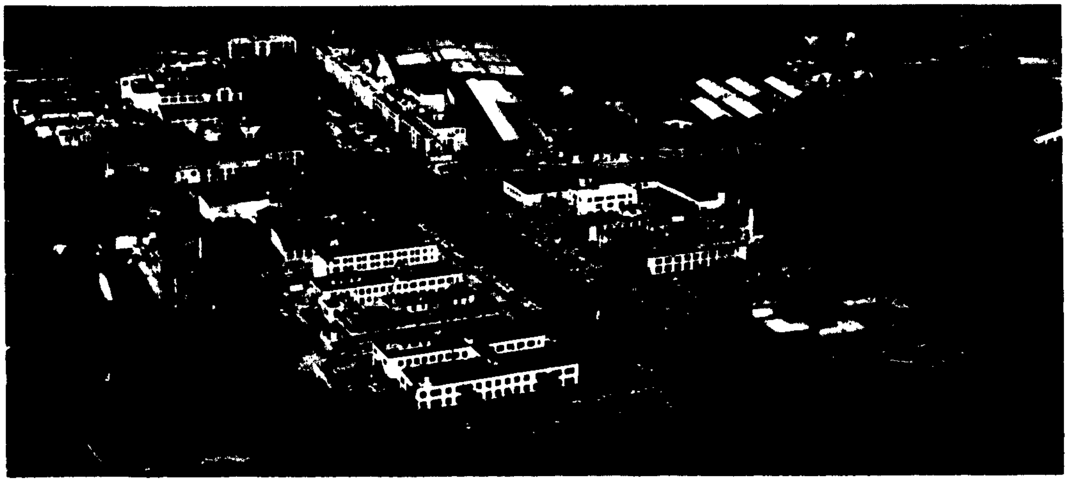
## FINANCING:

Funds are allocated from (a) the Office of Naval Research for the self-generated research program and (b) other sources, principally the Navy Materiel bureaus, for specific research projects.

## COMMAND AND TECHNICAL DIRECTION:

The present Director is CAPT A. E. Krapf, USN.

The current Director of Research is Dr. R. M. Page.



## Highlights of the Year

~~The purpose of this Annual Report is to record the~~ unclassified technical accomplishments of the U. S. Naval Research Laboratory during the Calendar Year 1962. ~~In fulfilling that purpose,~~ this Report should ~~also~~ serve to give those who are unfamiliar with the Laboratory a general concept of NRL's varied activities and capabilities.

There are, as of the close of the year, some 375 research problems listed as current and active. They vary from long-term basic investigations to short-term evaluations of particular devices or concepts. To attempt to measure progress on all of these would be tedious to catalog and onerous to review. The endeavor has been, ~~therefore,~~ to select a few outstanding projects in each of NRL's twelve fields of research effort and to describe these as examples of the kind of work being done in each field.

The year has been one of solid progress in many lines, rather than one of glamorous new projects or headlined inventions. It has also been a year of expansion, marked by doubling in station area, the appropriation of money for a large modern building, and the addition of important new facilities.

The "highlights" of the year are briefly described in these introductory pages. More detail is given to these and other accomplishments in the pages that follow.

### Expansion of the Laboratory

By the end of World War II, the Naval Research Laboratory had crowded to the fences of its 55-acre enclave on the Potomac River. New buildings could be erected only by tearing down old ones; there was no space for antenna ranges; various electronic facilities interfered with each other; space was inadequate for parking. The immediate crowding situation was alleviated on July 1, 1962, with the formal transfer of the adjacent Bellevue Naval Magazine to the Laboratory—more than doubling the ground area of the station. Aside from a few large structures which have already been converted to laboratories, most of the buildings on the acquired land are temporary shelters which will be torn down as their space is needed.

In September, the 87th Congress appropriated funds for the construction of a new general-purpose laboratory building. When completed it will be NRL's first major structure to be built from the ground up for laboratory purposes since 1945. It is the first increment of an over-all renewal plan that would effect, over the next quarter century, a gradual modernization of the Laboratory.

## Solid-State Power Converters

Modern science has produced a number of exotic electric sources such as solar cells, thermoelectric and thermionic converters, and electrochemical fuel cells. Most of them are very-low-voltage devices, however; to do useful work their voltage must be stepped up many times. In the past, this problem has been solved by connecting many basic units in series—with consequent loss in efficiency and reliability.

NRL electronics specialists have developed a static inverter that is compatible with these new sources, most of which deliver 1 volt or less. It employs solid-state devices known as tunnel diodes. The inverter makes possible the design of simpler and more rugged power sources with outputs sufficient for many of today's highly specialized military applications.

## Shore-to-Ship Communication by Moon Relay

Having been the world pioneer in demonstrating (in 1954) the practicality of radio communications by the earth-moon-earth path, NRL scored another "first" by transmitting messages via the moon to a moving ship at sea. The signals were sent from the 60-foot antenna at the Laboratory's satellite research facility at Stump Neck, Maryland, and were received aboard the USS OXFORD cruising off the East Coast. The messages were error-free 60-wpm teletype transmissions; they were sent and received during the entire 10 hours of lunar visibility.

## Omega Navigation System

The Omega navigation system has been developed jointly by NRL and the Navy Electronics Laboratory. The system is capable of very-low-frequency (VLF) transmissions to ranges of 5000 miles or more. Thus, only six or eight stations would be required to provide navigational fixes—accurate to less than a mile—to planes, ships, or submerged submarines anywhere in the globe. At present, experimental stations are being operated in Hawaii, the Canal Zone, and New York State.

The Omega system is similar to LORAN in that it uses time difference in arrival of signals to obtain fixes. Omega, however, operates at a much lower frequency, presently at 10.2 kilocycles; phases of the radio-frequency cycles are used to determine the time difference. Receivers are being designed to provide lines of position continuously and automatically. Transmitter power requirements are comparatively low, about 5 kilowatts per station.

NRL's WV-2 "flying laboratory" obtained satisfactory navigational fixes during a trip to Labrador, Greenland, Norway, and England and on a second trip south to Chile and Argentina.

## An Assist to Brain Surgery

A local surgeon, Dr. John Gallagher, conceived the idea of reducing aneurysms—bubble-like malformations in the arteries that serve the brain—by shooting animal hairs into the bubble, causing the blood to clot instead of hemorrhaging. He needed a small, sensitive "gun" to do the shooting.

The problem came to NRL, via ONR, and wound up in the Electronics Division. There, a master craftsman, H. P. Hagemeyer, developed a pencil-size gun operated by compressed air. With it, a surgeon can shoot a sterilized hot bristle through an arterial wall just far enough but not too far.

To date, Dr. Gallagher has successfully used the hair gun in nine operations, at far less hazard to the patient than the usual clipping-off technique. The safer method of treatment may materially reduce the number of mortalities caused by the estimated 100,000 brain aneurysms diagnosed every year.

### Laser Development

The optical maser, or "laser," has characteristics that are so amazing that physicists are only beginning to delineate its full possibilities. In brief, it is a solid-state device that receives light from an ordinary source and amplifies it in such a way that the emitted beam is continuous, extremely narrow, and intensely energetic.

NRL's 1962 research in this field was particularly rewarding. Several luminescent glasses, developed from the Laboratory's earlier studies of the physical properties of dielectrics, were found to be excellent laser-fabrication materials when combined with minute quantities of certain rare earth elements such as neodymium, ytterbium, holmium, and gadolinium. One of these glass lasers, made of silicate glass containing ytterbium, produced the world's first ultraviolet laser. Another, in which the silicate glass was combined with neodymium as well as ytterbium, was the first solid laser to exhibit simultaneous stimulated emission of infrared light at two different wavelengths. A different type of experiment—conducted with a ruby laser in filtered water at David Taylor Model Basin—elicited the important negative information that a laser does not appreciably aid the transmission of light through water.

### Record Magnetic Field Strengths

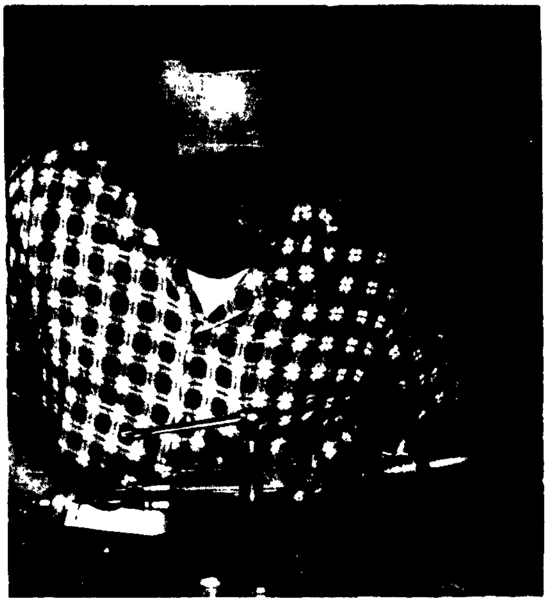
Early in the year, NRL's relocated and reinforced magnetic laboratory was completed. The facilities include a battery of powerful electromagnets, among them an NRL-improved Bitter-type solenoid. During March and April the solenoid achieved sustained magnetic-field strengths up to 156,000 gauss. This is believed to be the highest continuous field yet attained, anywhere. The figure may be compared with other recently reported maximum fields of 126,000 gauss at the National Magnet Laboratory, 128,700 at the Royal Radar Establishment in England, and 130,000 at Tohoku University in Japan.

The magnet in which this record field was generated is presently being used to extend measurements of the properties of the new superconducting material, niobium stannide, beyond 120,000 gauss, the highest sustained field available at NRL prior to this time. The 156,000 gauss upper limit was established not by any fundamental characteristics of the magnet, but by the maximum (3 megawatt) power supply available. Further improvements to the system are under consideration which it is hoped will permit going as high as 200,000 gauss.

# PART II
# TOOLS TO WORK WITH

"-- *from calipers to research reactors.*"

Additions and improvements are continually being made to the Laboratory's physical research plant. Often these are unique facilities not available commercially, so plans must be drawn up for the construction of a specialized unit particularly fitted to the specific need. Presented here are brief descriptions of only a few major ones—most of them built entirely to NRL designs.



*Step 1: A model maker performs final machining on a magnetron anode.*

*Step 2: In the chemical-processing unit the anode is cleaned prior to vacuum-firing. This unit handles all problems related to chemical cleaning and new chemical techniques.*

*Step 3: A tube technician vacuum-fires the anode by use of radio-frequency heating.*

*Step 4: Assembly of the magnetron is completed in the tube-assembly area, which contains radio-frequency brazing equipment, several hydrogen furnaces, a number of resistance welders, and a clean room.*

## Electron Tube Engineering

The Electron Tubes Branch at NRL is concerned with research and development in the field of electron tubes having specialized interest to the Navy. At present it is actively engaged in such basic studies as: millimeter-wave oscillators; electrical breakdown in vacuum; the behavior of gas plasmas as lasers; and the design of high-current-density thermionic and secondary emitters.

Within the Branch is the Engineering Section, a unique facility comprised of special equipment and skilled personnel to handle all phases of experimental electron-tube technology, including the fabrication of experimental models used in basic studies or in the investigations of new principles of electron tubes. The pictorial sequence presented here illustrates the various steps necessary in the construction of a prototype model tube. Not shown is the instrument-component unit for grinding and polishing glass, ferrites, and laser materials and for the evaporation of optical and transparent-phosphor coatings.

*Step 5: A glass technologist seals the magnetron in a glass envelope. The glass-technology area supplies the glass apparatus needs of all the Laboratory.*

*Step 6: A tube technician performs the final operation, tube processing. This step includes pumping, baking, emitter activation, and any necessary gas filling.*

*Over-all view of clean room mentioned in Step 4.*

## New Hypervelocity Accelerator

One proposed method of defeating an enemy ICBM during re-entry is by fragment impact on a vulnerable section. Damage to space craft and satellites by meteoroid impact also is of topical interest. Hence there is much current interest in techniques to accelerate fragments to velocities comparable with those of missiles and meteoroids.

One of the most successful accelerators for hypervelocities is the light-gas gun with expendable central section. NRL's first facility of this type was developed in 1956. Since then various modifications and methods of augmentation have resulted in increased accelerator capabilities over the years.

Recently a new hypervelocity accelerator facility was put into operation which has a light-gas gun designed to launch masses of from 10 to 40 grams at velocities greater than 6 km/sec. The compression section was made from two 3-inch naval guns, smooth-bored to a 3.25-inch diameter. The guns are fastened together, muzzle to muzzle, thereby forming a tube 20 feet in length.

*NRL's 3-inch light-gas gun facility for studying hypervelocity impact phenomena.*

The high-pressure central section is made of hardened steel 12 inches in outside diameter and 18 inches long. This section is used several times and then rebored to receive a replaceable metal insert and used several more times. The launch tube is 8 feet long with a bore diameter of 0.83 inch. The entire gun assembly is clamped with eight pipe vises mounted on a 30-foot reinforced I-beam.

The complete range consists of the gun and I-beam assembly; a baffled blast chamber (to reduce residual gas and blast effects), 20 feet long and 4 feet in diameter, with three instrumentation and viewing ports on each side; and an instrumentation section, which is a 16-inch (o.d.) heavy-walled tube 20 feet long, with three pairs of horizontally opposed ports, 5 feet apart, that are suitable for velocity measurements.

The target chamber is a reinforced-steel room, 10 feet by 10 feet by 8 feet high, with a 4-foot-square door at the rear for inserting large targets. There is allowable space for installing a ballistic pendulum which could be used to measure the momentum transferred to the target and hence permit the impact mass to be calculated.

Performance of the new gun has been satisfactory. The peak velocity attained has been 7.82 km/sec with a 6.5-gram Lexan cylinder. As more is learned of the capabilities and limitations of the gun, it should prove to be an increasingly valuable tool for hypervelocity studies.

## Magnet Facility

The largest sustained magnetic fields currently available in the world have recently been produced at NRL's magnet facility. The maximum field achieved, 156,000 gauss, was limited by the power supply available at NRL and not by any characteristics of the magnet itself. These fields were generated in a solenoid which combines the basic design features of magnets described by F. Bitter in 1938 with numerous improvements developed at NRL during the past 15 years. A current of 12,400 amperes at 245 volts is required to obtain the 156,000-gauss field. The joule heat developed during operation is extracted by circulating 660 gallons of water per minute through the magnet. The field is constant within 1 percent over a cylindrical volume 1.25 inches in diameter and about 2 inches long. This magnet is presently being used to extend studies of the superconducting

*High-Field Magnet Facility, showing location of three magnets. The fourth is out of picture at right.*

properties of niobium-tin beyond 120,000 gauss, the highest field available at NRL from 1952 to the present.

The magnet facility also includes two other magnets of the Bitter type. One, with an experimental chamber 4.25 inches in diameter, now reaches a field of 90,000 gauss. The other, with an experimental chamber of 2.5 inches, reaches a field of 105,000 gauss. Experimental apparatus can be inserted into either end of the latter solenoid. Additional improvements are being made to both these magnets with the aim of increasing their maximum field capabilities. These magnets are being used to study a variety of problems, among them the magneto-optic properties of semiconductors, superconductivity below 1°K, galvano-magnetic effects, magnetoresistance, and the effect of large fields on biological systems.

A fourth magnet, now under construction, will provide fields for sequential electronic and adiabatic demagnetization. Because of the special design of this magnet, it will also be possible to make measurements in fields of 100,000 gauss at temperatures below 0.01°K.

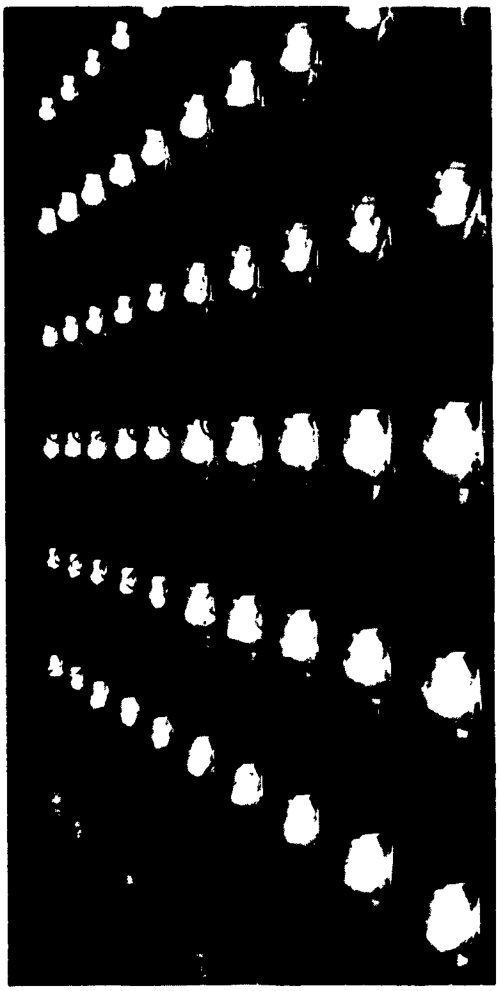
## Thirty-Million Degree Plasma Laboratory

In a new, high-powered, multimillion-degree plasma physics laboratory, scientists at NRL can produce—for a few millionths of a second—an atomic environment like that of the sun, where the internal temperatures are about 20 million degrees C. The ultimate goal, of course, is controlled thermonuclear fusion. Theoretically, this occurs if deuterium gas is heated until the deuterium nucleus is separated from the electron that ordinarily orbits around it; then, if the deuterium is made hot enough, the nuclei will collide with ample force to cause a nuclear fusion reaction, forming with equal probability either helium-3 and a neutron or hydrogen-3 (tritium) and a proton. When this happens, part of the nuclear mass is converted into energy—the same energy as that of the hydrogen bomb.

Deuterium is the hydrogen isotope found in heavy water. To get the gas into a plasma state, it must be heated to an extremely high temperature. The heating is done by magnetic compression: squeezing the gas in an intensely strong magnetic field. The magnetic envelope also provides thermal insulation and prevents the hot plasma from vaporizing the fragile walls of a quartz shock tube.

Although the concept is simple, the apparatus is not. The standard power supplied by the Laboratory is first rectified from ac to dc. The direct current is then fed to a 2000-kilojoule bank of condensers, which build up in voltage and store the electrical energy, taking about 30 seconds for a full charge. Then, by the simultaneous triggering of 400 switches, specially developed at NRL, the entire charge of electricity is channeled to the coil of an electromagnet. Currents of 10 to 15 million amperes have been produced, the highest reported to date by any laboratory. Inside the coil is a 6-foot guartz tube containing gaseous deuterium. The magnetic field instantly compresses the gas to a thin rope of ionized, fantastically hot plasma. Some 15 microseconds later the charge is expended, the field collapses, and the plasma cools. But meanwhile various spectrographs and streak cameras, peering through the gaps in the coil, have been busy recording and photographing the event.

The purpose in stepping up the power of NRL's plasma experiment is not to increase the plasma temperature beyond the 30 million degrees already achieved. The aim, rather, is to maintain a relatively large volume of stable plasma with higher densities for a longer time so that it can be carefully studied and the physical processes that take place more fully understood. By the extension of these techniques to much larger systems, it is possible that thermonuclear fusion may be harnessed and controlled for the production of energy for peaceful purposes.



*Spark-gap switches release a surge of energy in NRL's plasma-physics laboratory.*

## High-Level-Radiation Laboratory

A new high-level-radiation laboratory has just been constructed at NRL. It is the Navy's only research facility designed specifically for studying the effect of nuclear radiation on materials.

The heart of the new facility consists of five cells, each shielded by thick walls of high-density concrete, in which irradiated materials can be tested without danger of exposure to operating personnel. Three of the cells can provide protection against an irradiation source of 1000 curies of gamma radiation at 1 Mev; the other two can protect against 10,000 curies at 1 Mev. Within the cells are facilities for remote machine shop operations, for polishing and preparing radioactive specimens for microscopic examination, for physical and mechanical evaluation of metallurgical specimens; and for metallographic examination. Flexibility of design also permits chemical analyses, the study of atomic defects related to irradiation damage, and even the examination of nuclear fuel, if required.

Through radiation-shielding glass windows the complete interior of the cell is visible to within 2 inches of the corners of the front walls. Heavy-duty master-slave manipulators can reach all the cell area within view from the window. In addition, four of the cells are equipped with a high-capacity, remotely controlled, mechanical arm which is contained on a bridge and may traverse the cell from front to back, while the bridge may be moved laterally on the track. A 3-ton crane, operating in a similar fashion, also is located on the track. Thus heavy mechanical operations as well as delicate experiments can be performed within the cells.

Access to the cells is by way of 16-inch-thick steel doors, stepped on a radial pattern to prevent radiation leakage. Although each door weighs approximately 16 tons, friction bearings in the hinges allow manual operation. The top of the cells are composed of stepped plugs 2 feet thick, which can be removed by the bridge crane for installing equipment too large to pass through the doors.

*Looking down the manipulation room of NRL's High-Level-Radiation Laboratory.*

The facility was designed to provide as positive a separation as possible between the radioactively clean areas and those which may become contaminated. There are even two separate ventilating systems. The "clean" areas include offices, laboratories, conference room, sanitary facilities, reception area, and the manipulation room from which remote operations are controlled. The "contaminated" area, in addition to the hot cells and the working space in back of them, includes five isolation cubicles, isotope storage area, a major decontamination room, x-ray laboratory, records room, chemical laboratory, machine shop, sanitary facilities for maintaining control over potential radioactive contamination on working personnel, and the self-contained system for radioactive waste disposal. On the second floor are the utilities necessary for operating the facility: a system for cleaning the exhaust air from the hot cells, electric power transformers, and motor control switchgear.

Air enters the cells through dampered intakes from the isolation cubicles at the cell entrance door side. It is exhausted through rough-filtered ports near the floor level and then passes through a 30-inch duct under the floor to the second-floor area, where it is scrubbed and filtered to remove all traces of radioactive particulate matter.

The treatment system for contaminated waste is housed in a series of pits, each covered with a 2-foot-thick cover of high-density concrete. Radioactive particulate matter is removed from the waste water by mechanical filtration, and then the water is evaporated to a small enough bulk to facilitiate handling and disposal as liquid radioactive waste.

Through the use of this new facility, a better understanding will be obtained of nuclear radiation effects on the properties of engineering materials in general, with the ultimate aim of achieving safer structures and components for nuclear reactors.

## High-Capability Radar

Radar research on detection of missiles and other space targets requires a level of radar performance not obtainable with conventional military radars. In order to carry out a specific project, and also to make a suitable instrument available for similar work in the future, a radar of well-above-average capability has been constructed at NRL's Chesapeak Bay Annex. The central feature of this radar is a fully steerable paraboloidal reflector of 150-foot diameter, operable at frequencies up to 1400 megacycles.

Transmitters, receivers, duplexers, data-recording equipment, hydraulic drive components and controls, and a master control console are located in the equipment shelter on the antenna platform. The operating frequencies are approximately 140 and 435 megacycles, and the pulse power is 500 kilowatts. Data will be recorded in binary digital form on magnetic tape in such a way that standard general-purpose electronic digital computers can perform the data analyses, thus eliminating laborious manual processing.

*High-capability radar, with 150-foot steerable antenna, located at CBA.*

In the near future, a monopulse-tracking capability will be provided, which will permit automatic tracking once a target has been "acquired."

The radar system will have sufficient power to obtain strong echo signals from such targets as small aircraft, missiles, or satellites at ranges of 300 to 400 nautical miles. Weak, but detectable, echoes from missiles or satellites will be obtained at ranges of 1000 nautical miles or more. Very strong echoes will be received from the moon, which is a "very large" radar target at the approximate distance of 210,000 nautical miles.

The application that originally motivated the design and procurement of this sytem was the study and measurement of radar characteristics of missiles and associated phenomena. It is obvious, however, that an instrument of this capability will find many applications in the field of pure science as well as in military technology.

These applications may include a study of ionospheric electron-density profiles, radio and radar astronomy studies, space communication experiments, and the measurement of radar cross sections of various military airborne targets. Moreover, "bistatic" experiments may be performed in conjunction with other large-antenna installations.

# PART III
# A BROAD FIELD

"-- 375 problems in 12 fields of research"

The Naval Research Laboratory, after completing 39 years of service, finds itself still on the threshold of vistas just as impressive and inspiring as those of 1923. At no other time in history has such concentrated effort been directed toward discovery, knowledge, and invention. Almost the entire future a few decades from now will bear the mark of today's scientific research. And NRL is keeping pace with the times.

The problems described here do not cover the full scope of NRL's research effort. Reasons of space and military security restrictions make this impossible. The list is therefore only representative, a presentation of those efforts which have contributed most to scientific knowledge and to naval development.

## APPLICATIONS RESEARCH

### An Equalization Teaching Machine

The use of teaching machines for verbal skills, such as mathematics or languages, are currently in widespread use. Such machines are helpful because they permit each student to advance at his own individual rate of learning. Therefore, slow learners learn slowly and fast learners learn rapidly, and neither is penalized by an average learning rate, such as found in group teaching.

Engineering psychologists at NRL have now developed a teaching machine for use in the selection and training of personnel who are to control higher-order vehicles such as aircraft and submarines. Teaching the complex motor skill involved in controlling higher-order vehicles may be accomplished more efficiently if the trainee's own error regulates the task difficulty. This is basically what NRL's Equalization Teaching Machine does. Equalization is the term given to the task of compensating for the time delays between movement of the control and a change in the position of the vehicle. Such delays are characteristic of all higher-order vehicles. Learning to equalize is a complicated and time-consuming task, since the difficulty level of the training vehicle doesn't change to suit the proficiency level of the trainee.

The Equalization Teaching Machine consists of a closed-loop tracking task in which the trainee attempts to keep a dot centered on a cathode-ray-tube display by means of a control stick. An error feedback servo mechanism regulates the values of the quickening gains. (Quickening is defined as the technique whereby electronic feedback and summing circuits are utilized to present the operator with information concerning his own actions.) Varying the amount of quickening in the system changes the equalization requirements of the tracking task. A naïve operator is initially presented with a quickened task needing little equalization. As long as he maintains only a small error, quickening continues to be removed. If, however, the operator begins to make errors greater than a predetermined level, more quickening is added until he can again maintain a small error level. This technique of continuous variation of the amount of quickening as a function of error provides at all times an equalization task which is appropriate for the operator's level of proficiency.

Ordinarily, a simulator presents an operator with a specific task on which he becomes more proficient as a function of practice. Since the task is fixed, it usually cannot be scaled so as to be appropriate for all trainees. The Equalization Teaching Machine eliminates this problem by keeping the error level relatively constant and varying the task itself. The performance measure taken from this teaching machine is unlike that for a conventional tracking task, since tracking error for a specific task is not recorded. Instead, measurement is made of the amount of quickening needed to keep the system stabilized. This measure is directly related to the amount of equalization that the operator is furnishing.

The Equalization Teaching Machine may be used in the following ways:

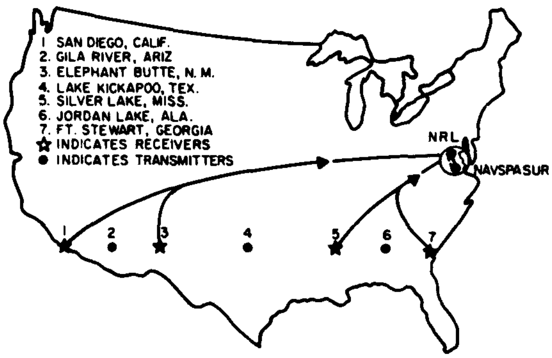
- Operator Selection: It has been shown that motor-skills tests, such as those used in pilot selection, are not especially effective in predicting performance on a particular aircraft simulator; in fact, equalizing skill is the prime factor in determining the operator's proficiency. Thus, it appears likely that the ability of a candidate to learn to equalize a higher-order system may be a very useful factor in the selection of operators for aircraft, submarines, space vehicles, and other systems.

- Operator Training: Since ability to equalize is considered fundamental in the control of various vehicles, the time required to learn to handle a specific vehicle might be greatly shortened if the trainee's basic ability to equalize higher-order systems were developed to a high degree. Also, there is safety provided in the event that a trained human must take over the tasks of equipment which has failed. For example, it would be highly desirable for astronauts involved in actual space flights to possess exceptional equalizing skill.

- Skill Maintenance: The machine provides the opportunity for daily practice in controlling higher-order systems in order to prevent loss of adequate skill by an operator.

### Automatic Detection of Unannounced Satellites

A digital system which automatically processes in real-time the data from the receiving stations of the Navy's Space Surveillance System (Spasur) is being developed by the U. S. Naval Research Laboratory, with the cooperation of the U. S. Naval Weapons Laboratory, at Dahlgren, Virginia. This new system, to be placed in operation during 1963, will augment the existing capabilities of the U. S. Naval Space Surveillance System (NAVSPASUR), a Navy organization also located at Dahlgren which has operational responsibility for Spasur. The system, called the Spasur Automatic System Mk 1 (SAS Mk 1) consists of the digital data link ADDAS (Automatic Digital Area Assembly System), two IBM 7090 computers, and associated equipment. The SAS Mk 1 will reduce from minutes to seconds the time for processing detection data on new satellites.




*Map of Space Surveillance Stations, showing how ADDAS data is transmitted to NAVSPASUR Headquarters and NRL.*

Spasur was developed by the Naval Research Laboratory for the primary purpose of detecting unannounced, radio-silent satellites passing over the United States. The detection network presently consists of four receivers and three transmitters located in the southern United States on a great circle at about 33° N latitude. Each transmitter sends out a continuous wave of radio energy in a fan-shaped beam that has a pattern which is very narrow in the north-south direction and very wide in the east-west direction. The receiving stations have similar antenna patterns. Satellites passing through the transmitter beams reflect radio energy to the receiving stations. The received energy creates a signal which indicates the angular position and movement of the satellite with respect to the station.

In the current system analog data from each station is transmitted over telephone lines to Dahlgren, where it is recorded on analog recorders. The data are interpreted by human operators, transcribed manually, and fed to a computer on punched cards. Since a space surveillance system must account for the existance of all satellites in order to detect the presence of new ones, the present method cannot long cope with the volume of data resulting from the increasing satellite population.

The SAS Mk 1 was devised to provide a automatic accounting of known satellites and produce a rapid warning of the detection of new satellites. Where minutes and sometimes hours formerly were required to process these data, only seconds are taken by the new system.

In the new system data from the Spasur stations are transmitted over telephone lines by digital methods via the ADDAS and are fed directly into an IBM 7090 computer at NAVSPASUR's operating center at Dahlgren. Data messages are sent from each station at the rate of twenty per second. Check signals included in each message assure that data is sent correctly. Recording of data on magnetic tape at various levels in the system provides insurance against loss of data during failures.

The 7090 computer stores orbital elements and the mathematical coefficients of the equation of motion for satellites and from these elements derives predictions for the time and angles which should be observed by the receiving stations for each known satellite transit of the transmitter beams. Station signals are processed through ADDAS and are reduced to sighting angles in the computer. Data falling within preset tolerances of predictions are assigned by the computer as new observations for the associated satellite. New observations are used periodically to compute adjustments to orbital elements. New predictions are generated from the adjusted elements for comparison with future observations. In this manner the system keeps track of most known satellites automatically and provides information to the operators on those satellites requiring special analysis.

When two or more stations receive unpredicted, coincident signals which intersect at a height appropriate for earth satellites, an observation is considered to have been made on an unknown object. The computer produces, within seconds, a printed report containing the station observation data and derived orbital parameters for evaluation and required action by operating personnel. Operating personnel can insert instructions into the computer when it is necessary to control various data-processing functions.

The computer prepares routine reports periodically to allow the operators to monitor the system performance. Satellite data of an operational nature are furnished the North American Air Defense Command, the Fleet, and other Department of Defense agencies.

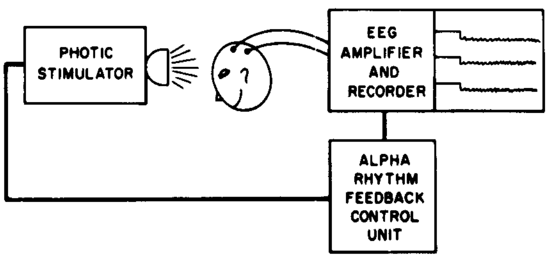
## Brain-Wave Modification by Flicker

For many years physiologists have been aware of the electrical activity of the nervous system and brain. By attaching a pair of electrodes to the surface of a person's head and amplifying the potential difference between the electrodes, a recording known as an electroencephalogram (EEG) of his electrical "brain waves" may be obtained. The EEG waves have been classified as alpha, beta, etc., rhythms, according to certain characteristics of the waveforms, mainly frequency. The rhythm dominant in most normal human subjects, which has a frequency between 7 and 13 cycles per second and a magnitude on the order of 25 to 50 microvolts peak to peak, is called the alpha rhythm.

The nature and origin of the alpha rhythm are not completely understood, and much experimental work is being performed to explain them. One approach has been an attempt to correlate the EEG response with various kinds of stimuli, and with overt behavior, with and without stimulation.

When a normal human subject is exposed to a flickering light at a frequency that is about the same as his natural alpha rhythm, it is often possible to cause the alpha rhythm to synchronize with the flicker. If the flicker frequency is then increased or decreased, the alpha rhythm follows, maintaining synchronism. When this procedure is successful, the subject's alpha rhythm is said to be "driven" by the stimulation.

As one might expect, the relationship between behavior and the alpha rhythm has military implications. For example, sunlight shining through the rotating blades of a helicopter could produce rhythmic low-frequency photic simulation. Similarly, bursts of gunfire could produce auditory stimulation. Thus, it is hypothesized that a stimulus applied at the proper time during each cycle of the alpha rhythm will reinforce the alpha rhythm.




*Schematic of closed feedback loop for presenting photic stimulation to a human subject. Such stimulation often causes the alpha rhythm of the subject to synchronize with the flicker of the light.*

Equipment known as an Alpha Rhythm Feedback Control Unit has been designed and constructed by the Naval Research Laboratory to aid in determining the validity of the hypothesis. The input signal to this equipment is obtained from an EEG amplifier—the same signal that is recorded on the electroencephalogram. The output is a pulse which triggers a 10-microsecond flash of blue-white light, one flash occurring during each cycle of the input signal. The flashes can be set by the operator to occur at any desired phase of the input cycles, even though the alpha-rhythm frequency may vary.

Since the effect of the photic stimulation is to modify the alpha rhythm, and the stimuli are derived from the alpha rhythm itself, a closed feedback loop is formed. This closed loop, combined with the capability of presenting the stimuli to the subject at any predetermined time during each alpha cycle, is expected to provide the means to test the validity of the hypothesis.

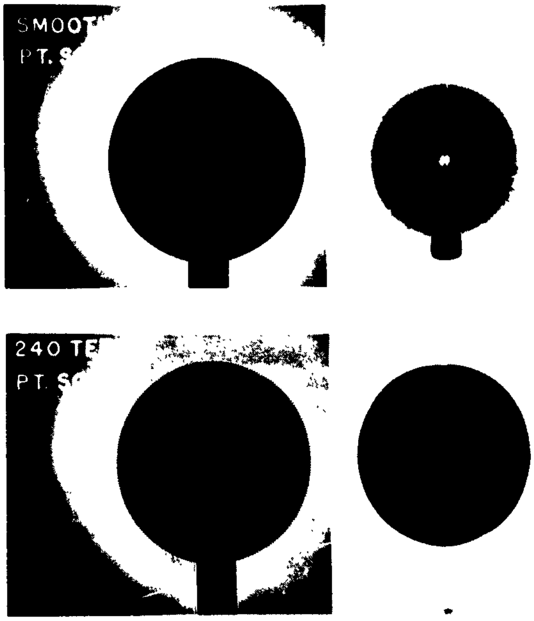
The equipment was tested at NRL with simulated brainwaves. It has now been installed at Baltimore City Hospital, where experiments are being performed with volunteer hospital patients.

# ATMOSPHERE AND ASTROPHYSICS

## Improved Coronagraph

From the ground, the outer solar corona can ordinarily be studied only at times of total eclipse, when the moon blots out the solar disc (leaving only the corona visible) and also reduces the sky brightness to nearly a nighttime level. For satellite-borne solar "observatories," the sky light is absent; and if the bright surface of the sun is eclipsed by artificial means, such as an opaque disc placed at some distance in front of the telescope aperture, the corona then stands out clearly against the black sky of outer space and becomes visible (and thus measurable) in the field of the telescope. A telescope used in such a way is called a coronagraph.

Although the earth satellite has made the corona accessible for continuous observation,



*Photograph of shadows cast by smooth-edged disc and the NRL-designed saw-tooth-edge disc. Heavy exposures at right show how light creeps into the geometrical pattern.*

the observation itself is still very difficult. The limiting factor now—instead of skylight—is the very bright light of the solar disc itself. A smooth-edged occulting disc diffracts sunlight into the coronagraph, and special methods had to be developed to prevent any sunlight from entering, since it is desirable to measure a brightness which is one billion times dimmer than the sun.

Scientists at NRL have solved the problem by modifying the occulting disc of the coronagraph. Saw teeth have been cut around the edge of the disc so that light diffracted from the edge is redirected away from the aperture of the coronagraph. The disc presently being used has a total of 240 teeth around the edge, each about 0.7 millimeter high, with an angular spacing of 35 degrees.

The observed coronal pattern is never the same from eclipse to eclipse, and the changes which occur are extremely large. In addition to the long-term changes, there are no doubt day-to-day and even hourly changes, though little about these is known. Continuous observations of the corona will do much to increase our knowledge of these processes occurring in the sun. NRL's improved coronagraph will provide this increased coverage. After being tested in two separate rocket flights, it will become part of the instrumentation included in NASA's S-17 Orbiting Solar Observatory.

## Automatic Weather Stations

Next to an aggressive nation, weather can be the Navy's worst enemy, especially during storms or hurricanes. Thus, weather forecasting—predicting what this enemy will do—is extremely important to Naval operations. To this end, NRL scientists have for several years been engaged in the problem of obtaining reliable weather data from remote outposts on land or over the ocean.

Routine measurements of weather variables in the Arctic regions are hampered by two factors: the difficulty of setting up and manning meteorological stations and the fact that the mere presence of a human being can affect the measurements made at extremely low temperatures. Nevertheless, the Navy (as well as the other Services) must have regular and reliable forecasts of weather conditions in these areas. It is equally difficult to obtain weather measurements over the ocean. Yet it is here, where hurricanes and typhoons generate and move, that there is a particular need for additional observational coverage.

NRL has met this challenge by the development of automatic weather stations. One of these, called PAWS (Polar Automatic Weather Station), is specially designed for the Arctic. Mounted on a sledlike structure for portability, it can be set up by only two men in a few minutes after delivery to the site. Once in operation, it is fully automatic and will function unattended, telemetering back to a remote receiver, in Morse code, on a preset schedule, accurate weather information: barometric pressure, air temperature, station direction, wind direction, and wind speed. Provisions are also made for interrogating the station by radio at any time. The battery supply permits normal operation for months.

Another weather station developed by NRL is the Transobuoy, a seagoing version of the PAWS. Its instrumentation components are identical to those of the PAWS, but they are encased in a water-tight, double-walled, plastic buoy (either anchored or free-floating). A telescoping ballast structure provides stability in all types of weather. In addition to the weather variables measured by the PAWS, the Transobuoy provides information on sea-water temperature, and a ultrahigh-frequency beacon transmitter is provided for aircraft homing to locate the buoy or for use as a navigational aid. The present battery systems permits operation for one year.

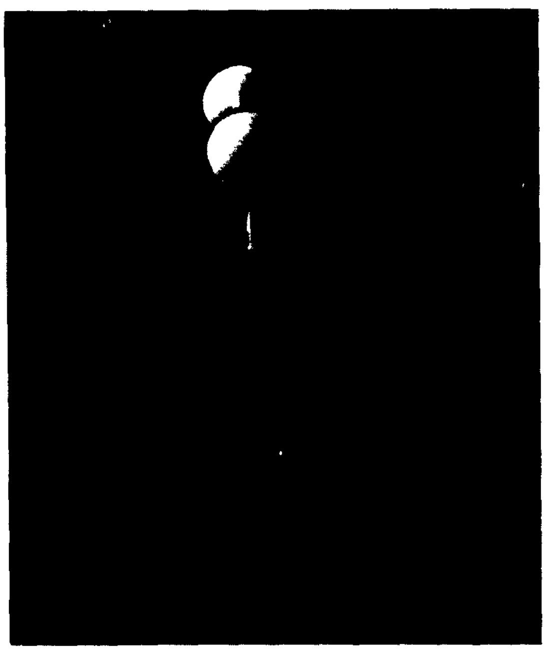
*NRL's automatic weather stations. The PAWS (left) and Grasshopper (center) as used in the Antarctic during Operation Deepfreeze. The Transobuoy (right) being lowered into the North Atlantic Ocean. (Grasshopper photograph courtesy of U. S. Coast Guard)*

Five of the polar stations (plus four Grasshoppers, an earlier NRL development), are now being utilized by Operation Deepfreeze in the Antarctic. Eight of the transobuoys are going into operation in the ocean along the Pacific Missile Range, to telemeter data back to Fleet Weather Centers along the West Coast. With these three types of automatic weather stations, the Navy now has a reliable but inexpensive method of obtaining weather data from remote or inaccessible areas for use in a wide variety of Fleet operations.

## Water Vapor in the Stratosphere

Water vapor in the stratosphere plays an important role in the absorption of solar and earth radiation. Also, a knowledge of the distribution of water vapor in the stratosphere and its changes with seasons could reveal much about the circulation of the air in this outer region. Difficulties with instrumentation, however, have made measurements extremely difficult, and there is no general agreement among scientists concerning the results obtained so far.

NRL scientists are measuring water vapor in the stratosphere with a special frost-point hygrometer carried aloft by means of a balloon. A silver mirror in the instrument is automatically controlled to stay at a temperature such that a given amount of frost will be retained on it; the temperature of the mirror is then measured and telemetered to a ground receiver. From the recorded temperature it is possible to calculate the amount of moisture in the atmosphere at a known altitude.



*A special frost-point hygrometer, carried aloft by balloons, to measure water vapor in the stratosphere.*

The NRL scientists have launched the hygrometers at several locations in the United States and also in tropical regions of India. These flights have pointed up the difficulty of obtaining accurate measurements of the moisture in the stratosphere because of the problem of obtaining an air sample whose water vapor content has not been altered by the presence of the balloon and instrumentation. Often, moisture given off by the instrument and balloon exceeds the amount normally present in the dry portions of the stratosphere (approximately one millionth of that on the ground).

Measurements to date indicate that the amount of water vapor increases with altitude between 50,000 and 100,000 feet. If this finding is verified by additional measurements, the determination of its cause will be of great importance to meteorology.

## New Solar Spectra

A significant step ahead was recently made in the study of the sun from rockets, a study commenced by the Naval Research Laboratory in 1946. An Aerobee-Hi rocket, instrumented by NRL scientists, was flown from the U. S. Naval Ordnance Missile Test Facility at the White Sands Missile Range on 22 August 1962. The rocket carried four separate spectrographs, twice the number ever before flown in a single rocket, all of which operated with great success and were recovered by parachute without damage.

The new spectra are outstanding in having far greater resolution than any obtained so far. One instrument covered the range 2000-1200A with three times increased detail. This spectrum now shows clearly how the different emissions arise from the different parts of the solar atmosphere near the temperature minimum between the photosphere and corona, the strange cool region where shock waves from the sun's interior commence to break through and create intense heating as they travel outward, eventually causing the outer atmosphere to reach a temperature of one million degrees in the corona. In the spectra, absorption lines and emission lines, coming from just inside and outside of the coolest region, are clearly separable.

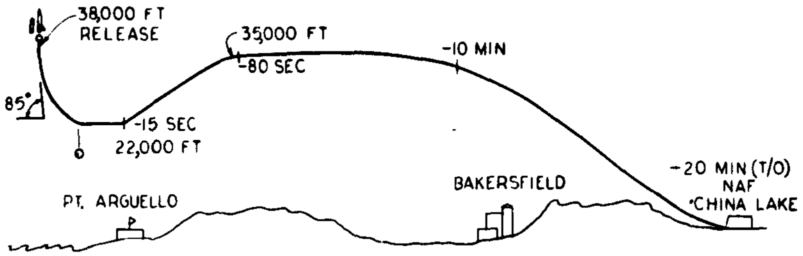
A second, even higher-resolving, spectrograph covered the region from 1250 to 800A. Most exciting of the spectral lines photographed were the second line of the hydrogen Lyman series, Lyman-$\beta$, which turns out to be just as deeply self-reversed and nearly as broad as Lyman-$\alpha$, and the five-times-ionized oxygen lines nearby. The oxygen lines have bright knots at the limb, which are completely absent in Lyman-$\beta$, showing clearly that they arise from much higher in the chromosphere than Lyman-$\beta$.

The two other spectrographs were like the original grazing incidence instrument flown on June 12, 1961, covering the range 170-700A, in which thin aluminum filters were used to remove stray light. Spectra of three times greater resolution were obtained, with the result that a number of the lines discovered in the earlier flight were found to be blends of two or more lines. Most of these lines have not been identified, and they present astrophysicists with a difficult and tantalizing puzzle. This is similar in some ways to the "coronium" problem, which was solved in 1945, after some 50 years of speculation, when Edlén showed that the green coronal line seen during eclipses was from 13-times-ionized iron and that the temperature in the corona must therefore reach one million degrees. In the new spectra, lines of 14- and 15-times-ionized iron stand out clearly. But for the most part, the identity of these lines in this region, sometimes called extreme ultraviolet and sometimes x-rays, is still a first-order mystery.

## Project HiHOE

As man learns more about the upper atmosphere he will be able to develop much more reliable weather forecasting, radio communications, guidance and control of high-altitude missiles, and countermeasures against enemy weapons. All of these are important to the capability of our Navy, and all are directly affected by conditions in the upper atmosphere—pressure, temperature, density, and composition. Especially composition. Under a program designated as Project HiHOE, NRL scientists have developed instruments for investigating the ionized hydrogen, helium, and atomic oxygen in the upper atmosphere. Theory says these ions exist somewhere in the high upper region, but so far they have not been positively identified by either rocket or balloon flights; and satellites have not carried the proper instruments for their detection. The ion-detecting devices for Project HiHOE, all designed and built at NRL, are housed in a specially instrumented nose cone to be carried aloft in a two-stage rocket.

Project HiHOE is a combined effort of NRL and the Naval Ordnance Test Station, at China Lake, California. The problem of getting the



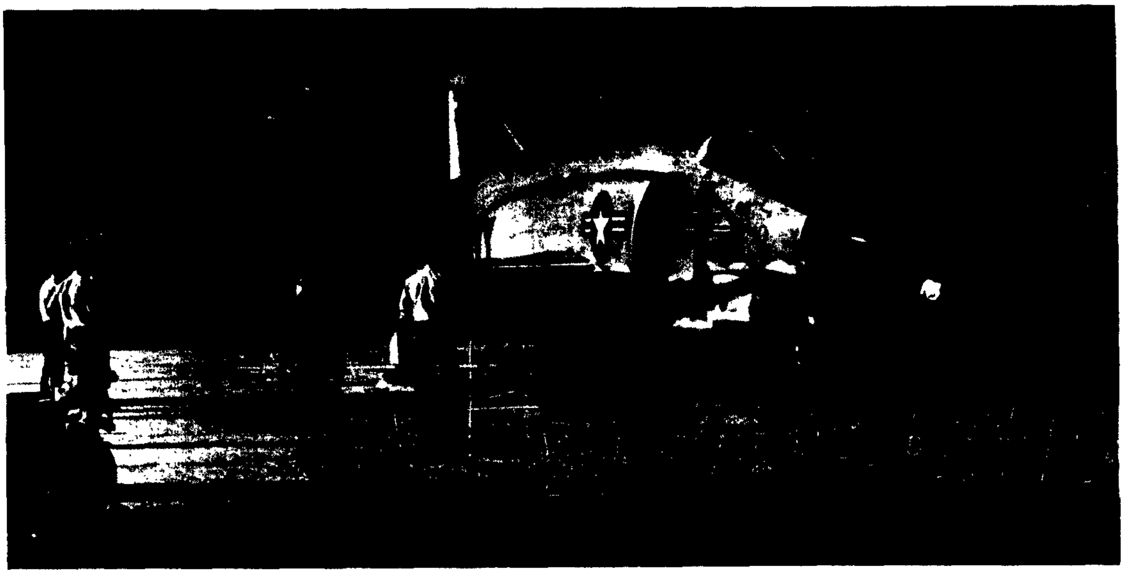

*Flight profile of HiHOE air launch.*

NRL instruments to the desired altitude rests with NOTS. A group of scientists there have solved the problem by the development of an inexpensive, two-stage, solid-propellant rocket (the Caleb) capable of attaining 1000-mile altitude when launched from an airplane.

The first successful launch of the Caleb rocket with a scientific payload took place in July 1962. Caleb was carried aloft by a McDonnell F4H Phantom fighter and launched over the Pacific at 35,841 feet. After a five-second delay, the first stage ignited and burned for 55 seconds. With ignition and separation of the second stage, the 180-pound instrument section was boosted to an altitude of 725 miles over a horizontal distance of 840 miles.

The use of aircraft as a rocket launch platform has obvious advantages of economy, mobility, and flexibility of launch location. At time of launch, the Caleb rocket was being carried along at 984 feet per second. It was above at least half of the earth's atmosphere, but still possessed the energy that a ground-launched vehicle would have expended in going through the atmosphere. A similar launch from the ground would require a much more expensive and sophisticated propulsion system and would have a top altitude limit of 200 miles.

Equipment failure prevented measurements by the mass spectrometer; but before Caleb disappeared over the radio horizon, it had sent back more than 1100 seconds of useful telemetry data to Pacific Missile Range sites, indicating that the original requirement of a 100-pound payload carried to a 1000-mile altitude could be met. Later flights are expected to produce much new scientific data concerning the true composition of the exosphere.



*Caleb rocket, ready for air launch. Ion-detecting devices, all designed and built at NRL, are housed in the nose cone.*

## Radio Astronomy

Under a continuing basic program of radio astronomy, NRL scientists observe and study the microwave emissions from the sun, moon, and planets within the solar system and from other radio sources outside the solar system, or "radio stars," as they are popularly called, such as the well-known nebulosities in the constellations Cassiopeia, Cygnus, Virgo, Sagittarius, Taurus, and Orion. The NRL program is conducted with the aid of highly directional radio telescopes ranging from 10 to 84 feet in diameter and with increasingly sophisticated instrumentation, such as maser developments, improved receiver sensitivity, and superior mixer crystal performance.

In June 1962 a solid-state maser amplifier at 9.4-centimeter wavelength was installed on the 84-foot radio telescope. The primary observational program was a search for linearly polarized components of the radiation from discrete, extra-galactic sources, by means of a rotating, plane-polarized, horn-feed antenna. In addition, observations were made of the planets Jupiter and Saturn. The first observations with this instrument have indicated that the radiation from sources Hercules-A and 3C433 are both about 10-percent linearly polarized and that from Jupiter is roughly 15- to 30-percent polarized. The amounts of polarization of these radiations give an indication of the average magnetic field through which they pass.

It is from studies such as these that man learns about the character of the universe—how it was formed, how it behaves, its effects on our planet, and what it holds in store for space travelers.

## Solar Radiation Satellites

The first orbiting solar observatory, NRL Solar Radiation Satellite I (1960 Eta 2), had a lifetime of about four months, during which numerous measurements were made of solar x-ray and Lyman-$\alpha$ radiation. During 1962 the significant data from SR I was analyzed and published. From these, the following conclusions have been drawn:

- For a period from July 13 to August 3, 1960, Lyman-$\alpha$ day-to-day changes did not exceed 18 percent. During a Class 2 flare, Lyman-$\alpha$ did not rise above the quiet sun level by more than 11 percent. Although insufficient to be of geophysical significance, an 11-percent change in total flux from the solar disk would mean an increase of a factor of 100 in local brightness within the limited area of the flare region. It should be recognized, however, that the accuracy of the Lyman-$\alpha$ measurement was poor and that the figure quoted for the upper limit does not imply that any real increase of Lyman-$\alpha$ was positively detected.

- The quiet sun does not omit an x-ray flux below 8A in excess of the limit of measurement in SR I, namely, $0.6 \times 10^{-3}$ erg $cm^{-2}$ $sec^{-1}$. Whenever x-rays in the 0A to 8A band were observed above this level, some optical indication of activity was usually detected.

- If the x-ray flux exceeded $2 \times 10^{-3}$ erg $cm^{-2}$ $sec^{-1}$, radio fadeout and other sudden ionospheric disturbance (SID) phenomena occurred simultaneously.

- Important variations in x-ray emission in this wavelength band take place in about one minute.

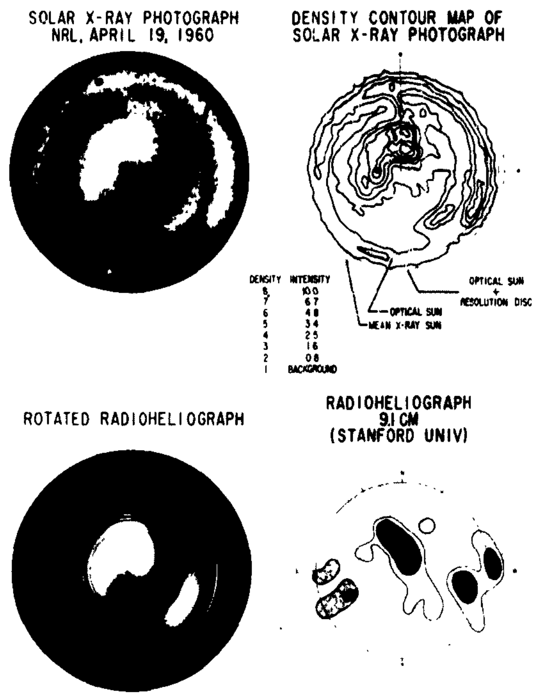
- Active prominence regions, bright limb surges, and small limb flares produce x-ray events that resemble those accompanying disc flares.

- Long-duration x-ray events of sufficient intensity to produce ionospheric disturbances can accompany rising limb prominences.

SR III (1961 Omicron 2) was launched on June 29, 1961, as one of the pair of pick-a-backs on top of Transit 4A. It went into orbit without separating from its partner, Injun I, and as a result did not acquire the desired spin stabilization. Although far less productive in data than SR I, it nevertheless produced some interesting results. For example, x-rays of wavelength greater than 8A, which are absorbed above the D region, do not contribute to SID phenomena, whereas x-rays of 2A to 8A absorbed within the D region are the important influence.

## X-Ray Photographs of the Sun

A program of solar x-ray photography was initiated at NRL in the spring of 1960, when a simple pin-hole camera was flown in an Aerobee-Hi rocket. A thin plastic film flashed with aluminum covered the pinhole to exclude ultraviolet and visible light. The objective was to observe




*NRL's x-ray photograph of the sun is compared with a 9.1-cm radioheliograph of the sun obtained at Stanford University on the same day. In each case radio emissions originate as a result of similar temperature conditions. The x-ray photograph was smeared through about 160 degrees during the 5-minute exposure of the rocket flight because motion about the direction to the sun was not compensated for by the pointing control. The microwave image was rotated in a similar manner while it was being photographed, and the resemblance is very close.*

the distribution of soft x-radiation (1A to 100A) over the solar disc in order that the results of long- and short-term variations of intensity could be interpreted in the light of the theory of solar x-ray emission. A second camera was flown in June 1961, from which pictures were obtained in three wavelength bands between 10A and 100A. In both flights the rockets were equipped with pointing controls to aim at the sun.

The photographs obtained with the pin-hole cameras show the locations of x-ray sources in the sun. The brightest of these sources was 70 times the quiet background intensity, and about 75 percent of the total x-ray flux came from less than 5 percent of the area of the solar disc. Within the accuracy of the camera, the x-ray emission extended to about 0.06 solar radius (43,000 km) above the limb.

# CHEMISTRY

## Battery Research

The inherent disadvantage of electrochemical sources of power, such as storage batteries, is their low energy output per unit weight and volume. Nevertheless, there are innumerable military applications which depend exclusively on such sources for their electrical power. Consequently, one of the oldest research programs at this Laboratory has been the unremitting search for improvement in batteries.

One achievement marked for 1962 was the discovery that the capacity of the silver oxide-zinc cell, which already has the highest output for its size of any storage battery, can be increased by as much as 50 percent over normal capacity. This can be done by simply superimposing a proper choice of a pulse current to the normal charging current.

In a more theoretical vein, an analysis has been made of a related problem: the effect of

*Testing a full-size lead-calcium submarine storage cell to determine cause of failure in float condition.*

internal resistance on the distribution of the current density over the face of the electrode during discharge of a battery. It has been possible to derive an equation which describes the potential of a battery during discharge as a function of its discharge rate. This equation will make it possible to design a battery of minimum weight for a given set of operating conditions without the necessity of running a whole family of discharge-vs-time curves in order to establish the over-all characteristics of the battery.

The background of experience of NRL electrochemists in research on lead-acid batteries has been applied to the solution of a serious problem which arose in connection with the lead-calcium storage battery, which plays an essential role in nuclear-powered submarines. Many of these cells failed early when operated under the required float* condition. Although a modified procedure has since enabled these batteries to be used, it has not been possible to use them in the required manner. After an exhaustive investigation it has been possible to show by electron as well as optical microscopy that a considerable difference in morphology of the active electrode material exists between a cell which will float satisfactorily and one which will not float. This information is now being placed in the hands of the manufacturer in order that modifications in the active electrode material will permit these batteries to be floated as required.

## Antioxidants for High-Temperature Lubricants

Since World War II, aircraft power requirements have increased manyfold as the sound barrier has been approached and then breached. This trend has imposed increasingly severe requirements on the oxidative and thermal stabilities of the engine lubricants. Whereas early jet engines were adequately lubricated with petroleum oils, it soon became necessary to go to properly inhibited synthetic aliphatic diesters, most of which were originally developed at NRL. These lubricants are currently used in all modern military and commercial jet-powered aircraft. Jet engines in the Mach 2 and 3 range, now in the development stage, are anticipated to have oil temperatures of 450°F or higher in the sump and 650°F at the bearings. Such engines will require lubricants more stable than the currently used aliphatic diesters.

Research at NRL has shown that the oxidative stabilities of two promising classes of thermally stable fluids—fluoroesters (an NRL development) and polyphenyl ethers (developed under Air Force contract by Monsanto Chemical Company and Shell Development Company)—could have their upper operating temperature range increased as much as 100°F to 150°F by the introduction of certain metals or slightly soluble organometal compounds as inhibitors. This improvement has brought the stable limit of these fluids up to 650°F, establishing a range compatible with Mach-3 service. The discovery has considerable scientific interest because these new inhibitors, such as copper metal and metal salts, have been long known to function in

*A laboratory demonstration shows the effects of inhibitors on the stability of polyphenol esters, fluids that show promise as jet engine lubricants. Three samples of the same fluid was oxidized at 650°F for 24 hours. There was very little viscosity change in the fluid being poured from the beaker in the right hand, to which barium metal had been added, or to that poured from the left hand, which had a barium compound added. The untreated fluid (foreground) solidified to the consistency of asphalt, and the tube had to be broken before the contents could be inspected.*

*Float: to charge continuously so as to maintain full charge, without overcharging.

hydrocarbons and ester oils as oxidation accelerators. The work at NRL thus provides a new approach to the stabilization of other unconventional fluids now being examined as high-temperature jet engine lubricants and opens the door to new research on oxidation-inhibition mechanisms.

## The Surface Chemistry of Adhesion

Long-term surface-chemical studies of the wetting and spreading of liquids on solid surfaces have recently thrown a flood of light on the important but controversial subject of adhesion—what makes things stick. The chemical properties of a surface affect adhesion in large part because they alter the dynamics of adhesive spreading and wetting. Incomplete wetting of the adherend surface, by the adhesive while still fluid, may leave voids or gas pockets, especially wherever there are pores and cracks in the surface. These pockets serve as points of stress concentrations which are responsible for a major decrease in the theoretical or thermodynamic joint strength. Where many surface voids exist they may serve to cause a zipper-type failure under an applied shear stress.

The problem of voids at the interface can be minimized by applying the adhesive while it is at a low viscosity and by extending the curing time long enough to permit optimum penetration of pores and crevices in the adherends. Where complete wetting is obtained, joint strength then becomes so great that failure will occur in the adhesive rather than between the adhesive and a surface. A chemical reaction of the adhesive with the surface is usually unnecessary and often undesirable.

Where the adherends are low-energy (soft) surfaces, the specific adhesion may be as low as one third that between high-energy (hard) surfaces. Hence, an adsorbed monolayer may have an important effect on the specific adhesion. Application of these concepts does much to explain the easy parting action or "mold-release" effect of many film-forming substances, such as fatty acids, silicones, and fluorocarbons. The film may inhibit satisfactory bonding, in two ways simultaneously, by lowering the specific adhesion or stickiness and by preventing complete wetting—thus causing the surface gas pockets that lower the shear strength of the joint.

The same principles have been shown to be operative in reducing the adhesion of ice to lubricated surfaces. Their recognition has provided guidance for further research and has indicated limitations which must be dealt with in seeking anti-icing coatings.

The better understanding of wetting and spreading phenomena, reached through fundamental surface-chemical research at this Laboratory, has provided a rational and fruitful approach to practical problems in fields as diverse as textile finishing, instrument lubrication, floor finishes, tire-cord adhesion, and rocket cases, and has prompted the establishment of surface-chemical research groups in at least a dozen industrial laboratories.

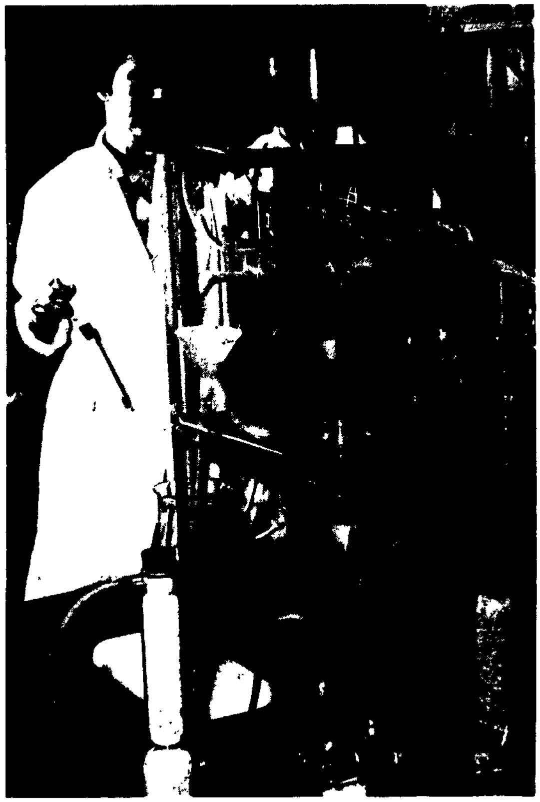
## Atmosphere in Closed Space

### Atmosphere Analysis

The problem of identifying trace components in contaminated atmospheres has long been of interest to the Navy and has assumed increased importance because of possible long-range physiological effects on men from continuous exposure in nuclear submarines or spacecraft. The concentration of most of these contaminants is usually less than a hundred parts per million and frequently less than a few parts per hundred million. The amounts are so small that relatively few of the contaminants have yielded to direct analysis by the infrared spectroscopy and gas chromatography techniques available.

Recent developments in gas chromatography, for use both in preliminary separation and for direct analysis, have furnished powerful tools which NRL chemists have used most effectively in attacking these important Naval problems. In the analysis of organic vapors in nuclear submarines, it has been shown that the atmosphere contains more than 200 individual components. Many of these up to the $C_{10}$ range have been identified, at least tentatively. Of greater significance, because of their known higher toxicity, has been the analysis of the aromatic compounds present. This analysis was based on a sample obtained by adsorption on active carbon followed by separation via liquid chromatography into aromatic and aliphatic compounds, the aromatic fraction then being analyzed by gas chromatography. Over two dozen aromatic hydrocarbons have been identified and their concentrations in the submarine atmosphere determined. Fortunately, of those compounds for which toxicity limits have been assigned, the concentrations can be held below the allowable limits.

Contaminants in the atmosphere within the Mercury spacecraft also are sampled for analysis by carbon adsorption units. Following flight, these units are delivered to NRL, where the contaminants are recovered by a special vacuum and cryogenic technique. Because the total amount of contaminant recovered is small and complex, generally comprising a dozen or more contaminants, the analysis has required the development of special equipment and techniques. The sample is resolved into its components by gas chromatographic procedures. Each component is recovered from the output of the chromatograph with a unique fraction collector developed at NRL. The components are identified and their concentrations determined by means of infrared and mass spectral techniques. These techniques have determined individual contaminants at concentrations as low as one part per billion. A wide variety of chemical classes of compounds are represented by the individual contaminants found in spacecraft atmospheres. The concentrations found so far have been within tolerable physiological limits, although some would be quite toxic if much higher. The sampling has also been useful in another way; some of the compounds provide possible clues to the identity of overloaded and malfunctioning equipment.



*A scientist samples algae from a photosynthetic gas exchanger. This system provides fresh oxygen while removing carbon dioxide from the atmosphere.*

Breathable Atmosphere

As another phase of providing breathable air in closed spaces, NRL has continued its efforts in providing better ways of absorbing carbon dioxide and generating oxygen. Although separate and adequate units for each of these functions are now used on nuclear submarines, NRL has been developing combined systems which might form the heart of a completely integrated air-purification system on nuclear submarines.

One such system is based on the sulfate cycle, which utilizes the electrolysis of an aqueous solution of sodium sulfate to decompose the water into hydrogen (which would be pumped overboard from the submarine) and oxygen (for breathing), accompanied by the formation of sodium hydroxide and sulfuric acid. The first product, sodium hydroxide, is then used to absorb the carbon dioxide in the atmosphere and to form sodium carbonate. The resulting sodium carbonate is neutralized by the second product, sulfuric acid, evolving carbon dioxide in a concentrated form for pumping overboard, and reforming sodium sulfate. Any excess sodium hydroxide is also neutralized by the sulfuric acid, and the cycle is complete. All that is required is the addition of electric power and of replacement water. The feasibility of the system has been demonstrated in pilot plant studies.

NRL has also been investigating a combined oxygen-generating and carbon-dioxide-absorbing system of the mass culture of algae under artificial light. An efficient semi-pilot plant unit has been developed in which, under closely controlled conditions of light intensity and rate of dilution with fresh medium, the algae exhibit a remarkable degree of reproducibility in gas exchange rates. The original target of but 75 liters of algal suspension for sustaining one man has been gradually bettered, with the figure now down to 42 liters. The high power requirement of about 40 kw per man, however, as indicated by the operating characteristics of this particular unit, diminishes the utility of the system for use on nuclear submarines and indicates the need for optimizing the use of light energy if the system would otherwise be usable in spacecraft.

Gas Leak Detector

When all the problems of maintaining

"mountain-fresh" atmosphere in a submarine have been solved—the air is scrubbed and regenerated, and even the tobacco smoke is removed—there remains an additional problem: gases that may leak from machinery (such as refrigerators) or from pressure vessels, particularly those in use on nuclear submarines. Unfortunately, some of these contaminants, even though detected in the internal atmosphere, cannot be removed by the new standard scrubbers. The source of the contamination—the leak—must be located and then eliminated. The first of these jobs is done effectively by the thermistor-bridge leak detector. A portable thermal-conductivity comparer, it can detect—near or close to its source—leaks of any gas having a thermal conductivity different from that of the ambient air.

Many leak-detection methods, including Pirani tubes, mass spectrometers, ionization types, and thermal conductivity cells, were investigated to determine their possible utility in the problem of maintaining a habitable atmosphere. Some lacked versatility because they were sensitive to certain gases only, some were too large and complex, and most responded to concentration rather than rate of change, thereby becoming virtually useless in poorly ventilated areas where the ambient level of gas had built up to a fairly high concentration. The thermal conductivity bridge principle was selected as most suitable for a portable detector featuring simplicity, versatility, reliability, and ease of operation.

Experience with the device in use aboard nuclear submarines during the past year has been most encouraging and indicates that the present design is both sensitive and reliable.

*Construction of a research tube for measuring thermionic emission requires conditions of extreme cleanliness. Entire assembly of the tube is performed in the inert atmosphere of the NRL dry box. In such an atmosphere an incandescent light filament (shown at the upper right in the dry box) can be operated without the conventional glass bulb, so it serves as a pilot light in a simple test to determine the amount of oxygen in the atmosphere.*

## ELECTRONIC DEVICES

### Work Function of Thermionic Converters

In vacuum tubes and thermionic converters (devices for converting heat directly into electricity) the primary source of electrons is the material which, when heated to a sufficient temperature, emits electrons. It follows, then, that the "best" of these devices are the ones containing a material that emits a plentiful supply of electrons at relatively low temperatures. The energy required to remove electrons from the surface of a material is called the work function of the material and is measured in electron volts. Work function will vary widely between different materials, depending on surface conditions and cleanliness.

A few years ago scientists at NRL perfected very accurate and rapid measuring equipment for determining the average electron emission properties of different materials. During the past year a number of the uranium compounds have been measured to ascertain their suitability as electron emitters for use in thermionic converters in nuclear reactors. Such thermionic converters change the nuclear reactor heat directly into electrical energy by fission heating of the electron source. Materials such as the borides, silicides, nitrides, oxides, and carbides of uranium have been accurately measured and compared.

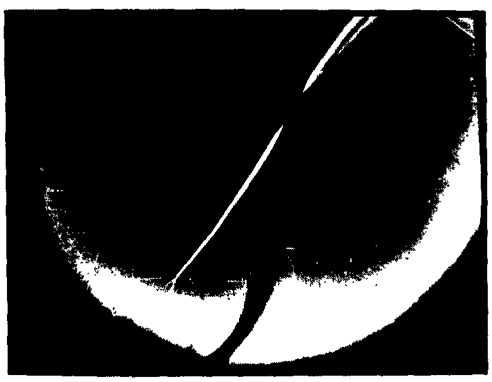
It is known that the work function of a material will vary between points on its surface. Recently, NRL scientists have developed an electron-beam scanning technique whereby the detailed work function of a surface can be examined, in addition to its average emission properties. As a low-energy, probing, electron beam is moved across the surface of a material, it either strikes or does not strike the surface, depending on the work function at that point. The distribution in work function over the surface is then determined by the amount of beam current received by the surface as the beam energy is varied.

This method is very useful for observing differences in the work function of the surface during activation and processing of an electron emitter material. Measurements conducted on activation and poisoning effects of uranium carbide show good agreement with thermionic measurements made on the same sample. The method is also useful in other chemical and semiconductor studies, where detailed knowledge of surface work function of a material is desired.

## Plasma Physics: The "Spark-Streak" Phenomenon Explained

During the past several years, NRL physicists have observed an interesting phenomenon occurring in certain plasmas. When a tube containing xenon gas, for instance, is excited by a radio-frequency power of several hundred watts, a fringe magnetic field may cause the outer sheath of the gaseous plasma to become unstable and erupt a luminous jet. This jet, or "spark streak," shoots into the plasma and may remain imbedded there for hours. It is observed as a steady, white line, brightly visible in the fluctuating radiation of the plasma itself.

For a long while the exact nature and cause of the spark streaks remained a mystery. More recently the phenomenon has been elucidated,



*Closeup of a typical spark streak. The dark streak is a turn of the induction coil. A faint reflection of the spark streak is visible in the background.*

first by hypothesis and then by experimental evidence. Apparently the steady streak is a manifestation of a "dissociative recombination" of molecular ions. Initially, the applied magnetic field causes an instability in the boundary, or sheath, of the plasma by upsetting the required ratio of positive and negative r-f currents traversing the sheath. The unstable sheath front sometimes erupts, and because the front contains a high ion density, favorable conditions prevail for the dissociative recombination to occur. The "spark streak" is thus a motion of the sheath front.

This elucidation constitutes a solid contribution to man's knowledge of plasma physics.

## Solid-State Inductors

The essential building blocks of electronic circuits are the resistors, condensers, and inductors, which are interconnected to tubes, transistors, or semiconductor devices. All of these "blocks" have been successfully miniaturized—tiny crystal diodes taking the place of bulkier elements—except inductors. There seemed to be no way of substituting small solid-state devices for wire-wound inductance coils whose dimensions are frequently measured in inches.

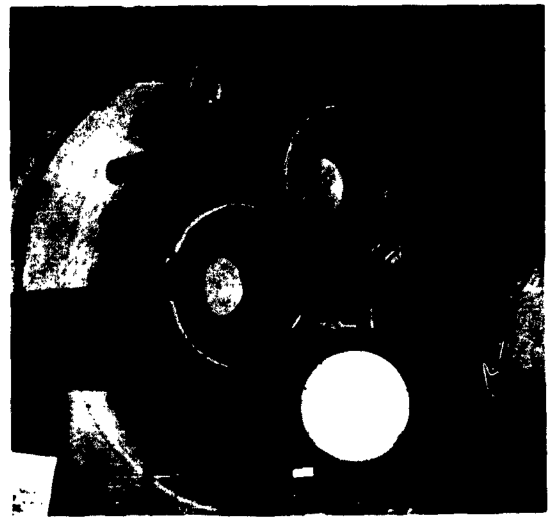
By a theoretical analysis of a special diode structure, an NRL electronics engineer determined the requirements for inductive behavior. Further experimental work at the Laboratory has resulted in the development of a tuned circuit with a high-performance inductive element that is a double-base diode instead of a coil. It has been shown that this type of inductor not only effects an obvious saving in size and weight, it also performs in certain respects better than a conventional inductive component.

## Miniaturization

As is true with many another electronic system, the sophistication of identification devices has resulted in large increases in their size, weight, and cost. The counterattack on these increases is miniaturization. For a number of years, NRL has had a modest but productive program in this field. An outstanding example is the miniaturization of a message encoder in standard use by the Armed Forces (AN/APA-89).

The encoder generates coded pulse trains when triggered by an associated interrogation decoder. There are three different modes of operation with a total of 4192 preselected codes available. The coded pulse trains from the encoder modulate the transmitter of the transponder. The NRL version of the encoder is completely transistorized and is contained on two 3-inch by 3-inch plug-in printed-circuit cards. Functionally it differs from the older model in that the pulse trains are generated by transistor and diode logic circuits whereas, in the AN/APA-89, vacuum tubes and a delay line are used. This difference has resulted in an encoder that occupies one-third the volume, weighs one-fifth as much, and consumes 1/25 as much power as the AN/APA-89.

The use of plug-in, printed-circuit cards should result in relatively greater ease of field maintenance. In addition, it is expected that in production quantities this encoder will also be less expensive. The performance of the encoder equals or exceeds that of the AN/APA-89 in all respects.



*NRL scientist uses ultrasonic flaw detector on metal hardware of a missile. (Aerojet-General Photograph)*

## MECHANICS

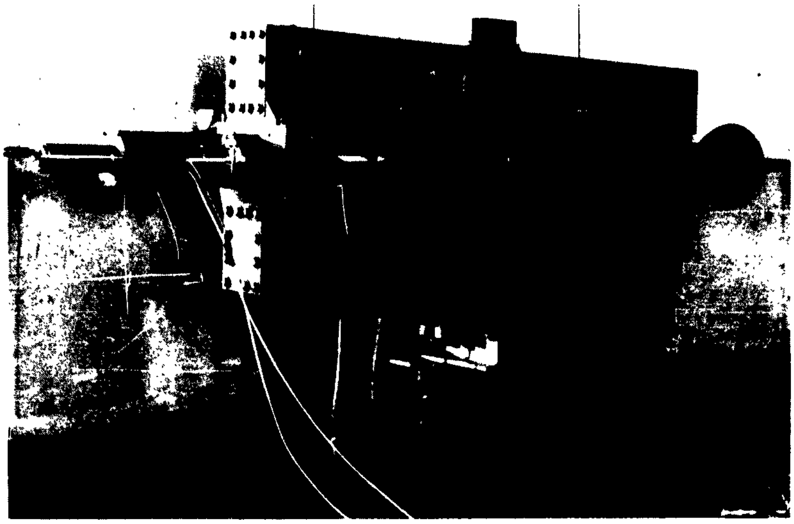
### Nondestructive Flaw Detection

Nondestructive tests have been used for many years to determine the existence of flaws in structural materials. There are many techniques involved, which overlap and supplement each other; the use of several methods is necessary to assure the integrity of materials when the cost of failure is particularly high, as it is in rocket components for missiles and space vehicles. Scientists at NRL have done their share of innovating in the field of ultrasonic flaw detection; they also have acted as advisors to the Special Projects Office of the Navy's Bureau of Weapons, and serve on the Polaris-Minuteman-Pershing Nondestructive Test Committee.

In an effort to make nondestructive testing techniques more automatic, these scientists developed a scanning machine that is 100-percent effective in inspecting sheet steel intended for missile motor cases. This involved setting up a system that "looks" at the steel from many different directions at once in order to detect flaws of any orientation in the plate. Of course it would be possible to inspect the plate many times, turning it a bit on each inspection, but that would be too slow. The NRL system consists of immersing the sheet-steel plate in water and positioning a multiple transducer head over it. The head then automatically scans back and forth across the plate, and the flaws are indicated on an automatic recorder.

NRL workers have also demonstrated that it is practicable to inspect missile hardware after the missile is assembled on the launching pad. In one instance, ultrasonic tests made shortly before scheduled flight revealed that certain elements of the guidance system, the molybdenum "jetavators," were cracked. This test points up not only the feasibility but the necessity of examining nozzles and other brittle hardware for flaws just prior to use, if there is a possibility that they have been damaged in transit or during installation.

Another recent development is a method for ultrasonic inspection of porous materials, such as sintered tungsten. Here, as in the inspection of sheet steel, the method of choice was to immerse both the material and the sound transducer in the same bath, or "coupling fluid." But the material, being porous, would be contaminated by absorbing the couplant. This problem was neatly solved by wrapping the part to be tested in adhesive vinyl plastic, sealing the edges with electrician's plastic tape. The water-proof jacket in no way interferes with the transmission of ultrasonic energy.



*NRL set-up for shock-testing a control-rod drive mechanism for the reactor of a nuclear submarine. In this test the drive mechanism is mounted to simulate its position in the reactor. A malfunction of the mechanism could result in excess power generation, endangering the lives of the entire crew, even though the submarine hull might receive only negligible damage. The extra ruggedness built into reactor components to ensure survival under enemy attack will provide additional reliability for normal operations.*

## Reliability in Combat Performance

In the event of attack, our surface ships and submarines must be able both to survive and to retain their capacity to retalliate. Many attacks will not cause disablement by hull damage, but the ship may still be "lost" if only one piece of complex machinery or equipment receives mechanical shock damage. For this reason, all system components must be tested for reliability under extreme environmental conditions prior to actual use.

For many years the Laboratory has conducted research studies on underwater-explosion effects on ships, examining the basic phenomena, developing methods to improve shock resistance, and evaluating these methods under realistic conditions. In 1961 an improved method for designing shipboard machinery and equipment was proposed to the Bureau of Ships. During 1962 this method was made the basis for many new procurements. Its usage will assuredly yield better ships and submarines, less vulnerable to attack by bombs or torpedoes, depth charges, or mines.

To extend still further our knowledge of basic phenomena and the transmission of shock through ships, a more precise description of structural characteristics is required. The key lies in better methods of physically measuring mechanical impedance. Accordingly a program was undertaken to compare the different procedures used by various investigators in the field. The aim has been to establish measurement reliability by eliminating the variations that lead to widely different conclusions. In the laboratories, known impedance theorems were applied by use of the varying measurement techniques. Other studies, many of them continuing, seek to verify the techniques used for impedance testing of NASA satellites and payloads. This kind of theoretical and practical research will undoubtedly result in an increased reliability of civilian and military space payloads, with no increase—possibly a decrease—in cost.

Improvement of future designs is one need; a second and more immediate need is evaluation and improvement, where possible, of present-day ships. To this end the Navy is conducting full-scale shock tests on both submarines and surface ships, with underwater explosions controlled so as to cause desired shock loadings. Laboratory personnel participate extensively in these, with special instrumentation on board during the tests. These experiments determine any "weak links" in shipboard systems, provide actual data for use in design, and permit evaluation of analytical methods under actual conditions. During 1962 two modern submarines were tested, and a great deal of valuable information was obtained on their performance under attack. These research studies and tests will assure better ships for our defense and our crews.

## Hypervelocity Kill Mechanisms

The reasonable hypothesis that an enemy missile re-entering the atmosphere at re-entry velocity could be defeated if struck on a vulnerable section by a fragment has quickened scientific interest in hypervelocity impact techniques. Because of NRL's leadership in this field, it was designated by the Advanced Research Projects Agency to be the chief functionary in a study to determine the feasibility of defeating ballistic missiles by fragment attack. The responsibility involves in-house research as well as additional work with approximately eight contractors, including Air Force and Army laboratories. The object of the study is to investigate all possible means for increasing the lethality of fragments used to attack enemy vehicles and for reducing the vulnerability of our missiles.

Also, one of NRL's scientists represents the Navy on the Tri-Service (Army, Navy, Air Force) Committee on Hypervelocity Impact. The principal duty of the Committee is to foster free exchange of information between the Services, primarily by means of a symposium, held every eighteen months, in which all aspects of hypervelocity impact are covered. The proceedings of each symposium are published in two separate volumes, one classified and one unclassified.

The development of suitable projectile accelerators is an important and necessary preface to a fruitful experimental program. NRL techniques employed for accelerating projectiles to super velocities include light-gas guns (see p. 10) and electrically exploded foil. Since the velocities that are being achieved at NRL (ca. 32,000 fps) are greater than orbital velocity, much can be learned by these controlled experiments. Direct evidence of projectile behavior is obtained by radiographic and photographic techniques and by observing the impact effects of various types of projectiles on a wide variety of targets.

A mathematical analysis of NRL's two-stage, light-gas gun, conducted on the Narec over a wide range of gun parameters, has shown that the velocity of a lightweight projectile could be increased by over 50 percent if the initial temperature of the driver gas could be raised from 300°K to 2400°K. So far, projectile velocity has been increased about 10 percent by raising the temperature of the gas and surrounding compression tube to 500°K.

These results have led to the application of electrical heat to one of the light-gas guns. A 250,000-joule capacitor bank and appropriate switching circuitry will supply the additional energy to the gas in one or more stages, thereby resulting in a higher average pressure at the base of the projectile. Maximum current achieved during discharge of the capacitor bank is 10 million amperes. It is anticipated that velocities can be extended to 40,000 fps. The results, when combined with other studies, should eventually throw more light on problems concerning impact damage to missile structures: extent of additional damage caused by thermal effects after an incoming missile has been damaged prior to or during re-entry; aerodynamic stability of damaged vehicles; impact and thermal damage to internal components; and vulnerability of assumed enemy vehicles.

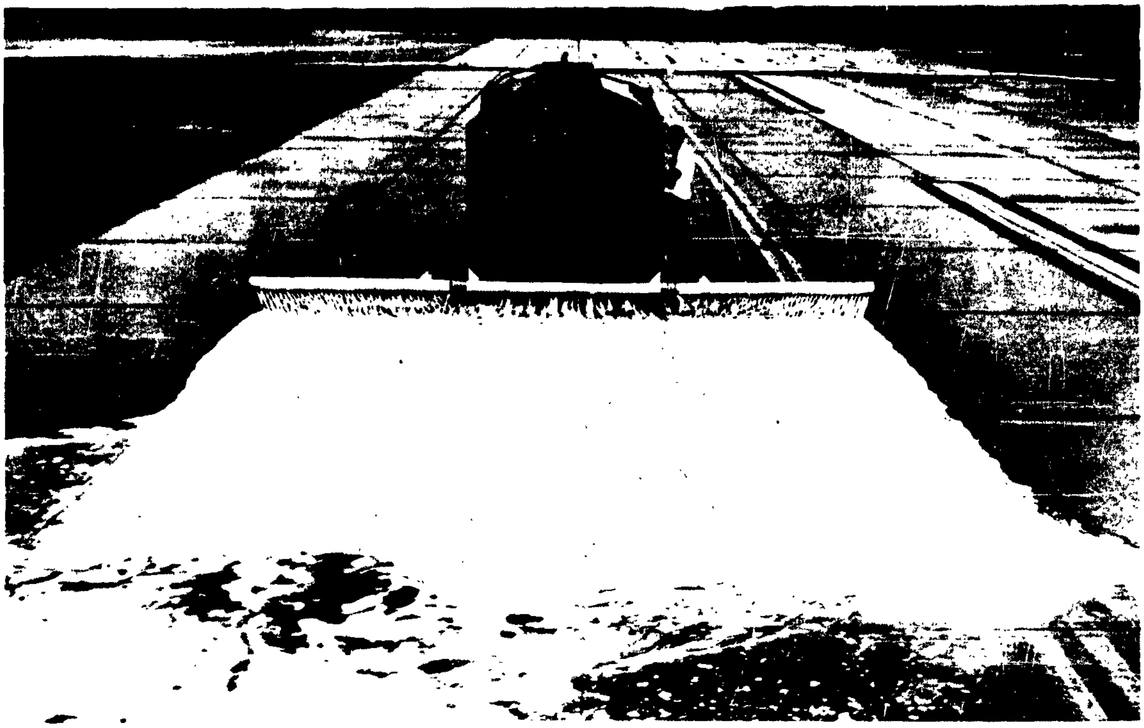
## Fire-Fighting Research

Foaming the runway as a means of preventing aircraft fires during an emergency landing was for years a more-or-less widely accepted practice, despite a lack of technical knowledge to substantiate any reputed benefits. Recent research (1960) at NRL not only proved that proper runway foaming definitely will suppress sparks caused by friction between aircraft metal and pavement, but also established the conditions (i.e., type, depth, and age of foam, type of runway surface, and type of metal used in aircraft construction) under which foam is the most effective.

At that time the foam was applied to the runway by means of a special spreader attached to a crash-rescue foam truck, but this system had limitations in width of foam pattern, speed of application, and capacity. So engineers at NRL have designed a multipurpose foam-generating device which can be used with conventional tank trucks. This system can spread a layer of foam 2 inches deep and 24 feet wide at a rate of 300 feet per minute so long as there is water in the tank. It will enable our largest attack bombers, when confronted with completely disabled landing gear or other landing malfunctions, to land with a greatly lessened danger of fire.

When necessary, the system can be used to refill empty fire-fighting vehicles at a crash scene. Acting as a "nurse truck," it transfers its water and foam-forming concentrate to the fire truck in just six minutes.

Another spectacular development during the past year is a vehicle in which two agents are used for fighting crash fires. It has a capacity of 400 pounds of potassium bicarbonate dry chemical and 1000 gallons of water and foam-forming



*A new multipurpose foam-generating device developed at NRL can spread a layer of foam 2 inches deep and 24 feet wide at a rate of 300 feet per minute.*

concentrate. By the simultaneous use of these two agents, aircraft crash fires can be controlled and extinguished in a fraction of the time required by the old single-agent vehicles which used foam only. The potassium bicarbonate agent is the "Purple-K" material which NRL tests in 1957 proved to be twice as effective as the sodium-based powders previously used.

## METALLURGY

### Radiation Damage to Metals

Recent NRL studies have demonstrated conclusively that high-energy nuclear radiation markedly increases the brittleness of reactor steels, the degree of damage decreasing with higher temperature during exposure. Moreover, the amount of damage which occurs when the reactor is operating at normal temperatures may be sufficient to cause brittle failure of reactor pressure vessels after long-term exposure. The magnitude of these radiation effects led to the investigation of post-irradiation heat treatment as a possible means of recovering the initial properties of exposed steels.

Various steels that have been or may be used in reactors have been tested in the laboratory under conditions which simulate actual reactor conditions. How the laboratory findings compare with those obtained during reactor operations is the objective of experiments now being conducted in two nuclear power plants—the SM1, at Fort Belvoir, Virginia, and the SM1A, at Fort Greeley, Alaska.

Certain observed effects of post-irradiation heat treatment on the brittleness of reactor pressure-vessel steels may be summarized.

- For steels irradiated at low temperatures (200°F to 300°F), essentially complete recovery is possible with a short-term treatment at temperatures as low as 600°F.
- When irradiation is at higher temperatures, the same steels exhibit less recovery under comparable annealing conditions.
- After about 24 hours of annealing, re-embrittlement occurs in some steels, although re-embrittlement is avoided at annealing temperatures of 750° or above.

• The degree of recovery from damage apparently is a function of the irradiation temperature, the total neutron exposure, and the time and temperature of post-irradiation heat treatment.

Unfortunately, it is still not possible to name a "radiation-insensitive" reactor steel, because in general the findings listed above are applicable to all the steels which were tested. Rather, it seems that more questions have been raised which are yet to be answered. But the data obtained to date by scientists at NRL are the basis for safe operating procedures, as regards temperature, radiation level, and pressure, for reactors currently in use. The continuing operation of three Army nuclear plants, previously faced with the possibility of a shortened operating life because of anticipated radiation damage, is a forceful demonstration of this contribution.

*Special experimental equipment in NRL's new High-Level Radiation Laboratory* *(see p. 12)* *is checked out for operational performance. This facility will be used to determine the effects of nuclear radiation on reactor and other structural steels.*

## Pitting Arrested in Navy Boilers

Since the time when ships were converted from sails to steam propulsion, engineers have been plagued with the problem of pitting and corrosion in the steel boiler systems. Just one small pit can cause leakage, resulting in expensive and time-consuming shut-down for repairs. A continuing program of investigating corrosion mechanisms at NRL has at last paid off. Specialists in corrosion research have not only isolated the major causes of pit development but also produced cures on a laboratory scale.

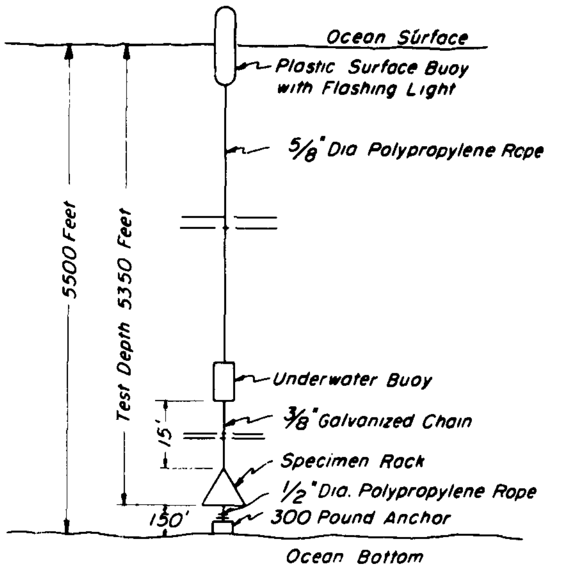
Previous studies on the corrosion behavior of steel under boiler operating conditions showed that corrosion could be controlled by additives to the boiler water which act to generate a protective surface film. Even so, the pitting problem continued.

At the present time, sodium hydroxide and disodium phosphate are the additives used in shipboard boilers to reduce corrosion and scale formation. Recently the NRL investigators determined that the mechanism of pit formation is temperature dependent. Under the high temperature and pressure conditions encountered during boiler operation, excessive concentrations of sodium hydroxide in regions of extreme heat penetrate the protective film and produce a drastic pitting attack. In addition, during shut-down of the boiler, air-saturated water at room temperature is capable of breaking down films that are normally effective at operating temperatures, and again pitting occurs. As these pits develop, the steel reacts with the water to produce a loose deposit of iron oxide. If this material is not removed from the water before operation of the boiler is resumed, it will be transported and concentrated in areas of low water motion, where it may produce hot spots on the boiler wall or interfere with film formation.

Additional experimentation revealed that the use of lithium hydroxide rather than sodium hydroxide will result in a thicker and more stable film which successfully resists breakdown under either condition. If these laboratory results are reproducible in practical operation, a simple method will be available for protecting steam-generating systems from pitting attack.

## Corrosion of Structural Materials Deep in the Ocean

In the development of underwater detection systems, the ultimate aim is to provide components which will survive the corrosive effects




*Schematic of NRL's deep-sea corrosion exposure system.*

of the deep sea and remain operational for periods of several years. Although current investigations are providing data to characterize more exactly the corrosive environment near the ocean bottom, predicting the nature of the corrosion for a given material in this environment is not a simple task. To aid in understanding the corrosion problems and to help solve the materials problem, NRL has initiated a series of evaluation tests by which deep-sea corrosion data are collected for various components placed in service by other groups.

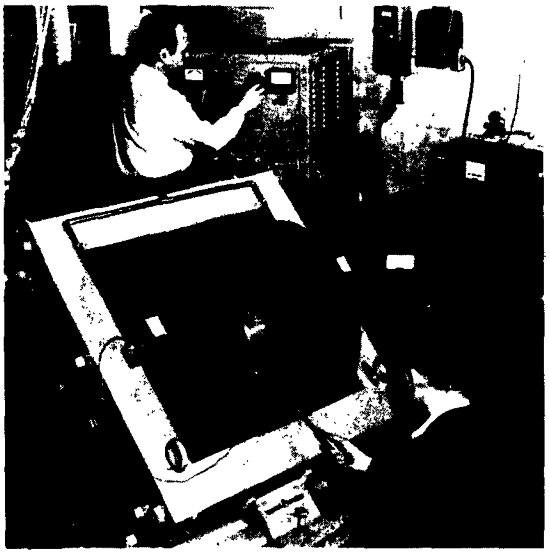
Recent observations of a limited number of structures and components retrieved from the ocean's depths after rather short service periods have verified that severe corrosion can be expected in this environment. In order to provide a more adequate test for a greater variety of materials over a longer period of time, a special deep-sea corrosion-exposure system was designed by which both metallic and nonmetallic samples, fastened through insulating fixtures to an aluminum test rack, can be suspended deep in the sea. In April 1962, duplicate sets of specimens were placed at 940 fathoms in the Tongue of the Ocean. One set was removed in July after nearly four month's exposure, and the rack was returned to the bottom for additional exposure.

Preliminary examinations of this first series of specimens confirmed the earlier observation that corrosion effects at the ocean bottom are at least as severe as those near the ocean surface. All of the structural-steel specimens showed extensive corrosion, and all of the stainless steels showed crevice corrosion. The attack on aluminum alloys was strongly dependent upon the alloy composition. Copper and copper-base alloys were stained and showed some evidence of surface corrosion. Titanium, Inconel, and Monel displayed no outward evidence of corrosion. Cathodic protection of steel specimens by the use of sacrificial anodes was effective at this depth; but the accelerated corrosion of unprotected steel suggests an increase in the current demand, which would shorten the life of the anode.

## Effects of Nuclear Environment on Magnetic Alloys

An engineer faced with the task of designing control equipment for use in a radiation field must first know the effects of nuclear environment on the magnetic materials used. This type of information is also useful to a scientist interested in the mechanisms of irradiation effects and magnetic interactions. At NRL a program is under way which seeks to satisfy both requirements.

One phase of the work consists of determining the effects of nuclear irradiation on the magnetic properties of ferromagnetic alloys,



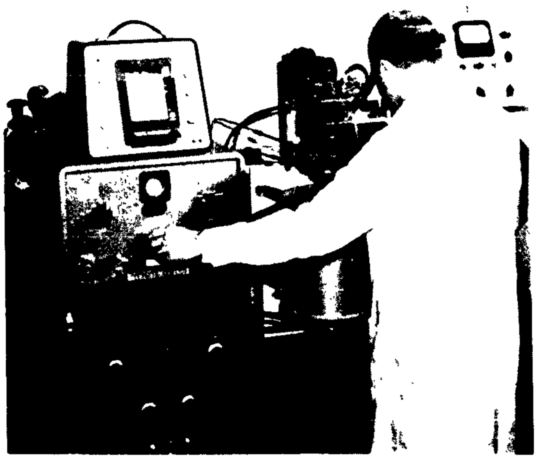
*NRL physicists map magnetic field strengths of a large electromagnet used to study the effects of radiation on magnetic materials and the effects of a magnetic field on electronic properties of metal alloys.*

materials which undoubtedly will play an increasingly important role in nuclear devices. Earlier research at NRL has indicated that alloys which have been given enhanced magnetic properties by thermal and mechanical treatment are most likely to fail when subjected to irradiation. In some materials this tendency to failure is minimized or eliminated if the material is irradiated while in a saturated magnetic state. Indeed, in some cases it is possible to obtain better magnetic properties by this process.

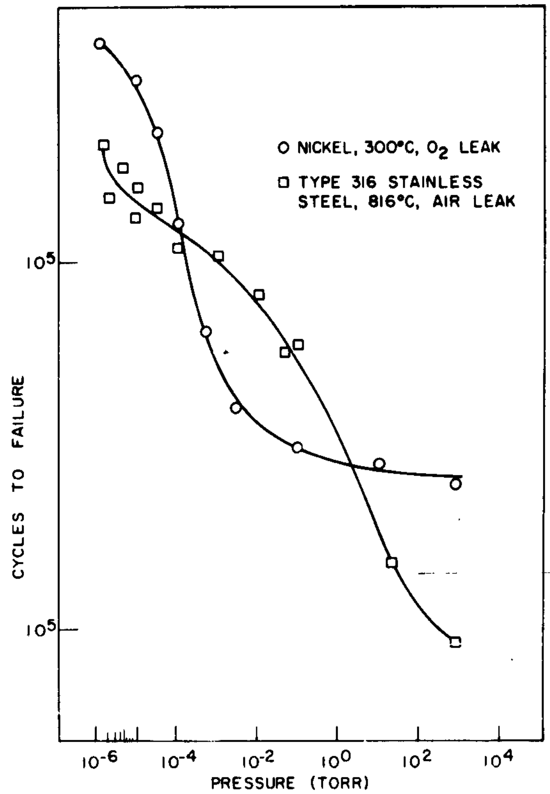
The use of thermal anneals as a means of restoring magnetic properties lost by irradiation at various ambient temperatures is being investigated through a cooperative program with the Oak Ridge National Laboratory. It has been found that no change in magnetic properties results from low-temperature (90°K) irradiation, but significant modifications occur during the warm-up to room temperature and subsequent thermal anneals. This would indicate that isolated irradiation-induced defects, per se, are not responsible for the property changes. The magnetic properties are affected only when the defects are mobile and can diffuse through the crystal lattice. It also has been found that the temperature at which complete recovery occurs depends upon the state of magnetization of the alloy. This would indicate an interaction between defect migration and magnetic structure.

## Effects of Atmospheric Contaminants on Fatigue Strength of Metals

Many propulsion systems now under development for Navy vehicles require that the



*High-temperature vacuum and controlled-environment fatigue tester, used at NRL to study the effects of environment of high-temperature fatigue at high-strain amplitudes.*




*Example of data obtained with NRL's high-temperature, vacuum, and controlled-environment fatigue tester. As the pressure of the oxygen in the environmental chamber is increased, the fatigue strengths of nickel at 300°C and Type 316 stainless steel at 816°C are reduced. Of especial interest is the form of the curve for nickel. At a pressure $3 \times 10^{-3}$ torr the fatigue strength is one-tenth that at a pressure of $1 \times 10^{-6}$ torr. At $10^{-3}$ torr the oxygen concentration in the chamber is equivalent to 4 ppm of oxygen in an inert gas, such as helium.*

metals operate at high temperatures in environments about which little is known. Among them are gas-cooled reactors, whose turbines are driven by jets of helium or other gases. As the jet of gas strikes the turbine blades, it causes each in turn to vibrate, a condition known to scientists as reverse bending. After an extended period of use, the blade suffers fatigue and, of course, eventually fails. Which brings us back to the question of environment. Recent work at NRL indicates that impurities in the gas used as the working fluid may have an important effect on the fatigue life of the metal.

Because there was an inadequate background of research experience useful for determining how these environments will affect the strength of metals, the scientists sought means of duplicating environmental operating conditions in the laboratory. The result is a machine—the only one of its kind—capable of performing reverse-bending fatigue tests in controlled environments at elevated temperatures. A permanent magnet is fastened to a sheet-metal specimen gripped upright inside the environment chamber, which in turn is surrounded by a split-type furnace. Two electromagnets outside the chamber alternately repel the permanent magnet to vibrate the specimen at its resonant frequency. A servo-mechanism control system provides a constant amplitude of vibration, a stable center of vibration, and a means of automatically terminating the test when a crack has formed in the specimen. Pressure is controlled by leaking gases into the vacuum chamber. Data, recorded in the form of graphs showing cycles to failure versus pressure, demonstrate that the fatigue life is reduced by an increase in concentration of reactive gas in the testing environment.

The results are of great importance in understanding the effect of environment on high-temperature strength. They demonstrate that if such experiments are to be meaningful, very precise control and analysis of impurities in the gas should be exercised in future work, since even very small amounts of contaminants may have large effects.

## Oxidation-Resistant Coatings for Niobium

Vehicles that will sustain high-speed flight in the atmosphere, high-speed exit from the atmosphere, or even higher-speed re-entry require metallic construction materials which will retain their strength at very high temperatures. This problem has stimulated an extensive development program at NRL in the class of materials known as refractory metals. While the strength of these metals has been increased considerably by alloying, no similar advance has been made to increase the oxidation resistance to an acceptable level. Admittedly this is an unfair evaluation of the results of these efforts, for any increase in high-temperature strength is a useful achievement. Nevertheless, a tremendous increase in oxidation resistance must be attained before the material can be considered acceptable, and since normal alloy additions have not endowed the metal with this "stainless character," the development of protective coatings has become a most essential part of the refractory metal program. This affords the engineer more latitude in materials selection, provided a new set of complex requirements for the coatings can be met. Obviously, these requirements include durability at the service temperature, efficiency as an oxygen barrier, and ease of application. Since a completely continuous coating is seldom possible to apply and even more difficult to maintain under thermal and mechanical stress, an adequate coating must possess some capability for self-repair at the service temperature.

One such coating, developed at NRL for niobium and niobium-base alloys, was capable of repairing a 3/8-inch wide swath cut through the coating. This coating, a series of niobium-zinc compounds, achieved its unique protection and self-repair capabilities by a novel mechanism called the vapor-phase-transport process. In this process, niobium was selectively oxidized from the compound, and the liberated zinc vaporized, oxidized, and, by accreting on the surface, formed a continuous zinc-oxide layer. The zinc oxide was the oxygen barrier; the niobium-zinc compounds provided a high-temperature reservoir of zinc. When the oxygen barrier was broken in service, zinc vapor poured through the opening, and a plug of zinc oxide formed to repair the damage. The coating has one limitation, however; the maximum temperature at which it is effective is approximately 1800°F.

The NRL scientists then turned their attention to a coating, developed elsewhere for tantalum, which owed its moderate self-repair capability to the presence of a liquid "bridge" in place of the vapor phase. This coating is a tin-aluminum alloy which appears to provide both a modest reservoir of aluminum in solution as well as a path for the movement of aluminum from underlying metal to the overlying aluminum-oxide layer (the oxygen barrier). Such a mechanism offers a possible new route to protective coatings of greater usefulness at higher temperatures than the zinc vapor-transport system.

A variety of these low-melting aluminum alloys have been applied to niobium and its alloys by dipping, by suspending powders in organic vehicles, and by wrapping the substrate in alloy foil. These specimens have been evaluated by exposure at temperatures of 1500°, 2300°, and 2500° and in a few instances at temperatures approaching 2800°F.

The best coating to date is the tin-aluminum alloy, and the best composition appears to be about two-thirds tin. When applied to a pure niobium surface as a suspension in lacquer and given a preliminary bake at 1900°F, the coating is found to be protective for several hundred hours at 2300°F and for more than 100 hours at 2500°F, with one or more rapid cooling cycles to room temperature each day.

Studies of this type of coating are continuing, for the high mobility of the barrier-forming elements in the fluid layer provides a self-repair capability that is not achieved in other types of coating systems.

### Fracture of High-Strength Materials

It is unrealistic to assume that large, complex structures such as the pressure hull of a deep-diving submarine can be made to flawless perfection. Small material and fabrication flaws can slip through the most careful inspection systems, but if the material has been selected on the basis of the NRL criterion (NDT) for critical temperatures, the initial load-carrying ability of the structure will not be impaired. In high-performance structures, however, service loads can cause small innocuous flaws to grow to a size which will eventually lead to failure. Thus, resistance to crack growth becomes a most important material property when maximum performance of a structure is expected for approximately 20,000 duty cycles.

The rate of crack propagation from cyclic loading is one aspect of low-cycle-fatigue studies now being pursued at NRL. The aim is to develop a reliable laboratory test for use in ranking new materials, determining the integrity of structures with the existing flaws, and analyzing the performance of expensive models now used in evaluating structural design.

The experimental setup consists of a rotating-beam machine which accommodates specimens with diameters up to 1-1/2 inches. The propagation of the crack through the specimen is sensed by transducers which follow the drop in the loading beam. Signals from the transducers are either recorded photographically from the oscilloscope or graphically with an oscillograph.

A method for analyzing crack propagation in terms of crack depth, number of load cycles, or nominal stress for either bending loads or direct loads has been developed from the reduction of data for HY-80 steels. For a bending load in a rotating test, the crack rate in these notch-tough materials was found to be directly proportional to crack depth, and an initial nominal stress equal to 50 percent of the yield strength causes complete penetration of the crack in 20,000 cycles. The crack propagates rapidly after it starts moving, and half of the load-bearing life involves the movement of the crack through only 10 to 15 percent of the total section.

Also during the current year, considerable effort has been applied to high-strength steels and titanium alloys in thin sections for such critical applications as rocket motor casings. This involved both evaluation of available commercial materials and studies of the effects of individual material factors, such as composition, on crack toughness. Compared on the basis of equal ratio of yield strength to density, certain titanium alloys and a recently developed class of highly alloyed steels were shown to have markedly better crack toughness than the commoner and cheaper low-alloy steels. Yet the low-alloy steels deserve detailed attention since for economic reasons these will continue to be used in many applications.

The addition of small quantities of vanadium appears to be of prime importance, the beneficial effect on crack toughness being associated with small inherent grain size in the steels. Within a certain range, the major strengthening element, carbon, appears to have little effect on crack toughness at a given yield strength level.

## NUCLEAR AND ATOMIC PHYSICS

### New Linac for Nuclear and Radiation Research

An electron linear accelerator (Linac) is now nearing completion at NRL for use in vital basic and applied research in the rapidly growing fields of nuclear and radiation physics. This accelerator will produce a beam of electrons having an energy adjustable up to 55 million electron volts, with an average electron beam current of 200 microamperes at 40 million volts. Eventually, the Linac will replace the obsolescent 22-million-volt betatron, which was constructed during World War II for radiography of ordnance shells and later converted to an instrument for research in nuclear physics. The Linac will produce an electron beam about 5000 times as intense as that from the betatron.

The basic component of the Linac is a 20-foot length of evacuated tubing in which a traveling microwave field accelerates electrons injected into one end. Irises in the tubing have been used to match the phase velocity of the microwaves precisely to the velocity of the electrons. By riding the crests of the waves, the electrons gain about 3 million volts per foot. The key item which has made this type of accelerator so efficient and practical in recent years is a high-power microwave amplifier klystron similar to those developed for radar.

Because of the Linac's extremely intense beam, a much broader basic research program will be possible. Nuclear structure will be investigated through elastic and inelastic scattering measurements and through electron-induced nuclear reactions. Further, very intense ionization can be produced, in gases or thick solids up to the range of the electrons, for investigations in other fields.

Secondary beams of x-rays, positrons, and neutrons also will be available, with intensities high enough to permit many significant experiments. The x-rays will be used to produce radioactive isotopes for tracer studies. Since these radio-isotopes are usually different than those produced by neutrons in a reactor, the NRL Linac will complement the NRL reactor in providing more complete coverage of radioisotopes.

Nuclear and atomic interactions of positrons will be compared with those of electrons to determine the effects of charge on interactions. It will be possible to produce monoenergetic photons from the annihilation-in-flight of positrons so that the properties of photonuclear reactions can be investigated in much finer detail. The Linac will also provide an intense short pulse of neutrons, which is ideal for the separation of different energy neutrons by means of their time of flight over a fixed range. In many ways, the pulse of radiation from a Linac can simulate in the laboratory the pulse of radiation from a nuclear explosion, thereby providing the means for investigating radiation effects on components and on microwave transmission.

## Production and Storage of Intense Electron Beams

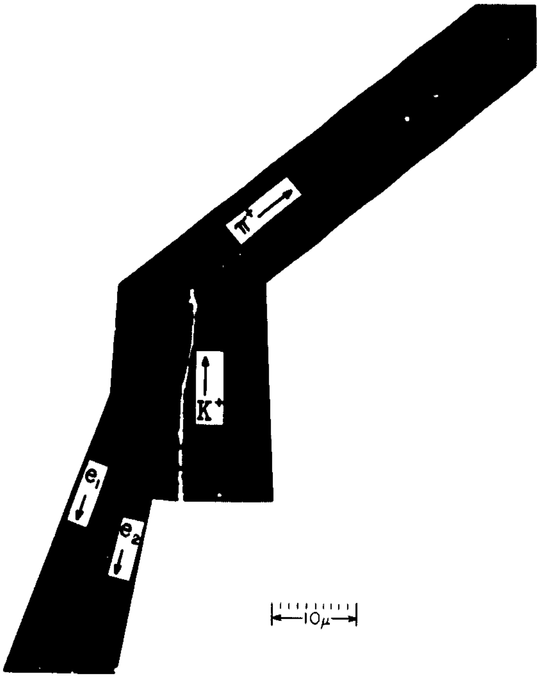
The production and control of intense beams of relativistic electrons could lead to many important applications: strong x-ray sources, high temperatures, strong electric and magnetic fields, microwave power generation, and ultrahigh-energy accelerators. An electron storage ring under construction at NRL is designed to contain very high currents (in the range of hundreds to thousands of amperes) at voltages up to three quarters of a million volts. It will furnish an environment in which intense beams can be studied and therefore will form a bridge between present beam-handling techniques and what will be required for a new generation of particle accelerators containing beams of very much higher current density. A test of the first sixteenth of the ring with a low-energy beam was entirely successful and has spurred efforts toward the completion of the entire ring and tests with a 1000-ampere electron gun.

Electron beams of the contemplated magnitude also represent a new field for theoretical investigation. NRL scientists have recently succeeded in producing for the first time a self-consistent theoretical model of a "sheet" beam which has greatly advanced the understanding of resonant behavior of intense beams. Some of the results have indicated stabilization procedures involving the use of external feedback paths which will be useful in experimental work.

Further fundamental studies of both a theoretical and experimental nature should produce the full potential of intense beams having kilomegawatts of power.

## Mean Lifetime of the Neutral Pion

In 1935, from theoretical considerations of the forces associated with nucleons (the protons and neutrons comprising the nuclei of atoms), H. Yukawa predicted the existence of a new particle. He suggested that the nuclear force between nucleons was due to the virtual emission and absorption of a charged particle of mass about 200 times the electron mass. This particle, the $\pi$ meson or pion, manifesting the strong interaction between nucleons, can thus be described as the quantum associated with the nuclear force field. The $\pi$ meson subsequently was discovered in 1947 during investigations of cosmic radiation by Lattes, Occhialini, and Powell, who used what was then a new particle detector, the photographic nuclear emulsion. At that time they observed only charged $\pi$ mesons and found them to be unstable; they decayed (disintegrated) with a lifetime of the order of $10^{-8}$ seconds. Neutral $\pi$ mesons also were predicted later and subsequently observed in 1950. These neutral pions decay so rapidly, however, that their lifetime has not been measurable until recently.




*Photomicrograph of one of the K-meson disintegrations. The $K^+$ meson comes to rest and decays into a $\pi^+$ and $\pi^0$. The $\pi^0$, although not directly observed, comes off opposite but collinear with the $\pi^+$ and immediately decays—in this case via the "Dalitz mode" $\pi^0 \rightarrow e^+ + e^- + \gamma$. Only the electron-positron pair is observed.*

The average lifetime of the neutral pion can now be measured through the use of improved detection techniques developed at NRL and the Bevatron accelerator in the Lawrence Radiation Laboratory of the University of California at Berkeley. Accelerated to an energy of 6 billion electron volts in the Bevatron, protons were allowed to smash into a metal target. The resulting nuclear particle collisions caused complete breakups of the nuclei, releasing most of the 30 known new elementary particles. From the numerous products released, a beam of one particular type—the positive K meson—was selected by the use of magnets and electrostatic deflectors. These were then brought to rest in a block of about 100 layers of Ilford fine-grained nuclear emulsion.

The nuclear emulsion is basically similar to that used in ordinary photographic film, but about 100 times thicker. The passage of a charged particle through the layer of sensitive emulsion produces images which, when examined under a high-powered microscope after photographic development, are seen as tracks in the emulsion.

After the K mesons stopped, they disintegrated within one-tenth of a billionth of a second. Although there are a variety of ways by which the K mesons break down, only one was of value in measuring the lifetime of the neutral pion. This one way, which occurs 25 percent of the time, happens when the K mesons break down into a charged and a neutral pion. The charged pions leave a track in the emulsion just as the charged K mesons do; but the neutral pions, which were being studied, did not leave any track, their existence being known from other scientific evidence.

The neutral pions, which also are unstable and decay rapidly, break down in two ways. The most common, which results in two gamma rays (particles of high-energy electromagnetic radiation which are neutral and don't leave tracks in the emulsion), could not be used. The second way, which occurs one time in 80, provided the means by which the life span of the neutral pion was measured. In this case, the neutral pion breaks down into one gamma ray and a pair of electrons, one positive and one negative, the latter leaving visible tracks. By measuring the distance between the end of the K meson track and the point where the electron tracks started, it was possible to determine where the neutral pion began and where it broke down. It is known that the pion from the K meson decay moves at a velocity of 80 percent the velocity of light. From the measured distance, which was three millionths of an inch, and the velocity of the neutral pion, it was possible to obtain the time it took the particle to decay in each of the 77 cases observed. The average lifespan of the neutral pion was found to be $(1.9 \pm 0.6) \times 10^{-16}$ sec. This is a million times shorter than that of any other directly measured elementary particle lifetime.

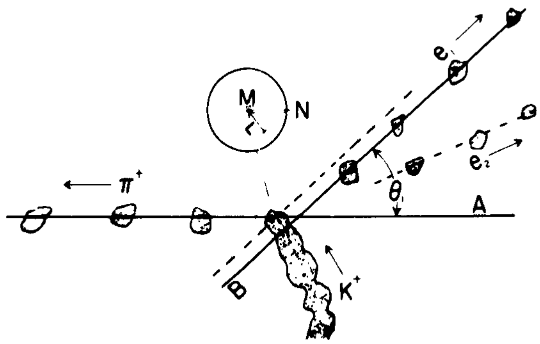



*Illustration of the NRL measurement technique. MN is the $\pi^0$ flight distance projected on the plane of the emulsion. Its value is obtained by a measurement of L and θ.*

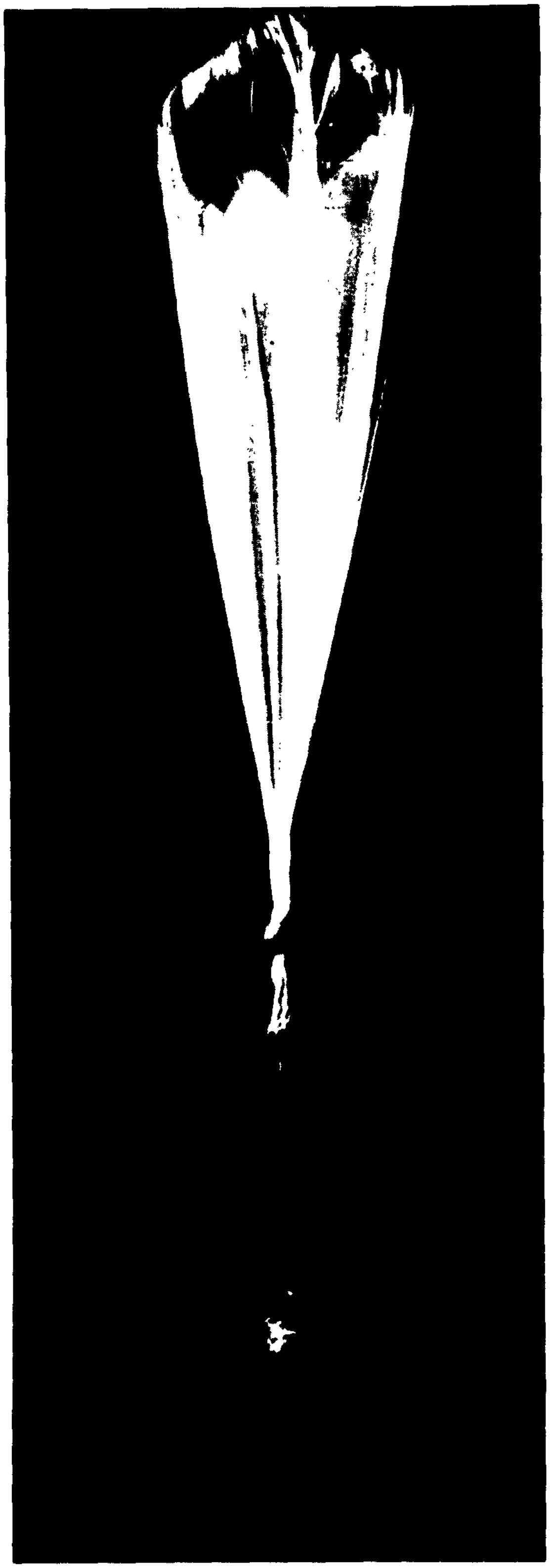
A product of basic research, the determination of this universal constant is expected to help in providing a better understanding of the forces holding together the nuclei of atoms. The charged and neutral pions appear to act as a nuclear glue, holding nuclei together in a manner still not fully understood by science.

## Lithium, Beryllium, and Boron in the Primary Cosmic Radiation

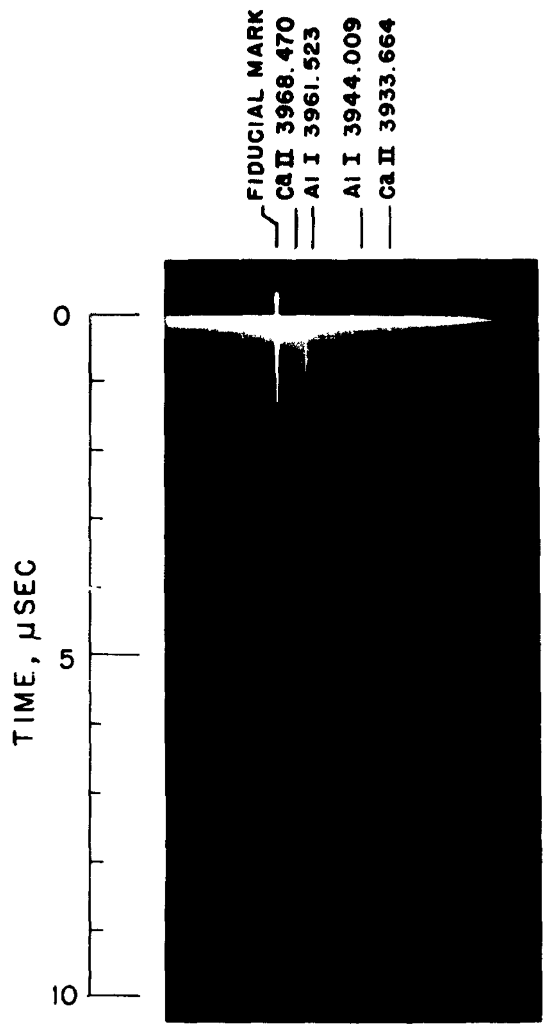
The "universal" abundance of the light elements lithium, beryllium, and boron is known to be exceedingly low—about one atom to a billion hydrogen atoms. For a decade controversy has raged over whether or not the primary cosmic radiation contains a significant fraction of these light elements. This question has an important bearing on the "age" of the cosmic radiation and on its propagation through interstellar space. The incidence of heavier cosmic-ray nuclei, ranging from carbon to iron, at the top of the atmosphere has been well established. For the lithium-boron group, various investigators have reported conflicting intensities, all the way from zero to fluxes approaching those of the heavier atoms. A major difficulty has been the separation of secondary light nuclei, generated as collision products in the upper atmosphere, from the true primaries.

Scientists at the U. S. Naval Research Laboratory, in a high-altitude balloon flight (136,000 feet for seven hours), exposed a stack of photographic emulsion and obtained a reliable answer to the lithium-boron problem. This was made possible by the very small residual atmosphere above the detector and by the use of several independent methods of identifying the incident nuclei. It was found that the ratio of the light elements to all heavier ones in the primary cosmic radiation is nearly 20 percent. Thus the relative cosmic-ray abundance of the light elements exceeds their relative "universal" abundance by several orders of magnitude.

These light cosmic-ray nuclei probably originate in the fragmentation of heavier ones by collision with interstellar hydrogen. The observed ratio indicates that the primary radiation and its progeny travel several million light years before reaching the earth. This does not imply that the cosmic-ray sources are as far away as this, for the magnetic fields of the galaxy bend the paths of the particles into very tortuous orbits.



*Skyhook balloon used to carry aloft large stacks of photographic emulsions for cosmic-ray investigations.*




*Time-resolved spectrogram of an exploding aluminum wire 1 mil in diameter. The calcium lines are due to a residue of chalk-dusting.*

## Production of X-Rays by Exploding Wires

When electrical energy is deposited at a very high rate into a fine hollow wire, the wire reaches a very high temperature and literally explodes. Small-scale electrical explosions of this type are being used at NRL in the study of mechanical, optical, and x-ray effects of matter at extremely high temperatures (plasmas). The experiments are providing a more exact knowledge of high-temperature phenomena, particularly the density and temperatures of electrons and the density of neutral and ionized atoms.

Large amounts of energy are stored in special, low-inductance capacitors and then discharged rapidly into the wire. Peak power at the time of explosion is $10^{11}$ watts, which is equivalent to all the electrical power being used in the United States at any one time. At the time of explosion pulses of soft x-rays are generated. Photographs of the x-ray emission are captured by means of a pin-hole camera in which thin beryllium foil is used to filter out visible light from the explosion. The most probable explanation for the origin of the x-rays is that they are produced by free electrons in the plasma which are accelerated by the electric field and interact with nuclei in their paths.

The electron temperature of an aluminum wire exploded by these techniques has been determined from the x-ray pulse produced during the explosion and found to be about 12,000,000°K. The x-ray pulse appears to be emitted near the time of maximum power (about 25 billionths of a second after initiation of the explosion) and lasts for only about eight billionths of a second.

With presently existing instrumentation, it is not possible to make a time-resolved study of the radiation from an exploding conductor during the short period of time that the x-rays are being generated; but time histories of the visible light following the explosions have been made with a special spectrograph, the N9GS, built at NRL. Temperatures and densities can be deducted by a comparison of the adjacent spectral lines on the spectrogram. For an aluminum wire, a continuum emission was seen to persist for only a fraction of a millionth of a second after initiation of the explosion, followed by a line emission which persisted for as long as 14 millionths of a second. The plasma temperature at a time of one millionth of a second after the explosion was initiated was 50,000 K.

*Pin-hole camera image of the x-ray emission from an exploding hollow aluminum cylinder.*

## NRL Research Reactor

In 1961 the power of the NRL research reactor was increased from 100 to 1000 kw. Since that time the reactor has been operated at the maximum power for schedules varying from 40 to 80 hours per week.

Excellent utilization of the beam port facilities has continued. Five are now in use. Three have accommodated neutron diffraction apparatus: a powder diffraction spectrometer for investigating the magnetic and crystallographic structure of polycrystalline samples; a single-crystal spectrometer for similar studies on single-crystal specimens; and a third for producing polarized neutrons for studies of their interaction with matter. The two other ports have been used to determine the spin states of compound nuclei formed in resonance neutron interactions with materials.

Many shorter irradiations continue for radioisotope production or for radiation damage studies. During the past year, irradiations have been performed for neutron activation analysis, and studies have been made on fission products, the excited states of short-lived nuclei, chemical synthesis from fission fragment energy, thermoelectric power, dynamic response of crystal accelerometers, and irradiation damage in thin ferromagnetic films.

The Laboratory has continued its policy of cooperation with other government agencies desiring to utilize the reactor. Irradiation services have been performed on many items of medical interest, as well as those of engineering and physics. The Army Chemical Warfare Nuclear Defense Laboratory, the Food and Drug Administration, the National Bureau of Standards, and the National Institutes of Health are among those who have used the reactor during the past year.

## Monitor for Fuel-Element Rupture

The first indication of fuel-element rupture in a nuclear power plant is the presence of fission products in the primary coolant water. Heretofore, these fission products could be detected only after a sample of the coolant water had been subjected to time-consuming chemical processing.

*Beam port area of the NRL research reactor.*

NRL scientist have developed an instrument which will detect immediately a fuel-element rupture in water-cooled reactors. A prototype of the instrument has performed effectively in tests at operating nuclear power installations.

The NRL technique has the advantage over other system in that the coolant sample itself serves as the signal-generating medium. The principle of operation is based on the Cerenkov radiation produced when fast charged particles are slowed down in water. A sample of the primary coolant is exposed to a photomultiplier tube which generates light pulses that are proportional to the energy of the electron. The presence of fission products in the cooling water will be indicated by comparatively large light pulses produced by a few fission products which emit higher-energy beta rays. A relatively simple amplitude discrimination of the signals makes it possible to register only the pulses corresponding to beta radiation from the selected fission products and thereby detect fuel-element rupture. The pulses produced from the radioisotopes normally present in the cooling water are sufficiently small in amplitude so as not to trigger the discriminator.

Laboratory calibration has shown that the selected fission product isotopes can be detected in concentrations of the order of $10^{-5}$ microcuries per cubic centimeter of coolant water. This is sufficiently sensitive to indicate any significant fuel-element failure. Further, since the detector responds only to high-energy charged particles, the instrument is relatively insensitive to gamma rays, whose interactions with the water produce mainly low-energy electrons. This property allows operation in areas of high-background gamma radiation.

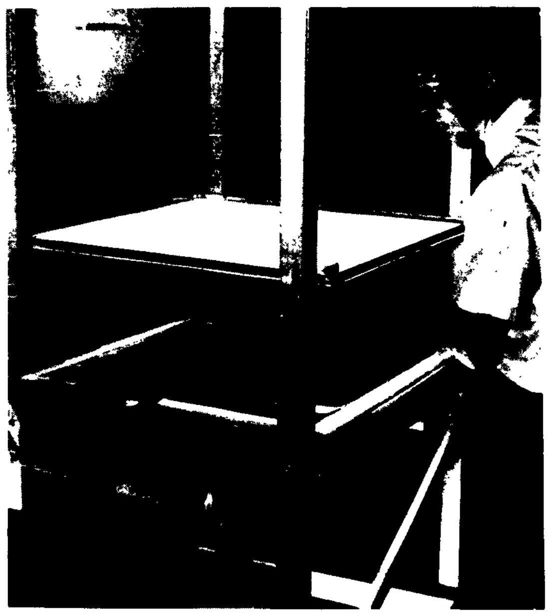
# OCEANOLOGY

## Damping of Capillary Ocean Waves by Surface-Active Materials

For centuries mariners have observed surface areas of bays, harbors, and the open ocean in which the capillary wave structure has been diminished or damped. It has long been known that these surface scars, called sea slicks, could be artifically produced by pouring fish oils or oxidized petroleum oils onto the water. These slicks also occur in areas of the ocean which are free from the byproducts of civilization, indicating that they may also be caused by residues of marine life. Until recently little was known about the chemical nature of the materials which cause this wave-damping phenomenon, and there has been no clear understanding of the mechanism by which the slicks cause wave damping.

In order to study quantitatively the damping of capillary water waves by thin oily films, a laboratory system originally developed at NRL was constructed to generate small circular waves of various amplitudes and frequencies. The waves were observed stroboscopically; their lengths and amplitudes being measured by a simple optical technique. The tray which contained the water was fitted with movable surface barriers and a surface tensiometer so that the effect of compaction of the monomolecular layers could be studied. The damping effects due to natural oceanic materials and to pure surface-active compounds have been studied in their relation to film structure and chemical composition.

It was found that practically the entire wave damping is caused by polar surface-active materials which (1) spread spontaneously into monomolecular layers on the water surface or (2) are adsorbed from solution onto the surface. Almost the entire wave-damping effect occurs at film pressures of a fraction of a dyne per centimeter, or a few dynes at most. Consequently, much less than a condensed monolayer,



*An NRL scientist examines a wave pattern produced in the laboratory for studying damping of water waves.*

or as little as 0.8 milligrams per square meter of certain monolayer-forming materials on sea water, is sufficient to reduce wave heights drastically. Further compression of the monolayer results in a slight additional damping; but, surprisingly, the major effect is produced at very low film pressures. It is concluded that the principal cause of wave damping by an organic film is the drag of the underlying water associated with the film molecules through hydrogen bonding.

## Radiation Chemistry and Oceanography

In an effort to reach a better understanding of radiation-induced chemical reactions, scientists at NRL are studying the radiation chemistry of dilute aqueous solutions. They have developed a special technique of analysis by which gas chromatography has been used to measure yields of molecular hydrogen as a function of pH and solute concentration. The results obtained should help in resolving the current controversy as to the hydrogen yields in irradiated acid solutions.

An unexpected outgrowth of the NRL technique is its application to chemical oceanography. During two recent oceanographic cruises (off the coast of Southeast Asia and in the Arctic), NRL scientists, in cooperation with personnel from the U. S. Navy Oceanographic Office, employed the technique for the first time in the routine determination of dissolved oxygen and nitrogen in sea water. Heretofore, the Winkler chemical method could be used aboard ship to determine dissolved oxygen; but the manometric techniques used for determining dissolved nitrogen were extremely difficult to carry out because of the motion of the ship, so that hundreds of samples of sea water had to be stored in tightly stoppered containers until the analysis could be carried out at a shore-based laboratory. The essential feature of the NRL method is a special sample chamber in which the gases are stripped from solution by an inert carrier gas which then carries them directly into the gas chromatograph for analysis.

The NRL work definitely established the feasibility of gas chromatography for routine shipboard determination of dissolved gases in sea water. Less time is consumed, sample size is reduced (2 milliliters, as compared with several hundred milliliters for other methods), there is no loss in either precision or sensitivity, and the instrumentation is relatively simple. In addition, the method is largely automatic, and the recorded results can be analyzed at some later and more convenient time.

In another study, NRL scientists investigated the radiation chemistry of alkaline solutions, which thus far has received comparatively little attention. An examination of the behavior of irradiated hypobromite solutions at high pH has resulted in what is believed to be the first reported determination of the yields of the radiolysis products of water in the pH range 12 to 14. Comparison with the currently accepted values for yields in neutral solution shows that there are no large changes in the alkaline range. The reproducibility of the results and the simplicity of preparation and analysis qualifies this system as an excellent chemical dosimeter.

*A sample of ocean water is analyzed by means of gas-chromatography techniques developed at NRL. The results (on the recording at right) indicates the amount of dissolved oxygen and nitrogen in the water.*

## Surface Oceanography

A basic understanding of the surface of the ocean is being achieved through an interdisciplinary approach involving studies of the physics, chemistry, and biology of the surface water. Usually, oceanographic samplings are made at around one-meter depths, by means of plankton-net towing methods. A radically new surface-sampling technique has been developed at NRL by which sampling buoys are dropped by parachute from aircraft or weather balloons and controlled by radio signals or timing devices. Emphasis is placed on obtaining samples of near-surface water before the intrusion of surface ships which disturb the environment.

Thus far the first few centimeters of the surface water have been investigated. Several interesting phenomena have been observed concerning surface particulate matter and pigments. These studies of sea samples are parallel with other Laboratory studies of the air-sea boundary and its physics, chemistry, and biology. A biophysics facility has now been established at the Chesapeake Bay Annex, where additional studies can be made under controlled conditions. Plans are underway for a "pilot-plant" ocean in which the environment will be regulated by the investigators in the laboratory rather than vary with the whims of nature. This will permit isolation of the agents responsible for observed changes, since the parameters of a controlled environment are known.

### Deep-Ocean Environmental Sampler

Ordinarily, samples of sea water or sediment taken at any ocean depth are decompressed to atmospheric pressure as they are withdrawn to the surface. Marine scientists have long desired to bring such samples to the surface at the same temperature and pressure at which they were captured, in order to study the physical and chemical properties of deep ocean layers exactly as they exist in their own environment.

The Naval Research Laboratory has now built a water sampler capable of retrieving a sample of water at the pressure at which it was taken. Transfer equipment also allows the sample to be transferred to another vessel without any loss of pressure. The sampler is in the form of a cylinder, 1-5/8 inches in diameter and approximately 9 feet long. The sampler has two chambers interconnected by flow control mechanism. The volume of the lower chamber, in which the sample is taken, is 41.6 cubic inches; that of the upper chamber is 57.5 cubic inches.

Before a sample is taken, the lower chamber is filled with water and brought to a pressure at which the sample will be taken; the upper chamber is air-filled at atmospheric pressure. The sampler is then lowered into the ocean to the desired depth. An electrically controlled explosive charge clears a passageway between chambers, allowing the prepressured water to escape into the upper chamber. The ambient pressure of the sea, acting on a floating piston in the lower chamber, forces the prepressurized water into the upper chamber. Near the end of its travel, the piston bears onto a tripping rod, which closes the sample inlet passages, thereby capturing a sample of sea water which had been forced into the lower chamber.

This equipment has been used successfully at sea to obtain high-pressure samples at various depths. Accessory equipment is being built which will allow microscopic examination of the water sample. Information which can be obtained with this new oceanographic tool includes, among other things, analysis of the dissolved gas and gases in the form of bubbles at different layers in the ocean and the observations of deep-ocean forms of life which are incapable of withstanding decompression.

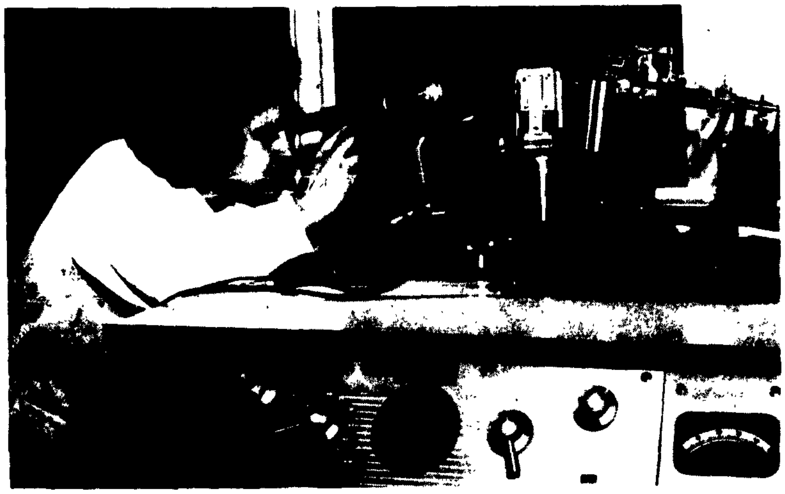
The problem of bringing a high-pressure sample of sea water to the surface without a change in temperature remains to be solved.

## OPTICS

### Determining the Properties of Materials

The fundamental structure of any material, that is, the arrangement of the atoms which compose it, determines its physical and chemical properties, such as hardness, stability, corrosion resistance, and chemical reactivity. In all fields of science, investigators depend upon this basic structural knowledge for the pursuit of their respective research projects and for the interpretation and understanding of their results. The key to determining the atomic arrangements by x-ray methods lies in the solution of the phase problem, that is, finding the phases of the x-ray waves scattered from the various planes of the material whose structure is being studied. Determining these phases is equivalent to solving the unknown structure because from them a three-dimensional diagram of the atoms may be readily computed.

About ten years ago scientists at NRL demonstrated that a solution to this problem existed; since then much effort has been extended toward formulating a solution in a convenient and reliable form, not only here but at other laboratories around the world. Eventually the NRL scientists developed formulations which were successfully applied to elucidate the structure of a variety of complicated materials. These materials are of interest in many different scientific fields, including mineralogy, biochemistry, and organic chemistry. Now, within the past few months, NRL scientists have



*Orientation of a crystal in an x-ray diffraction camera.*

developed new theories and procedures which exceed any previous method in simplicity, ease of application, and reliability and which constitute a major improvement over earlier schemes. For example, in hexaglycyl, a compound which forms part of the proteins of living tissues, two hundred atoms had to be located. Normally this would be a job of several years' duration, if it could be done at all; the NRL scientists were able to solve it in three weeks, even though much of the calculation was performed by hand rather than by high-speed computing machines. Incidentally, this is one of many structures which other investigators had tried but failed to solve by other methods of crystal structure determination. The structure investigation of another moderately complex organic molecule was completed within a week's time.

Another tool for structure investigation is electron diffraction. Recently a new application of this technique in connection with the study of excited molecules (highly reactive molecules with high energy) was developed at NRL. Within the past year the theory for the interpretation of the diffraction diagrams has been completely worked out. Both the theoretical and experimental results have revealed that previous concepts on this subject have been replete with misconceptions. The new information has widespread applications that cover such fields as tumor radiation therapy and the refining of gasoline, since in each case excited atoms and molecules are involved.

## Light Transmission Through Water

The study of hydro-optics has long been of interest to scientists at the Naval Research Laboratory. They have investigated the various properties of water that affect light as it is being transmitted, not only in an effort to increase our fundamental knowledge of the water world, but also because light and vision are so important in naval operations. The results have yielded basic data on the scattering and absorption of distilled and natural waters over the wavelength range from the ultraviolet through the near infrared. The results show that even in the blue-green region of relatively high transmission the attenuation of water is very severe.

Recently, some proponents of the use of laser sources in underwater applications suggested that there might possibly be very narrow wavelength "windows" in ocean water through which monochromatic laser light would travel more readily than at other nearby wavelengths. NRL work in 1961 revealed that within the experimental limits there were no indications of such windows in distilled water; the same results were found for sea water in 1962. Thus it appears that users of laser sources cannot depend on the existence of such favorable selective windows in the spectral region of 4000A to 7000A. The only detectable transmission maximum is the well-known blue-green maximum, which covers a relatively broad spectral region.

Through the years, NRL scientists have uncovered a wealth of data on hydro-optics, produced by other investigators, but the information is duplicated, unorganized, and difficult to correlate. They felt that such data were useful, but only if properly classified and cataloged. Accordingly, in 1961 the Laboratory published NRL Bibliography No. 20, "Transmission of Light in Water." Included are over 650 entries from more than 400 authors throughout the world whose works have been reported in over 150 periodicals during a period of 141 years (1818-1959). Most of the entries are annotated. Because its widespread interest to Naval personnel, biologists, oceanographers, ASW scientists, and others has created a demand beyond the original issue of 500 copies, the bibliography is now in its second printing.

Entries from the United States are more evident only in recent years, indicating the accelerated interest of this country in maritime and Naval affairs. Nevertheless, references collected by two NRL pioneers in the field, Hulburt and Dawson, during their early fundamental work on the optics of lake waters and pure distilled water, were of sufficient number to form the nucleus of the bibliography.

## Ships' Navigational Lights

Under International Rules all public and private seagoing vessels must display lights regulated in respect to number, position, range, color, and arc of visibility. At present masthead, range, and towing lights consist of an incandescent lamp in a clear glass Fresnel lens. These lights must be visible for at least five miles on a dark night with a clear atmosphere. Regulation side lights are mounted in deep red (port) and deep green (starboard) Fresnel lenses. Their minimum visibility range must be two miles.

The Navy's desire to increase the visible range of these navigational lights is understandable; and the immediate answer seems to be simple—increase the wattage. For the lights with white lenses, increased wattage would undoubtedly result in increased visibility, but white lights that are too bright will "outshine" the colored lights in an array, rendering them invisible to the human eye. Visibility of the colored lights can be increased by additional wattage or by the use of lighter-colored lenses, but either method would tend to desaturate or whiten the colored lights, resulting in less efficient color definition. Further, the Navy would like to replace the Fresnel lens, which is large, heavy, and expensive, with one of lighter material and smaller design, provided the same or an extended range of visibility could be obtained without sacrificing color identification.

Because of their wide experience in studies of light transmission and measurement, scientists at NRL were asked by the Bureau of Ships to investigate methods for improving the physical characteristics of maritime navigational lights and increasing their range of visibility within the range of positive color identification.

Six navigational lights were used in the study—one each of red, green, and white with Fresnel lenses, and one each of the same with plain glass globes. Complete photometric studies were made in the laboratory on all six in regard to their chromaticity and luminous intensity.

Visibility observations were then made in the field for correlation with the laboratory findings. The lights were arranged in a simulated navigational array at one end of the Navy's railroad track at Malcolm, Maryland. In one array the lights were all of the Fresnel lens type; in the other the light bulbs were encased

*A monochromator is used to measure the spectral energy distribution of a ship's white navigational light.*

in plain glass envelopes. Both arrays were operated at two intensity levels, as they are used on shipboard, bright and dim. When viewed head on by the observers traveling down the railroad track, the lights were so arrayed that they appeared as an oncoming ship at a distance.

The relationship between the laboratory data and observations in the field will now make it possible to predict the service performance of a given light source from laboratory measurements. One finding of interest is that the range of visibility of the Fresnel array was not significantly greater than that of plain glass.

## Improvements in Quantitative X-Ray Spectrochemical Analysis

The most difficult problem in quantitative spectrochemical analysis has always been the one of relating x-ray intensity to percent composition. This has led to a demand for increasing numbers of reference standards, that is, materials used as a reference, for which the composition is known; but preparation and measurement of such standards is expensive and time consuming. In 1962, NRL scientists have been substituting mathematical calculations for experimental measurements of reference standards. The results indicate a possibility of coupling x-ray spectrometers to a very simple computer for automatic direct calculation of quantitative chemical composition. One surprising bonus in the mathematical approach was the prediction of unusual specimen conditions in which an increase in chemical composition could lead to a decrease rather than an increase in x-ray intensity. This is contrary to all intuition but, once predicted, has now actually been observed in a mineral system. It may also be suspected in other practical applications, but without the mathematical predictions such data would most likely be disregarded as unrealistic.

During the past year new knowledge has been obtained on the properties of analyzer crystals for x-ray spectrometers. Careful measurements have revealed that, in alkali halides, the diffraction properties are permanently altered throughout the crystal by surface abrasion. In other types of crystals, such as calcite or quartz, only the surface properties are altered, and the original diffraction properties may be restored by etching to remove the worked surface material. These considerations are of practical as well as theoretical importance, especially for electron probe microanalysis, because doubling the crystal efficiency reduces the power requirement proportionately.

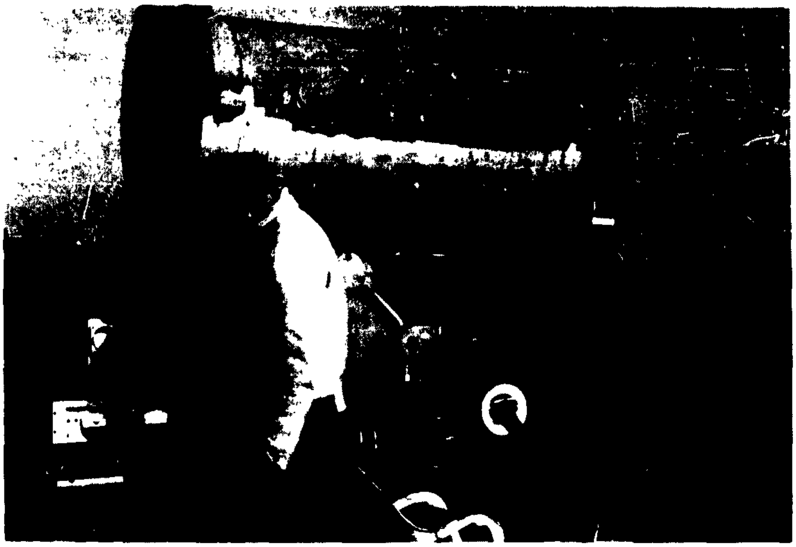
## Light Transmission Through the Atmosphere

Transmission of light through the atmosphere is dependent on scattering, absorption, and refraction. These properties have long been of interest in military applications, especially in relation to visibility, optical communications, and target detection; they have been studied at NRL since the science of physical optics became a part of the research program years ago. The early studies of E. O. Hulburt in this area had significant applications in Navy problems. For example, the present official ship-camouflage technique was established at NRL on the basis of the local work on atmospheric optics.

A few years ago, work in this area resulted in an atlas of the atmospheric absorption spectrum which shows the detailed high-resolution absorption structure characteristic of molecular absorption. This knowledge is now used widely by scientists, both at NRL and elsewhere, as a reference in determining the amount of light received from any source. For example, by comparing the complicated spectrum recorded from an atomic explosion with that of the absorption spectrum of the atmosphere, scientists are able to determine exactly what part of the structure is due to the explosion alone after the absorption in the atmosphere has been taken into account.

These high-resolution spectral studies eventually led to the very recent development of a simple, portable, photoelectric photometer by which the NRL scientist can now determine the distance which light has traveled through the atmosphere. The oxygen concentration in the atmosphere is essentially constant and known, so that a measurement of oxygen thickness in an optical path may be converted to a measurement of physical distance in the atmosphere. Oxygen thickness is measured by determining transmission in an absorption band of the gas. Spectral isolation is provided by a narrow-band interference filter which may be tilted to obtain in-band, out-of-band readings whose ratio is a measure of band transmission.

The data provides a working curve of signal ratio vs distance. Data obtained from the sun and from an incandescent lamp overlap and agree, thus establishing the expected result that



*A scientist measures the amount of light scattered back by the air from a searchlight beam. The amount of back-scatter is related to the visibility of the day and can be correlated with transmission of the atmosphere.*

the system is essentially independent of detector sensitivity and source characteristics. Further, once a working curve has been established no calibration of either detector or source is required, which means that the photometer can be set up immediately to obtain distances rapidly. The accuracy of this determination is under study.

The potential uses of this technique include passive optical ranging on uncalibrated light sources with uncalibrated detectors, and the determining of horizontal attenuation in any direction by a single-ended observation.

Other studies of light transmission in the lower atmosphere are concerned with the propagation of light by scattering and have included photographing a slightly elevated searchlight beam, from an aircraft and from the ground, in an attempt to compute irradiance at points in and out of the beam. These calculations show that at 35 kilometers from the source the irradiance on the beam axis is about 225 times that at a point 115 meters directly above the upper edge of the beam and 550 times that on the ground directly below. Since the irradiance on the ground is the light transmitted over the visible horizon, a strong light source is indicated for any effective transmission of light over the horizon. The studies also revealed that one watt in a directed beam (a typical search light, for instance) is about 75 times more effective in over-the-horizon light transmission than one watt radiated by a nondirective source, such as a bare lamp. The objective of these and similar studies is to evaluate the possibility of extended-range signaling by means of scattered rather than direct light.

## Long-Range Light Transmission with a Laser

As everyone knows, a light held a few feet above open water on a clear night can be seen only a mile or two away by a person also near the water—say in a small boat—owing to the curvature of the earth. But a group of NRL physicists, carrying out a series of optical experiments on Chesapeake Bay, recently succeeded in detecting a beam of light over a distance of 45 kilometers—about 28 miles. At the time, furthermore, a slight haze limited natural visibility to less than 10 kilometers. Both the light source (on Tilghman Island) and receiver (at Patuxent NAS) were only 6 feet above the water.

The mechanism by which the light was propagated over so long a range involves forward scattering from atmospheric haze particles. The light source was a ruby laser, a new light source which produces extremely monochromatic light in a remarkedly narrow, pencil-like beam with a spread of only 45 minutes of arc. The beam was trained at the distant receiver at an elevation of 1 degree. The detector, which had a receiving field of view of 2 degrees and was also elevated 1 degree, received the light not directly, but reflected from the atmosphere. Although the light is drastically attenuated in this way, such is the intensity of the laser's concentrated beam, and the sensitivity of the pick up, that reception of signals could presumably be extended to several hundred kilometers on a clear night.

These experiments, carried out with a laser of comparatively low energy, were exploratory, done in connection with a general study of the optics of the atmosphere. More sophisticated devices could extend the range much further and could presumably permit transmissions in daylight as well as in darkness. The latter presumption depends upon the development of narrow filters that will reject all of the solar radiation except in the region of the laser's emission.

# RADIO

## Millimeter Wave Research

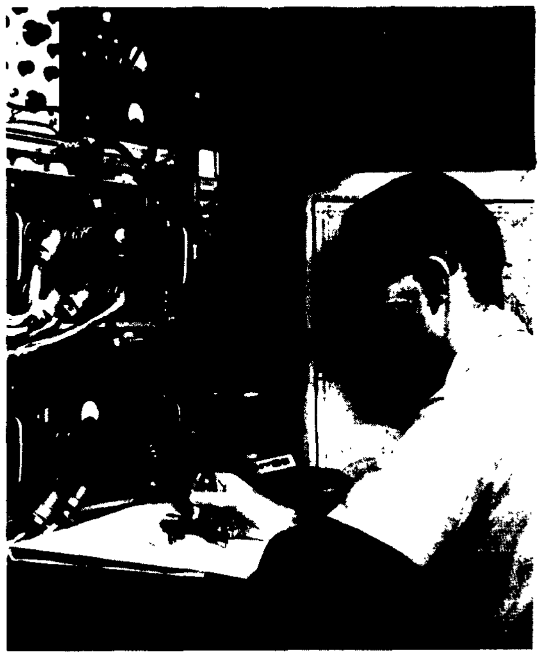
One of the most challenging facets of radio research is the problem of generating appreciable coherent power in the millimeter and submillimeter wavelength regions of the radio spectrum. The mechanical tasks involved are extremely exacting, because it is generally true that the shorter the wavelength the smaller the hardware; the skills required are approached—and approached only—by a master watchmaker working under a microscope. In addition to extreme precision, there are many other problems associated with thermionic emission, electron interaction with electromagnetic fields, electron optics and electron gun design, photoetching and electroplating, and heat-flow. But the pay-off for successful development would be higher-resolution radars with smaller antennas, more accurate miniaturized navigation and fire control systems, new communication systems, and valuable assists to basic studies in spectroscopy and plasma physics.

An approach to millimeter wave generation being pursued at NRL has been to devise an oscillator in which the simplest and largest resonant cavity suitable for a given wavelength is used in order to avoid the almost impossible task of making extremely small parts. A pencil-type electron beam passes through this cavity, causing electromagnetic field disturbances to reflect back and forth in the cavity. When the electron beam has the proper intensity and velocity to cause reinforcement of this disturbance, then oscillations can occur. The theory of this type of interaction has been worked out for all different cavity sizes and modes, and optimum geometry and beam velocity for best efficiency have been predicted.

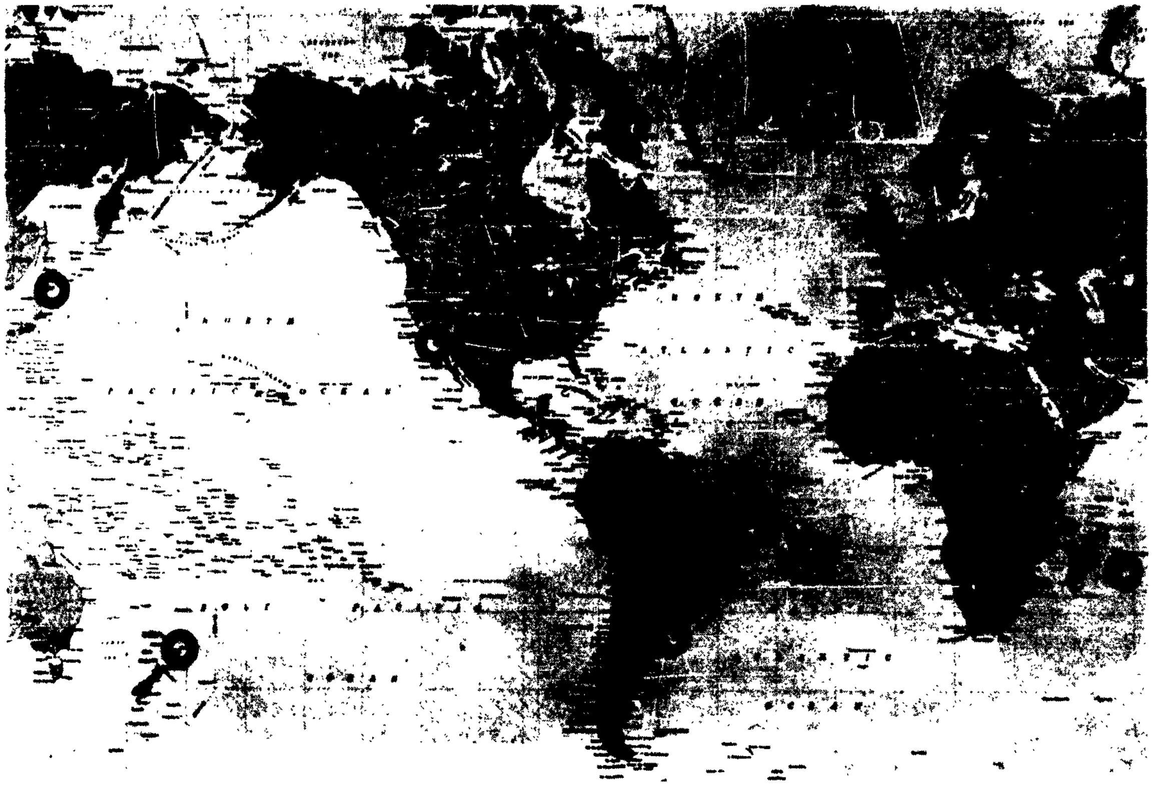
Tubes of this type have been built which produce a few watts of r-f power at 30-mm and 8-mm wavelengths. Performance has been in good agreement with theory. Tubes are being tested as 5 mm with the hope of eventually making a tube operate at 1-mm wavelength with considerable output power. The chief difficulty at present with the 1-mm tube is obtaining the required 1-ampere electron beam having the small diameter of 0.004 inch.

## Omega Radio-Navigation System

The Navy now has a radio-navigation system which will provide world-wide coverage with only six to eight transmitters. Development of the system, called Omega, is the result of over 10 years' work by both NRL and the U. S. Navy Electronics Laboratory, at San Diego, California. Studies by NRL have shown that each Omega transmitting station has a range of more than 7000 nautical miles and that position determinations with an accuracy of one mile or less can be obtained anywhere on the earth by ships, aircraft, and submerged submarines. Three Omega system transmitters—located in Hawaii, the Canal Zone, and northern New York—are now operating on an experimental basis.



*Experimental Omega receiver, housed in the two cabinet spaces immediately above the navigator's shelf of NRL's WV-2 Flying Laboratory. In long-range flights in the northern and southern hemispheres the receiver has shown that the Omega system provides accurate navigation information for aircraft. Future Omega receivers will be similar to this first experimental model, except smaller.*



*Possible locations of six transmitters for the Omega radio-navigation system.*

Eventually there will be six to eight transmitters spaced 5000 to 6000 nautical miles apart.

NRL has developed the Omega receivers, which will become standard equipment for ships, aircraft, and submerged submarines. These will be small models, weighing less than 50 pounds and occupying only about one cubic foot of space. NRL also has the responsibility for determining the range and accuracy of the system in various parts of the world, as well as the propagation characteristic of the radio-frequency transmissions at 10.2 kc.

The Navy Electronic Laboratory developed and installed the three transmitters. There is no need for the extremely high power now used at very-low-frequency radio communication stations. Omega is a very-narrow-band system, whereas communication systems need to be broad-band in order to accept and reproduce communications information. About 5 kw of power will be satisfactory for the Omega transmitters; up to 2000 kw are radiated from existing communication stations.

The absolute accuracy of Omega is primarily determined by the stable propagation of the radio waves. Variations in the propagation may cause errors in position determinations of about one mile, but these variations will be nearly the same over any area of several thousand square miles. This means that the system has a relative accuracy or repeatability much greater than the absolute accuracy. Recent determinations have shown that the relative accuracy is about 200 yards, so ships (or ships and aircraft) can rendezvous accurately by use of Omega, and ships in a task force can hold station with high precision.

In addition to its Naval applications, Omega has several possible commercial uses. One of these is the establishment of aircraft lanes across the oceans which will allow lateral separation of only 10 to 15 miles instead of about 120 miles as now required. Another important use is that fishermen may carry a simple Omega receiver in their craft as a means of determining an accurate return to the location of previous catches.

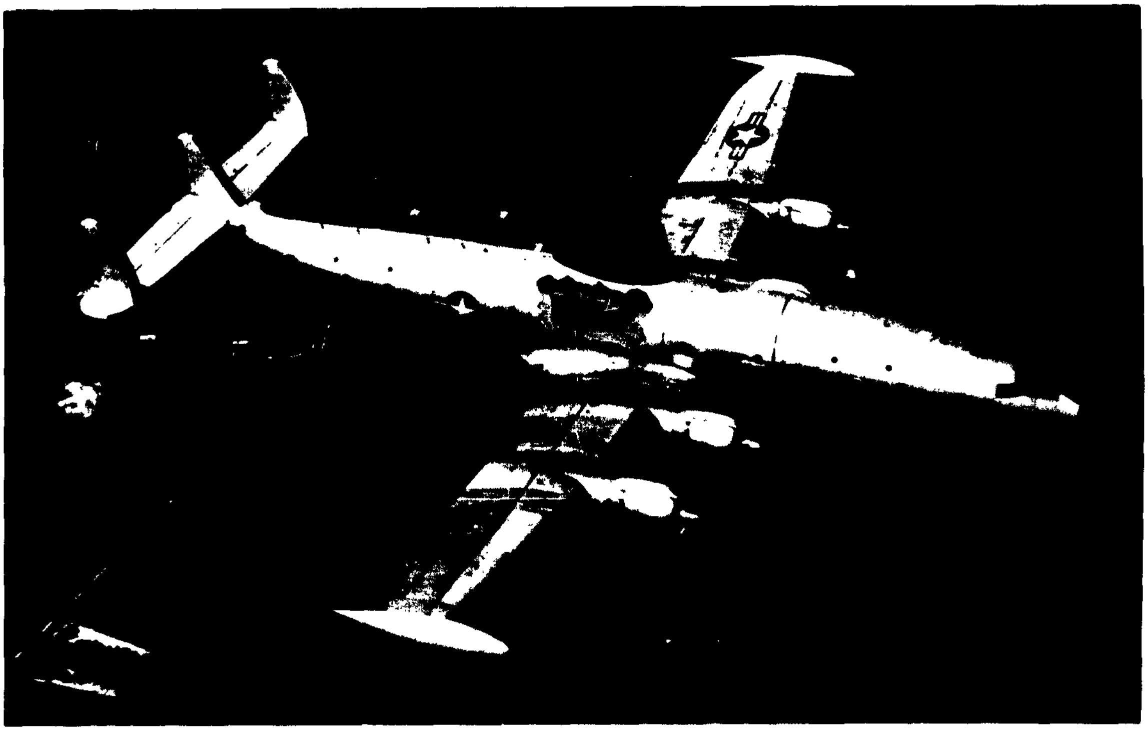
## Antipodal Effects on Radio Transmission

Much information concerning the reliability of vlf radio communications can be obtained by recording data at and near the electromagnetic antipode of a vlf transmitter (the point where many or all propagation paths converge). With proper receiving systems, all propagation paths can be studied collectively or independently, and the various attenuation coefficients, magnetic field effects, and variations in angle of arrival for all paths can be studied simultaneously. No known data had been obtained at the antipode of a vlf transmitter until February 1962, when NRL scientists undertook such study as part of a comprehensive investigation of vlf radio wave propagation. Amplitude and phase recording equipment was installed in NRL's "flying laboratory," a WV-2 aircraft specially fitted for wave propagation research. The objective was to measure vertical electrical fields in the vicinity of Perth, Australia, which is about 800 miles from the geographic antipode of the U. S. Naval Radio Station, NAA, at Cutler, Maine.

Daytime flights from Perth were made into the region of the geographic antipode on two consecutive days. A vertical whip antenna and crossed loops in the upper radome of the aircraft permitted omni-directional reception of vertical and horizontal fields. The antenna multicoupler allowed operations of several vlf receivers and also provided a variable-bearing cardioid pattern. Known antenna effective heights permitted absolute amplitude measurements. The phase of the received vertical electrical field was recorded relative to a rubidium standard.

NAA has a nominal radiated power of 1 megawatt at 14.7 kilocycles. In the vicinity of the antipode, the maximum vertical field strength was about 4 millivolts per meter, approximately twice as strong as that received at Seattle, Washington, only 3000 miles from the transmitter. The total antipodal field was 7.9 millivolts per meter, calculated by mode theory and assumed attenuation rates. An integration of the field components, based on fields observed at 60 to 600 miles from the antipode, yielded 3.4 millivolts per meter.

The limited data from this experiment indicate a very definite antipodal or convergence effect for the NAA transmissions. This likewise indicated that, at least during the period of this experiment, the propagation paths followed that of great circles and that the NAA fields, in reaching the Perth area, simply traversed the long and short great-circle paths from the trans-



*Artist's conception of the equipment and antenna installation aboard the NRL WV-2 during a study of the antipodal effects associated with very-low-frequency radio propagation.*

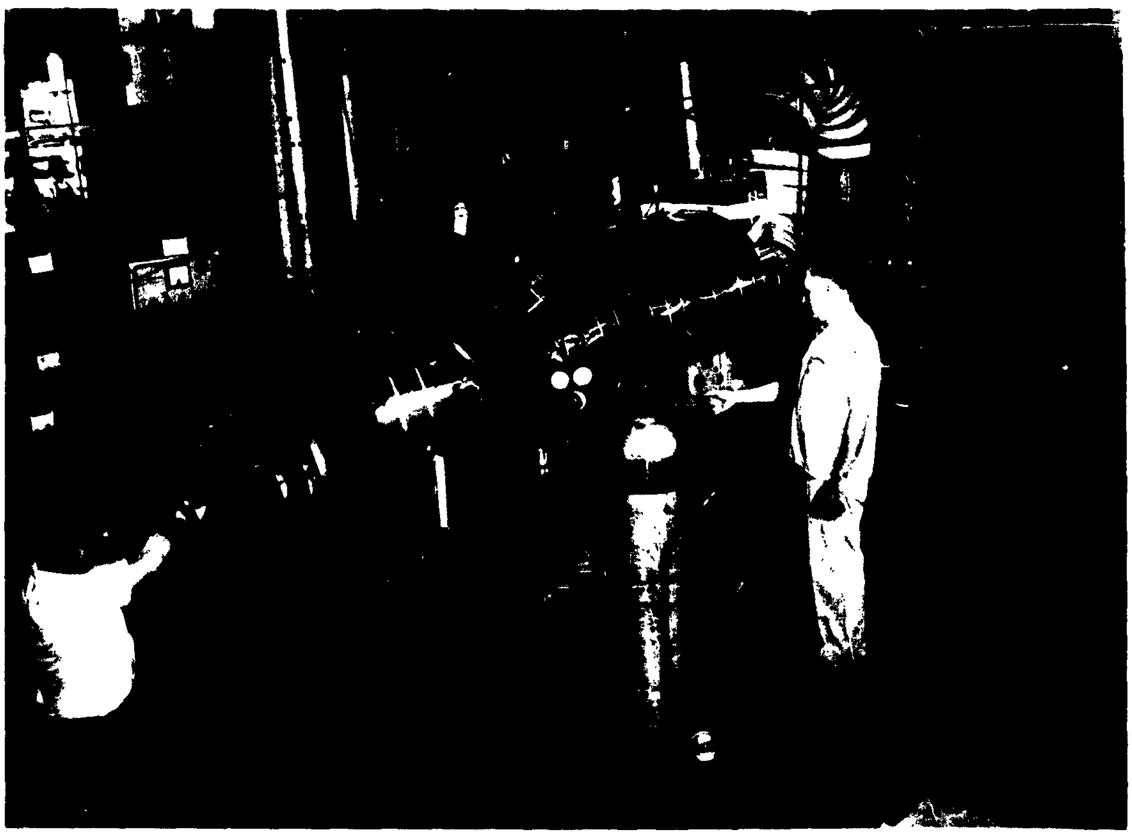
mitter through Perth. More data from additional flights must be obtained to determine the precise relationship of the electromagnetic and geographic antipodes and the stability of the electromagnetic antipode location and the variations of the field strength with time. With this knowledge, scientists can make more accurate predictions of the reliability of vlf communications in the ocean areas throughout the world.

## Space Simulation

The necessity for studying performance characteristics of aircraft components at simulated altitude was recognized prior to World War II. The extension of such facilities to higher simulated altitudes is a natural consequence of the rocket era. More important, however, is their use as research tools to supplement flight data obtained with high-altitude rockets.

Studies started at NRL in 1946 on the electromagnetic properties of flame plasmas have been extended to include all the plasmas which attend a missile or space vehicle in flight. Instrumentation suitable for maintaining up to 30 miles of simulated altitude, with laboratory-type rocket motors within the vacuum chamber, has been in use for a number of years and continues to provide new and extended experimental results.

Two smaller chambers, for studying both space-simulation techniques and some of the chemical aspects of plasma generation and plasma interaction with solids, also have been in use at NRL. One of these, 4 feet in diameter by 10 feet long and operating in the pressure region of 30 to 60 miles altitude, uses both liquid nitrogen and liquid helium to condense gases on cooled surfaces, in conjunction with a conventional booster and forepump to provide a high pumping rate. The other, 2 feet in diameter by 10 feet long, will simulate altitudes in excess of 100 miles. The walls are cooled with liquid nitrogen. Condensable exhaust products will deposit on the inside of the tank, thus reducing the pumping requirements of the diffusion and forepump.



*One of NRL's vacuum chambers for studying space-simulation techniques and plasma chemistry. This chamber will simulate altitudes in excess of 100 miles.*

Both of these systems have been used to conduct studies on methods of maintaining space-simulation pressures with high gas-release rates, in addition to studies on plasma chemistry. They have provided knowledge now being used in the development of two new systems, a small one (3 feet in diameter by 10 feet long) to be used in studies of materials and plasma interaction at the extremely low pressures of outer space, and a larger one (12 feet in diameter by 55 feet long) to provide continuous simulation of altitudes up to several hundred miles with high gas-release rates in the chamber.

Through use of these facilities, many experimental studies with rockets can be achieved at a very small fraction of the cost of a single high-altitude flight. Among these are investigations of propulsion, re-entry, and space plasmas to determine their electrical, dynamic, and chemical properties.

## Ionospheric Research by Lunar Radio Reflection

Even before the moon-reflection path was opened as a new communications channel, scientists had recognized the possibility of using lunar radio reflections as a means of studying the electron density of the ionosphere. The studies received added impetus in 1950, when it was realized that the slow deep fading of radio echoes from the moon was caused by polarization-rotation of the radio waves as they passed through the ionosphere in the presence of the earth's magnetic field (the Faraday effect). The amount of polarization-rotation is determined partly by the electron density of the region through which the waves pass. Hence, if the total polarization-rotation of a lunar radio echo can be measured, and if all other parameters are known, the total electron density of an earth-moon path may be estimated. Further, with simultaneous ionospheric sounding data to describe the ionosphere below the F-layer maximum, scientists can learn a great deal about ionospheric electron densities at levels above the reach of the conventional ionosonde.

Lunar radio-reflection experiments have been conducted by the Naval Research Laboratory since January 1962 by means of a high-power transmitter operating in the high-frequency band. A high-gain array has been used for both transmission and reception, and received signals have been subjected to extensive predetection bandwidth narrowing, involving a filter having an equivalent bandwidth of a fraction of a cycle per second. Observations on several occasions have indicated that moon-reflected signals first appear at times greatly deviant from the time of optical moonrise; usable data have been taken as early as ten minutes in time before optical moonrise, and moon echoes have begun to appear as late as 16 minutes after the moon's passage through the free space projection of the antenna's main beam. Measurements with the present system have provided excellent data on the fading period associated with the polarization rotation undergone by moon-reflected radio signals.

The striking periodicity in amplitude exhibited by the moon-echo pulses indicates that the Faraday rotation mechanism provides a powerful tool for exploring the ionosphere. The technique will permit the acquisition of valuable information regarding electron density above the F-layer maximum of ionization. Recent modifications in the high-power transmitting facility allow simultaneous transmission of two slightly separated frequencies. Data now being collected by the two-frequency facility will permit the determination of total electron density along the earth-moon path. Additional antenna installations now being constructed will provide increased possibilities for exploitation of the lunar reflection technique in ionospheric research.

## Microwave Polarization

An electromagnetic wave vibration is characterized by its frequency, its intensity, and its polarization—or the state of the transverse vibrations. By varying any of these parameters in an intelligent manner, the wave can be used as a carrier of information for communication purposes. Frequency modulation and amplitude (intensity) modulation techniques have long been in common use. For various reasons, the polarization "dimension" has been of little utility in conventional radio communications systems, the polarization usually being more-or-less fixed (i.e., vertical, horizontal, etc.). As electromagnetic (photon) beam technology advances at microwave, infrared, and optical frequencies, techniques for the measurement and control of polarization constantly increase in practical significance. New techniques for electronic control and modulation of wave polarization are needed for use in a broad gamut of directed beam systems—from microwave radar systems to optical communications systems in space.

Polarized radar waves impinging on a target are altered on being scattered from the target such that often the polarization of the echo appears to be unrelated to the polarization of the beam illuminating the target. There is a relationship, however (though often very complex), which is a function of the nature of the target, and thus might provide a basis for identification of the target. New findings in this area hold promise of better means of identifying certain types of radar targets.

Many advanced systems will require polarization diversity, that is, the ability to utilize more than one polarization state or perhaps to provide means for unlimited manipulation of polarization for special or varying situations. Some components and techniques for doing this have been developed at NRL, and others are nearing completion. Included are dual polarized antenna feeds and components which make possible simple polarization control in microwave antennas. Simple techniques also have been developed for modulating the polarization of a wave and for rotating the polarization of a wave at virtually any desired rate. A polarization simulator has been devised and is being used in the laboratory to synthesize problems involving complex polarization transformations which otherwise would be very difficult to study. By this means, the polarization transformation effects associated with various types of radar targets can be studied under stable, controlled conditions.

Valuable by-products of this research include a number of new nicrowave components and a family of simple mechanical amplitude modulators, continuous phase shifters, and frequency translators, having utility in scanning antenna arrays, for example. Most of the techniques and components developed have simple counterparts at optical wavelengths. Future work will include consideration of optical analogs for application to laser systems.

## SOLID-STATE PHYSICS

### Laser Research

One of the most significant products of basic research in solid-state physics was the recent advancement of maser technology. Maser stands for microwave amplification by the stimulated emission of radiation. The solid-state maser is an excellent high-fidelity microwave amplifier. It generates practically no noise, and it can detect much weaker signals than conventional amplifiers. For these reasons, it has been used, for example, in Navy radio telescopes to detect faint radio waves from distance astronomical points in space, such as the planets Venus and Mars, and to amplify the weak radio communication signals reflected from the Echo satellite.

At present the Navy is helping to extend the maser principle to materials and devices which can produce narrow or coherent beams of light in the optical region of the electromagnetic spectrum. These devices are called lasers (for light amplification by the stimulated emission of radiation).

The laser program at NRL is not only yielding new and improved laser materials but also achieving a better understanding of the spectroscopy of ions in solids in general, especially the factors that control spontaneous emission, or luminescence, and other optical properties. Thus the materials chosen for investigation are selected for their suitability for

*A horizontal dewar is positioned around an experimental glass laser etalon to facilitate stimulated emission studies from this material at the temperature of liquid nitrogen, 80°K. Surrounding the dewar vessel are several high-intensity Xenon flashtubes which are used to pulse-excite the luminescent glass etalon and may cause stimulated emission or laser action to occur in the rod. By spectrographic and oscilloscopic methods it is possible to determine whether or not stimulated emission occurred and, if so, when it started, how long it lasted, and the degree of intensity.*

study of the physics of energy absorption, energy transfer, and luminescence as well as for their ease of fabrication.

Crystalline materials are generally more suitable for the basic studies, because there is considerable information about their fundamental luminescent properties which can serve as a rough guide in predicting their laser potentialities. Glasses, by comparison, are poorly understood but have the advantage that they are more easily fabricated with good optical quality. Another advantage of glasses is that they may be made to contain 100 times as much of the luminescent centers as crystals. As a result, the energy density that one can obtain in glasses is much higher than that which can be obtained in crystals.

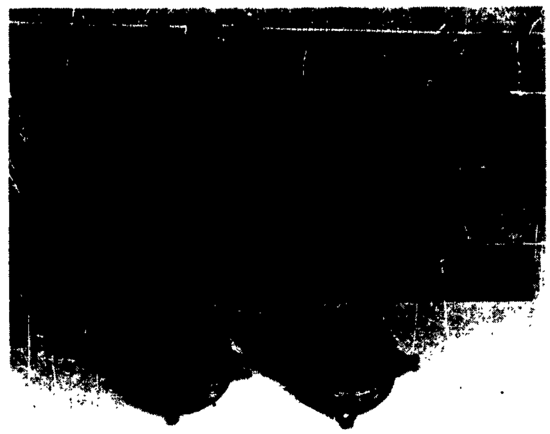
The glasses used in the NRL investigations are all formulated and melted at NRL; they are fabricated into lasers at NRL; and they are measured and evaluated with experimental equipment, much of which was developed and constructed at NRL.

There are two other phases of investigations concerning lasers. One involves a study of certain optical properties, such as spectral radiance and coherence of the stimulated emission, which make lasers unique in comparison with all conventional light sources. This investigation is exploring the potentialities of laser sources in the solution of naval problems. The other phase involves a study of the characteristics of the propagation of laser radiation in either air or water. These investigations are a matter of interest because of their relation to visibility, camouflage, optical signaling, and other optical problems.

## Thermoluminescent Dosimeters

There exist a number of materials which are capable of trapping and storing part of the energy deposited in them by ionizing radiations such as gamma-rays. If this stored energy can be subsequently released in the form of light when the material is heated to a higher temperature, the material is described as being "thermoluminescent."

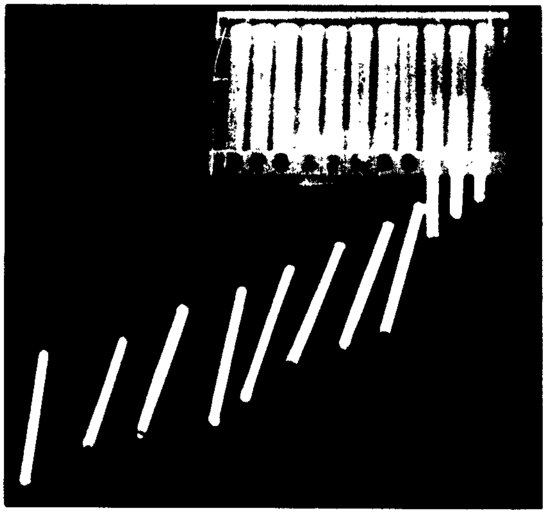
Such materials are not all equally sensitive to gamma rays, nor are they equally capable of storing energy for long times at room temperature. A particularly useful thermoluminescent material in these and other respects is the $CaF_2$:Mn phosphor devised at NRL in 1956.



*Two prototype models of personnel-monitoring dosimeters based on $CaF_2$:Mn thermoluminescence. The envelope at top is made of Pyrex; the one at bottom is metal and glass.*

This material was subsequently developed into prototype dosimeters for monitoring of personnel who work with ionizing radiation on a day-to-day basis. (Previously, most monitoring was done by photographic film badges, which were usually collected weekly or monthly, developed by normal wet-chemical procedures, and their darkening measured to determine the radiation exposure.) In the dosimeters developed by NRL, the phosphor is cemented to a graphite plate and then encased in an evacuated envelope to prevent deleterious atmospheric effects. Dose is measured by placing the dosimeter in front of a photomultiplier tube and passing electrical current through leads attached to the graphite. The amplified tube current is displayed on a strip chart recorder. The maximum light intensity, reached at about 280°C, serves as the index of the exposure received by the dosimeter. The usable linear dose range extends from $10^{-3}$ to $4 \times 10^5$ rad of $Co^{60}$ gamma radiation. The heating process restores the dosimeter to its original condition, so that it can be used repeatedly.

Recently a miniature dosimeter based upon $CaF_2$:Mn thermoluminescence has been developed at NRL. It consists of Pyrex tubing, 0.04 inch in diameter by 0.4 inch long, which encloses the phosphor powder. Total weight is about 16 milligrams. The usable linear dose range extends from $10^{-2}$ rad to $4 \times 10^5$ rad of $Co^{60}$ gamma radiation. The small size and wide range make these dosimeters especially useful for any application where space or weight is restricted, for example, in measuring radiation dose at internal positions in living animals.



*NRL's miniature $CaF_2$:Mn dosimeters with the lucite holder used on satellite flights.*

Another application for which they are admirably suited is the measurement of radiation dose in space vehicles. In a cooperative experiment with the Lockheed Missiles and Space Company, several of the miniature $CaF_2$:Mn dosimeters were flown on each of the six Air Force Discoverer satellites during the latter part of 1961. Four of these were successfully recovered and returned to NRL for measurement of the thermoluminescence.

The results showed that for satellites in polar orbits, with apogees ranging from 306 to 578 kilometers, the average dose rates were between 1 and 3 millirad per hour when the thickness of the shielding material was 1.7 grams per square centimeter. Comparison of these results with that of more heavily shielded groups of dosimeters supports the assumption that the dose was deposited mainly by protons trapped in the earth's field. By reference to other measurements of the proton field strength as a function of latitude and longitude, it is reasonable to conclude that most of the dose received by the dosimeters was probably obtained during transits of the satellites through the anomalous zone over the South Atlantic, where the trapped proton field dips to relatively low altitudes.

## Improved Plastics for Outer Space

The search for improved plastics for use in space vehicles—as windows or ports for cameras or panels for solar cells—necessitates more specific studies to determine the effects of an outer-space environment on the visible light transmission characteristics of these materials. A number of studies have been made which tabulate visual observations of discolorations resulting from ultraviolet and gamma-ray exposures, and a recent study described the changes of ultraviolet light transmission of ultrapure polymethyl methacrylate, the most common of these plastics. But quantitative data are lacking on the decrease in light transmission of commercial plastics in the wavelength region critical to solar-cell activation.

For many plastics the degradation mechanisms and the rates of these reactions are dependent on the total combined environment—high temperature, high vacuum, and radiation. Scientists at NRL have devised means for investigating these effects and those of other energies of electromagnetic and particle radiation. Specimens being studied include a variety of commercial plastics which can be cast or heat-formed into a desired shape, especially the materials used in aircraft bubble canopies. The apparatus used in the experiments combines a high-intensity ultraviolet light for irradiating the specimens and a combination mechanical and diffusion pump system for maintaining ambient pressure at approximately $10^{-5}$ mm Hg.

*An NRL scientist examines the degradation of a sample of plastic that has been irradiated in NRL's solar simulator for a period of 200 hours to test its effectiveness as a solar-cell shielding material.*

Temperature of the specimens is held constant at approximately 160°F throughout the exposure.

As irradiation proceeds, the materials discolor, becoming pale to dark yellow, indicating an increased absorption of blue light. Changes in optical density of the materials are being observed as a function of exposure times over the range of 3000A to 16,000A, and the decrease in their effectiveness as solar-cell shielding is being evaluated by measuring the short-circuit current output of a standard cell mounted behind the irradiated specimen.

Much still remains to be known concerning the mechanisms which produce the changes responsible for increased absorption as degradation progresses in the various materials, but already the project has paid off. The NRL study has indicated that there is a difference in stabilities among the materials used in aircraft canopies and that a more critical selection is required to determine those which can be used in outer space.

## Superconductivity

The discovery that certain alloys, such as $Nb_3Sn$ and Nb-Zr, retain zero electrical resistance in high magnetic fields and at high current densities has stimulated great interest in both scientific and industrial circles. These materials show great promise for use in superconducting magnets capable of producing 100,000 gauss or more over large volumes with very little power expenditure. Extensive data on the superconductivity of these materials are sorely needed, not only for clarification of their basic properties but also for use in magnet design.

The properties of these materials are being investigated with the NRL High Field Magnet Facility. (See p. 10.) The entire critical field curve of Nb-Zr has been measured, and the results indicate that magnets capable of yielding fields up to about 80 kilogauss should be feasible with this alloy. Magnets constructed of such material and yielding fields of around 50 kilogauss are currently available. The critical field curve of another such material ($Nb_3Sn$) has been measured up to 150 kilogauss, and these data indicate that this material is certainly useful for superconducting magnets producing over 200 kilogauss.

Further experiments will refine and extend the measurements described above. Also, other new materials with even higher field possibilities are now in the process of being developed, and these, too, will be studied when they are available.

## Magnetism

In 1820, Oersted discovered the magnetic effect of an electric current; in 1831, Faraday showed that a changing magnetic field produced electric effects in a conductor and made many other important magnetic discoveries. In 1961, Rado and his colleagues at the Naval Research Laboratory discovered a magnetically induced magnetoelectric effect.

The new magnetoelectric effect was observed while the scientists were searching for experimental facts and theories that would help to explain the elemental properties of antiferromagnetic materials. The material under study was a single crystal disk of chromic oxide, a material in which the orderly spin of electrons accounts in part for its low magnetic susceptibility. It was found that such a material exhibits an electric polarization which is directly proportional to an applied magnetic field. What may be called the "magnetoelectric parameter" was found to depend on temperature and crystal orientation and was increased greatly by magnetic annealing (cooling through the Neel temperature, at which point the material ceases to be antiferromagnetic).

In further studies of chromic oxide, with the use of the magnetically induced magnetoelectric effect, and the electrically induced magnetoelectric effect which was discovered earlier by the Russian physicist Astrov, NRL investigators found positive evidence for postulating a specific structure of the elemental magnets (domains) in an antiferromagnetic material. An atomic theory for both magnetoelectric effects was developed by Rado, and a review of magnetoelectric effects was given by Rado and Folen (Journal of Applied Physics 335:1126, March 1962).

The first successful synthesis of lithium ferrite crystal was accomplished at NRL in order to measure the microwave resonance absorption in this ferrimagnetic material. The resonance linewidth, which is a measure of magnetic losses, was found to be unusually narrow. While the magnetic losses were found to be somewhat larger in lithium ferrite than in highly purified yttrium iron garnet, the magnetization at saturation is twice as large in the lithium ferrite as it is in yttrium iron garnet.

These studies have not only contributed to the advancement of the theory of magnetism, they also have unveiled useful properties of lithium ferrite that make it suitable for use in microwave limiters and other devices.

# SOUND

## Sound Propagation Studies

When compared with the inherent precision of radar in detecting aircraft, sonar is inferior as a means of detecting submarines. Obviously, then, much more needs to be known about the physical behavior of underwater sound and the acoustical characteristics of the ocean. Scientists at NRL have tackled the problem through research in four separate but related areas, with the ultimate aim of improved sonar systems:

- The speed of sound—how it is determined and how it is influenced by temperature, salinity, and pressure in the sea.
- The path of sound—the actual geometry of sound rays, how fast they spread, and how far they penetrate into the ocean.
- The strength of sound—how much is reflected back from a target.
- The source of sound—the identification of underwater objects by the sound they emit.

Speed of sound is the basis for determining the range to a submerged submarine. Variation in speed as the rays pass through the sea is the underlying cause of deflection and bending of the searching beam. To understand and control these characteristics, the measurement of the speed of sound as it is influenced by temperature, salinity, and pressure in the sea is being pushed to its ultimate limits of precision. Equipment now in use is built to yield a precision of 1 part in 150,000. This means that under a typical sea condition, in which sound may be traveling at 1.5 kilometers per second, a change in speed amounting to only 1 centimeter per second can be detected. Sound-speed tables of values are being compiled which reflect this precision and which show variations with temperature, salinity, and pressure.

The path along which a point on the sound wave proceeds through the ocean is called the sound ray. Knowledge of the actual geometric shape of these rays, how fast they spread, how far they penetrate into the ocean, is dependent upon two elements: accurate laboratory measurements of sound speed and precise determination of salinity and temperature in the ocean. Establishing the relationship which exists between these two elements is the major purpose of experiments now being carried out at sea. The results should permit more reliable predictions of the exact sound field impinging on any point in the ocean.

The sound that comes back to the searcher in the form of an echo indicates the position and some characteristics of the target in the ocean. Thus a complete understanding of the physical mechanisms in the reflection process is a vital link in our chain of knowledge. Many measurements have been made of the reflection properties of target submarines; sonar engineers refer to this as determining target strength. Many of these measurements are made far at sea, and the ever-present motion and turbulence of the water cause the measured results to fluctuate wildly. To establish a firm physical basis for determining exact target strength, NRL is conducting a continuing program of reflection measurements under laboratory conditions. Targets which somewhat remotely resemble a submarine, i.e., spheres and spheroids, and which have precisely known physical properties are placed in a sound-radiation field of precisely known intensity and geometric configuration. Under these conditions, accurate measurements can be made of the sound reflected from the target.

Objects moving through the water produce sound which is independent of sonar echoes. An understanding of this phenomena is vital in submarine-hunting operations known as passive detection, that is, simply listening for submarines. Recent studies have revealed the physical details of vortex shedding as bodies of various shapes are moved through the water. These vortices are commonly observed phenomena in hydrodynamics. Under certain circumstances, they peel off the moving objects in regularly ordered series and, in doing so, they impart to the object alternating forces, setting the object into vibration, which gives rise to sounds or disordered oscillations of noise. The magnitude of this phenomena in exciting vibration in ship's plates has been determined for certain simple geometric shapes in the laboratory. This work contributes to the general fund of knowledge regarding the emission of noise from submarines and thus aids in the design of detection systems.

## High-Pressure Testing of Electronic Components

The field of oceanographic instrumentation is expanding rapidly in keeping with the increased importance of oceanography to the defense effort. One phase of NRL's research program is directed toward the development of instruments, to be used mainly in sonar systems or electronic probes, which will withstand the hydrostatic pressures of the deep-ocean environment. There are two approaches available—either the individual components must be built with the inherent ruggedness to hold up under the punishing pressures of the sea, or the entire equipment must be encased in a rigid, pressure-proof capsule. Economy of weight and cost makes the first method more attractive.

*An electronic component is lowered into NRL's small pressure tank for an exposure of 15,000 psig. Tests such as this determine whether or not the component will be able to withstand the pressure and temperature environment of the deep ocean.*

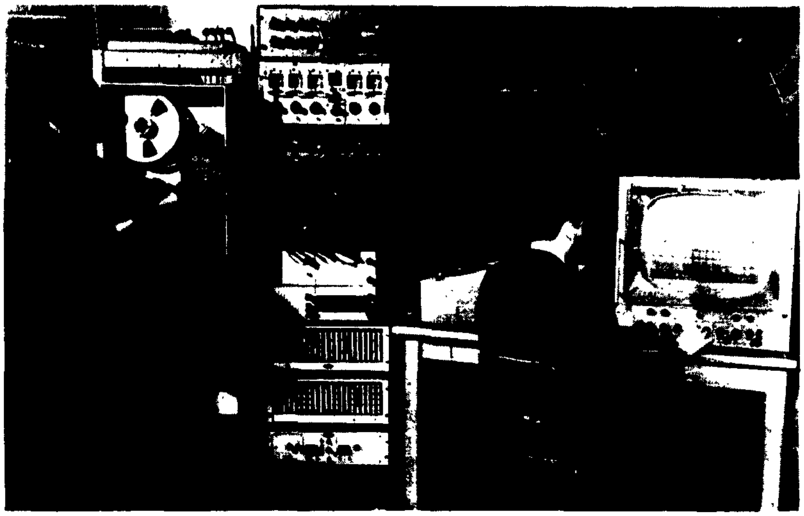
Recently, NRL's scientists exposed electronic components to hydrostatic environments equivalent to more than four miles submergence in the ocean. Data have been obtained on such components as resistors, capacitors, inductors, semiconductors, vacuum tubes (glass envelope), batteries, light bulbs, and potted circuits. In each class of components, designs were found that would operate under hydrostatic pressures up to 10,000 psig, at least for short periods.

Some of the findings were unexpected. For example, resistors manufactured by deposition of either carbon film or tin oxide on glass rods were not affected by the application of pressure, so their use can be recommended in critical circuits. Conversely, the standard carbon-composition resistor exhibited a reduction in resistance which was directly proportional to pressure. This behavior precludes its originally intended use under high pressures, but it can be adopted for use as a convenient and inexpensive pressure transducer. Also, the very thought of using glass vacuum tubes under high pressure seemed ridiculous, but some subminiature types withstood the full 10,000 psig without damage. The same was true for a high percentage of small neon bulbs, instrument bulbs, and penlight bulbs.

Since, in service, many equipments will be submerged for long periods, laboratory tests have included long-term exposures at high pressures. Several small pressure tanks were built in which exposures can be extended indefinitely. Limited tests with this equipment have revealed that plastic-encapsulated components which were unaffected by short-term exposure eventually failed with time. Further tests are needed before the long-term behavior of components under pressure can be predicted with reasonable accuracy. The environmental test facility has now been modified so that both temperature and pressure variations of the ocean can be simulated at the same time.

## Improved Data-Recording System

The relatively low frequencies at which much underwater acoustic research is now being done has made possible the application of many new techniques to the problem of signal processing. Recently NRL has developed an improved data-recording system by which information of sound waves in the deep ocean can



*Information obtained on sound waves in the deep ocean is monitored in the laboratory by means of special equipment developed at NRL. Raw data on the tape are reproduced on the oscilloscope screen at right. Processed data show up on the plotter beside the oscilloscope.*

be obtained at sea and brought back to the laboratory for analysis without loss of accuracy.

The equipment samples electrical signals coming out of a receiving transducer at any rate up to 10,000 samples per second. Each of these sample values is electronically converted into a binary number, and this number is recorded on magnetic tape. The numbers recorded on the tape are accurate to about 1 part in 1000, which is roughly 10 times more accurate than conventional magnetic-tape recording, and are in a form that is readily utilized by a standard digital computer or by any of several special-purpose signal analyzers.

One of the principal advantages of this method is that the samples from the original signal are taken at precisely determined intervals of time and recorded in coded numerical form on the tape so that inaccuracies in the speed of movement of the recording tape, or later stretching or shrinking of the tape, has no effect on the accuracy or the usefulness of the data. Another advantage is that once the data are in a digital computer, many different kinds of information can be extracted, or many different kinds of target-detection systems can be simulated, by merely changing the instructions which have been given to the computer. Further, data obtained from as many as eight different locations in the ocean can be studied simultaneously in the laboratory, which permits very sensitive comparisons of the sound from these different points.

The greatly increased accuracy of the experimental data obtained with this equipment has made possible a new understanding of some of the critical characteristics of sound traveling through the ocean. The system has already been successfully applied to several important classified research projects for which earlier techniques had proved grossly inadequate.

## Acoustic Sources

A vital part of all active sonar systems is the source of acoustic energy. The Naval Research Laboratory is engaged in a continuing program of research and development to provide the components, as well as complete acoustic sources, that will meet the needs of research programs in propagation studies and of the fleet for active sonar sources.

This program has resulted in the development of new components and techniques, an improvement in understanding of interaction phenomena, better system performance, and increased component and system reliability. Illustrative of the results of the work in one of these areas is the development of a solid-state transmitter and modular drive concept. A solid-state unit rated at three kilowatts has been developed to provide the electrical power for either transducer element or array. This unit provides the electrical power for the transducer directly from the 60-cycle supply, requires no warm-up time, and has a conversion efficiency of approximately 90 percent. It utilizes silicon-controlled rectifiers in the output stage and solid-state devices for the control of frequency, turn-on and turn-off operation, and protection. The inverter has been tested with individual transducer elements and arrays of transducer elements and demonstrates satisfactory, reliable performance.

The power rating of this inverter can be increased to 20 kilowatts by the use of available solid-state devices.

# CENTRALIZED SERVICES

## Applied Mathematics

The Applied Mathematics Staff is a part of the Office of the Director of Research. As such, it performs as a staff function for the entire Research Department. More particularly it provides a group of expert consultants who are available, on a cooperative basis, to any scientist at the Laboratory. The areas of analysis, numerical analysis, differential equations, differential invariants, and statistical analysis are emphasized. In addition to its consultative services, the group conducts a research program of its own in related areas of applied mathematics.

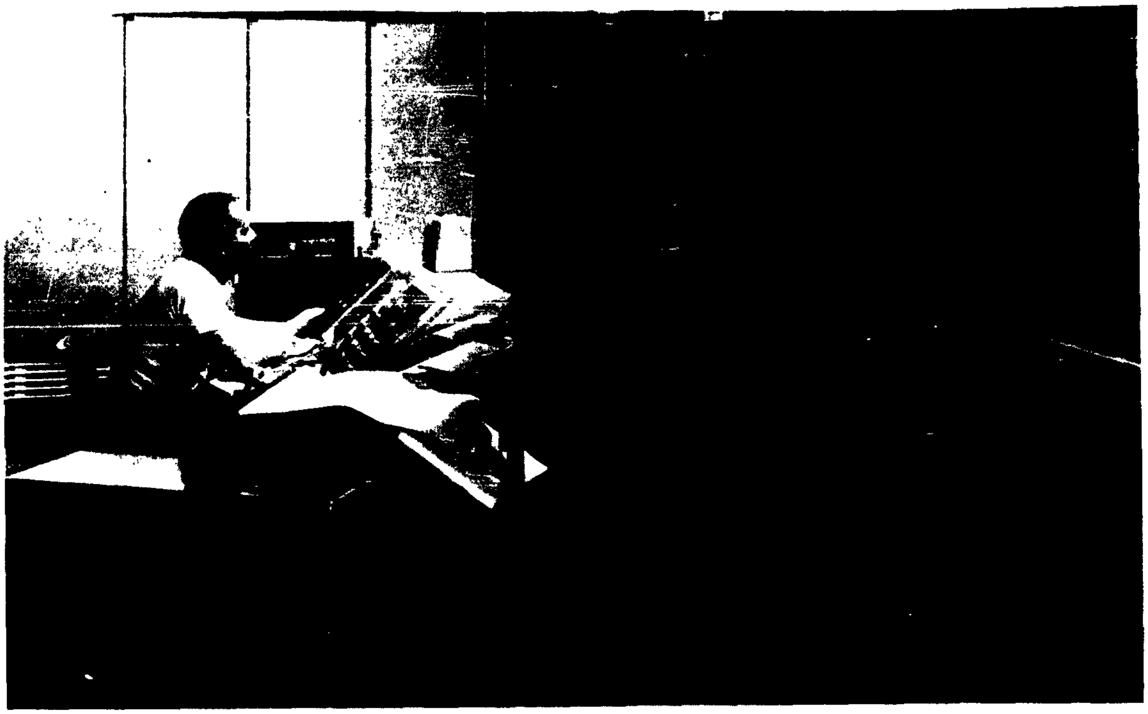
## Research Computation Center

All large-scale computing and data-reduction facilities at NRL are consolidated in the Research Computation Center, organized as a Branch in the Applied Mathematics Staff. The Center includes the NRL-developed medium-speed digital computer (NAREC), a commercial analog computer (REAC) installation, and various specialized facilities for data handling and data reduction. The Center is staffed by mathematicians, programmers, engineers, and technicians.

In general, members of the staff perform research and establish new techniques in the fields of numerical analysis and programming methods; prepare complete problems for solution on any of the facilities for those who desire it; act as consultants and a source of information in these fields for those who prefer to do their own analyses or programs; and maintain the equipment, making improvements when necessary or desirable.

## Shock, Vibration, and Associated Environments

The Centralizing Activity for Shock, Vibration, and Associated Environments is located at NRL. It serves the three Services and other government agencies, such as the National Aeronautics and Space Administration and the Na-



*An operator makes a manual check of a program in NRL's NAREC computer.*

tional Bureau of Standards, and their contractors. The Activity collects, correlates, and disseminates information on environments and their effects on military hardware, missiles, and space vehicles. Symposia are arranged and conducted as needed, and the symposia proceedings and related papers are published in the Shock and Vibration Bulletins. The 30th Symposium was held in October 1961, with an attendance of 820. The 30th Bulletin contained 94 papers and the proceedings of two panel sessions. It was published early in 1962 in five parts with a total of 1135 pages. The 31st Symposium was held at Phoenix, Arizona, in October 1962. The theme of this meeting was "The Application of Environmental Data to Specifications and Design Criteria." The large number of papers presented will be published in 1963.

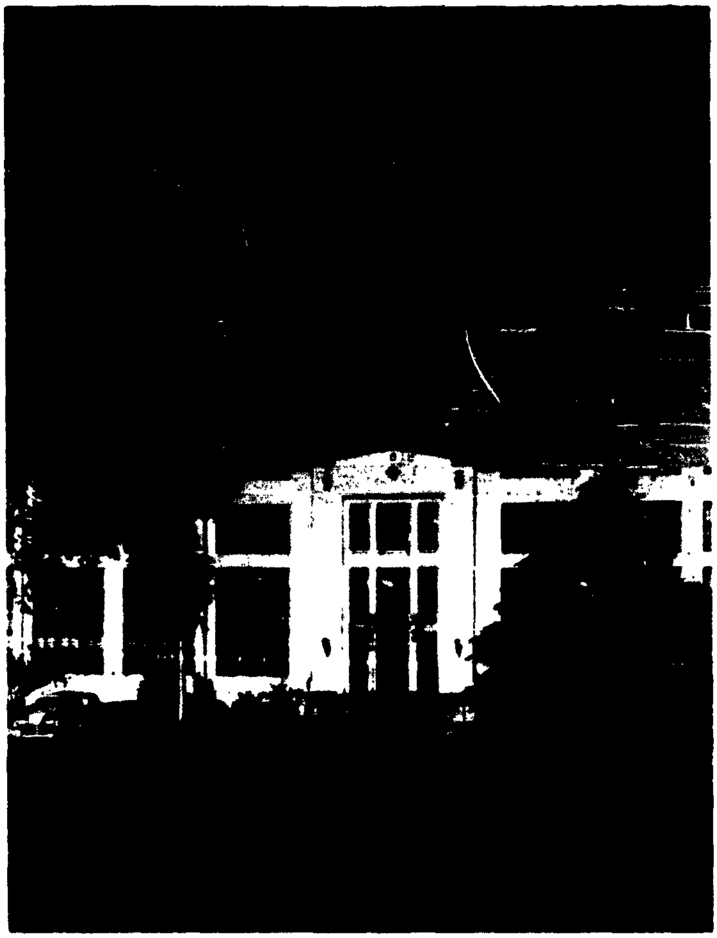
An "Index of Environmental Test Equipment in Government Establishments," first distributed in the spring of 1961, has continued in demand, and a number of additions and corrections to it have been distributed.

## Harbor Defense

The Navy's Harbor Defense Agency, also located at NRL, collects, correlates and disseminates information on harbor defense and countermeasures through the medium of the publication, "Harbor Defense and Countermeasures Bulletin," and by visits and correspondence. The past year has been a busy one. Assistance has been given to the Mine Advisory Committee of the National Academy of Sciences in their study on swimmer countermeasures, including the preparation of references and an opening address to a fact-finding meeting. In July a member of the staff attended a four-day planning conference organized at Long Beach by COMINPAC in which the new concept was discussed in detail.

# PART IV
# OUT IN FRONT

"-- one of the greatest scientific institutions in the world."



For thirty-nine years the Naval Research Laboratory has been expanding its program and facilities until today it is numbered among the great scientific establishments of the world. NRL scientists, in the course of their investigations, have been sent on distant expeditions to all parts of the globe. They have held key roles in scientific societies; were granted patents for inventions of use to the Navy; and have been the recipients of many awards for their outstanding accomplishments in all branches of the physical sciences.

The reputation of the Laboratory is further enhanced by the wealth of scientific information published in the open literature or in the form of NRL bound reports; by papers presented at scientific meetings; by exhibits and displays in this country and abroad; and by participation in national and international conferences devoted to the free exchange of scientific knowledge.

The following pages note some of the honors and achievements that have won recognition during the past year.

## LITERARY CONTRIBUTIONS

**Reports . . . . . . . . . . . . . . . . . . . 1,459***

**Articles in Scientific Journals . . . . 139**

**Papers Presented at Scientific Meetings . . . . . . . . . . . . . . . . . 329**

This figure includes 58 papers presented at international meetings, as follows:

Eighteenth International Congress of Pure & Applied Chemistry, Ottawa, Canada--(1)
Twelfth International Astronautical Congress, Washington, D. C.--(7)
Fifth International Congress on Ionization Phenomena in Gases, Munich, Germany--(3)
International Congress on Magnetism and Crystallography, Kyoto, Japan--(5)
International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Salzburg, Austria--(3)
Rutherford Jubilee International Conference, Manchester, England--(6)
International Congress on Vacuum Technology, Washington, D. C.--(1)
IAEA Conference on Programming and Utilization of Research Reactors, Vienna, Austria--(1)
International Scientific Radio Union, Austin, Texas--(3)
IRE International Convention, New York--(1)
Controlled Fusion Conference, Paris, France--(2)
International Atomic Energy Agency Symposium, Venice, Italy--(2)
International Conference on Vacuum Ultraviolet Radiation Physics, Los Angeles, California--(5)
International Scientific Radio Union, Washington, D. C.--(2)
International Conference on High Energy Physics, Geneva, Switzerland--(1)
International Conference on Paramagnetic Resonance, Jerusalem, Israel--(1)
International Conference on Spectroscopy, College Park, Maryland--(3)
International Astrophysics Symposium, Liege, Belgium--(3)
International Summer School on Optical Properties of Semiconductors, Ghent, Belgium--(1)
Second International Congress on Radiation Research, Harrogate, England--(1)
International Conference on the Physics of Semiconductors, Exeter, England--(4)
International Union of Crystallography, Munich, Germany--(2)

*This and following statistics compiled for a 12-month period from October 1, 1961, to September 30, 1962.

## PATENTS . . . . . . . . . . . . . . . . . . . . 57

Because these patents were granted to civil servants, the inventions may be used for governmental purposes without payment of royalty.

## AWARDS AND DISTINCTIONS

### Navy Award for Distinguished Achievement in Science*

Herbert Friedman . . . for extraordinary achievements in astronomy and astrophysics and scientific "breakthroughs" which are internationally recognized as being of major importance.

### Navy Distinguished Civilian Service Award

Martin J. Votaw . . . for his contributions to the earth satellite program, including the organization of an in-house satellite techniques capability, the highly successful payload instrumentation of Vanguard, Solar Radiation, and Low Frequency Trans-Ionospheric (LOFTI) Satellites, and the satellite design, construction, and program coordination for the Solar Radiation and LOFTI flights.

### Navy Superior Civilian Service Award

Edgar L. Dix . . . for outstanding ability in developing satellite instrumentation having a high level of sensitivity.

*The first such award by the Navy under the Government Employees Incentive Awards Act.

*The Distinguished Civilian Service Award, the highest honor bestowed on a civilian by the Department of the Navy, was established in 1944. Since then, a total of 43 awards have been presented to employees of the Naval Research Laboratory. Of the 22 recipients still employed at the Laboratory, 18 were present when this photograph was made (August 1962) with the Honorable James H. Wakelin, Jr., Assistant Secretary of the Navy for Research and Development.*

Louis T. Ratcliffe . . . for unusual skill in the design of shells, structures, and mechanisms for NRL satellites.

## Navy Meritorious Civilian Service Award

John J. Over, Jr. . . . for the design of reliable equipment that greatly increases the capability of satellites.

Peter G. Wilhelm . . . for the design of transmitters for satellite telemetry systems that provide a high modulation index and excellent stability over a wide temperature range.

Joseph Y. Yuen . . . for the development of special test procedures for screening satellite batteries that have been extremely valuable in the NRL satellite program.

## E. O. Hulburt Annual Science Award

William A. Faust . . . in recognition of his substantial creative contributions in the field of nuclear and plasma physics which have resulted in the establishment of many research programs.

## Awards from Scientific Societies

D. C. Council of Engineering and Architectural Societies . . . Albert I. Schindler, recipient of the National Capital Award for his distinguished achievements in the field of metal physics which have received international recognition.

American Society of Naval Engineers . . . William S. Pellini, annual award for his exceptionally outstanding contributions to the science of Naval engineering in the field of metals.

American Society for Metals (Washington Chapter) . . . Joseph M. Krafft, 1962 Burgess Prize in recognition of his outstanding contributions to the effects of high strain-rates and metallurgical factors on the plasticity and fracture of metals.

Société Française de Photographie . . . Herbert Friedman, the Janssen Medal, and Richard Tousey, the Ancel Prize, for their accomplishments in scientific photography from rockets.

Guggenheim Memorial Foundation . . . Maurice M. Shapiro, fellowship for a year's study at the Weizmann Institute of Science, Rehovath, Israel.

## Key National Roles in Scientific Societies (Partial Listing)

Robert J. Adams, Associate Editor, IRE Transactions.

Robert O. Belsheim, Vice-Chairman, Washington, D. C. Section, American Society of Mechanical Engineers; Director (1962-64), Society of Experimental Stress Analysis.

Henry P. Birmingham, National Symposium Chairman, Professional Group on Human Factors in Electronics, IRE.

Jeanne B. Burbank, Vice-Chairman, Washington-Baltimore Section, The Electrochemical Society.

Rube Chernikoff, News Letter Editor, Proc. IRE.

Robert B. Fox, Councilor, American Chemical Society.

Herbert Friedman, Director and Fellow, American Rocket Society; Representative, Inter-Union Committee on the Ionosphere, International Union of Geodesy and Geophysics; Chairman, Working Group 2, Committee on Space Research.

John H. Hill, Treasurer, Professional Group on Human Factors in Electronics, IRE.

Peter King, Navy Liaison Representative, National Research Council (Division of Chemistry and Chemical Technology).

John M. Leonard, Councilor, American Chemical Society.

Cornell H. Mayer, Vice-Chairman, Commission V, USA National Committee, International Scientific Radio Union; Member, Organizing Committee for Commission 40 (Radio Astronomy) Program, 12th General Assembly of International Astronomical Union.

Edward F. McClain, Commissioner, Scientific Manpower Commission, American Astronomical Society; Liaison Representative, Interdepartmental Radio Advisory Committee, National Academy of Sciences; U. S. Member, Commission 40 (Radio Astronomy), International Astronomical Union.

Donald M. Packer, Navy Representative, Committee Z-58 (Standardization of Optics), American Standards Association.

Thomas R. Price, Chairman, Unit Committee T-3J, National Association of Corrosion Engineers.

Sigmund Schuldiner, Secretary-Treasurer, Theoretical Division, The Electrochemical Society.

Sidney T. Smith, Chairman, Washington Chapter, Professional Group on Electron Devices, IRE.

Richard Tousey, First President, National Capital Section, Optical Society of America; Associate Editor, Journal of the Optical Society of America.

Irwin Vigness, President, Society of Experimental Stress Analysis; Secretary, Acoustical Society of America.

Joseph C. White, Board of Directors, The Electrochemical Society.

William A. Zisman, Secretary, Commission on Colloid and Surface Chemistry, International Union of Pure and Applied Chemistry.

## SPONSOR'S DAY

NRL played host to nearly 500 key personnel in scientific research, both military and civilian, who have a direct interest in the research program of the Laboratory. Known as Sponsor's Day, the "open-house" type of tour served to acquaint the scientific community with NRL's research for defense and its direct contributions to the new Navy.

After a brief welcome by the Director, informal discussions were held at ten centers of interest. An appropriate display added to the effectiveness of each presentation.

## SCIENCE TEACHERS SEMINARS

In an effort to further the increasing interest in science, NRL sponsored a series of seminars on basic science and engineering for local elementary, junior-high, and senior-high school teachers. The speakers, all of whom were NRL scientists, covered various topics in physics, chemistry, and mathematics and showed the interrelationship among these fields. Suggestions for classroom demonstrations and student projects which could be accomplished with a minimum of materials made the sessions informative and interesting. Following each seminar, the teachers had an opportunity to discuss problems or ask questions.

*Dr. R. M. Page, Director of Research, explains the LOFTI I satellite to a group during a science teachers seminar.*

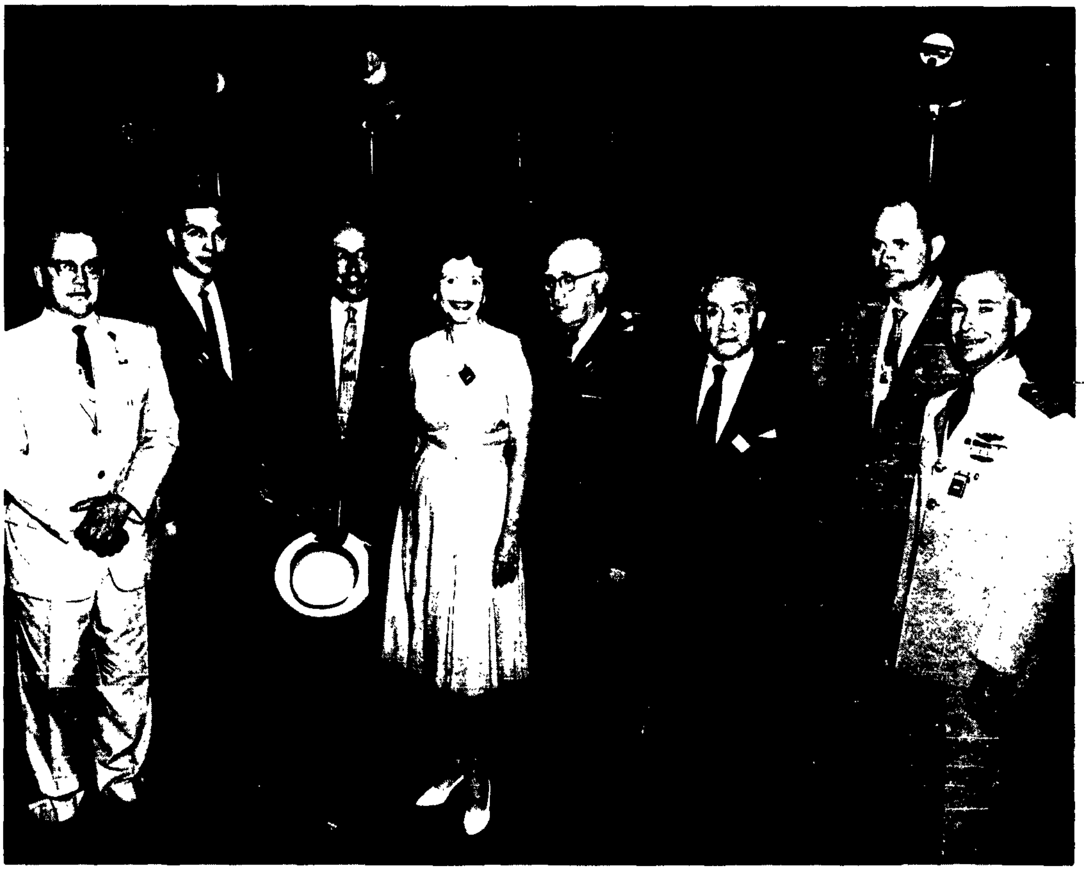
*The Honorable Joseph V. Charyk, Under Secretary of the Air Force, and VADM W. F. Raborn, Deputy Chief of Naval Operations (Development), toured the Laboratory in June 1962.*

## CONDUCTED TOURS

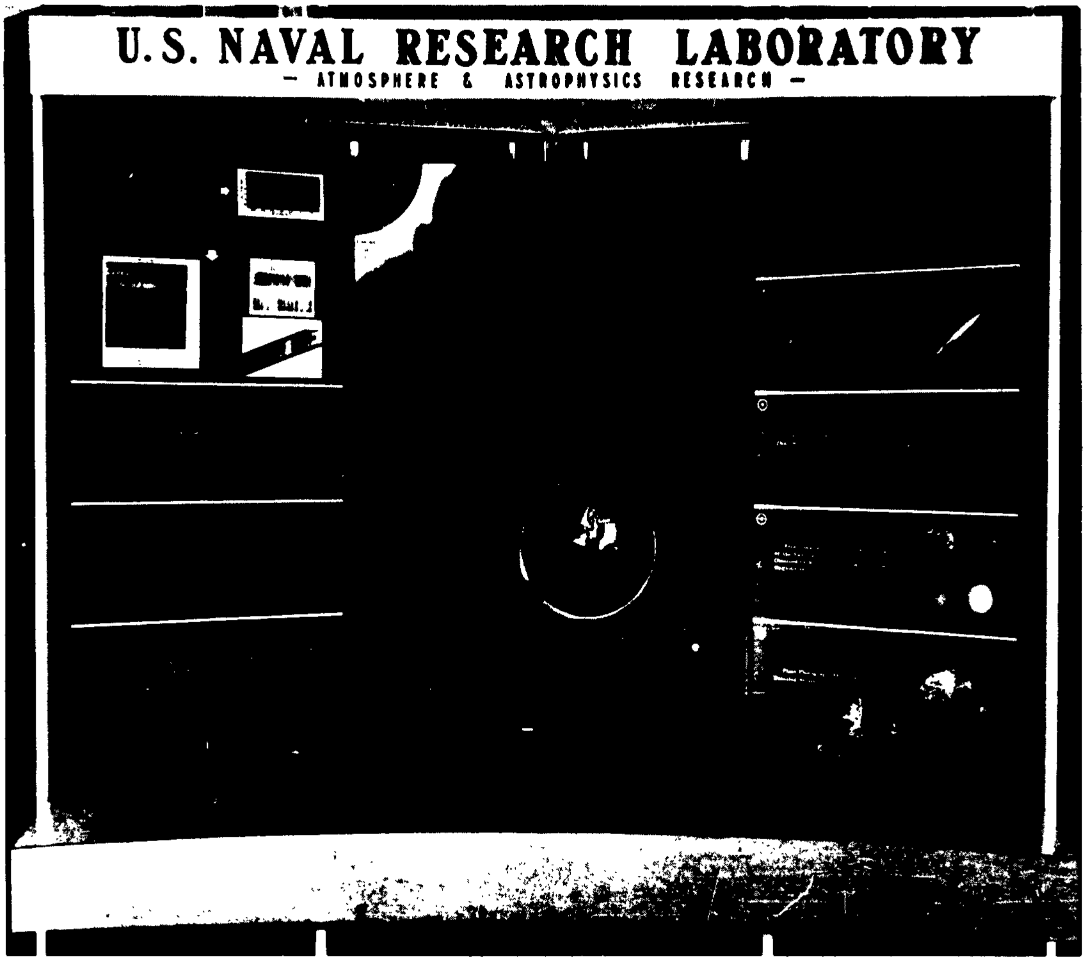
Because of its high standing in the scientific and educational community, the Laboratory receives many requests from groups to visit for a first-hand report on some of the projects. The requests are mainly from local high schools and colleges or from professional societies—either local chapters or groups holding a regional or national conference in Washington. Several groups were foreign students. During the past year, 37 conducted tours (a total of 961 people) paid tribute to the Laboratory's reputation as a leading scientific research institution.

## EXHIBITS

Exhibits during the past year covered 20 subjects at 10 different professional meetings. The time on display varied from one day through weeks or months. Included were exhibits on three subjects for the coordinated Armed Forces Day at Andrews Air Force Base.



*Television cameras of CBS came to NRL to film a segment of the network's "America Wants to Know" series which featured a panel discussion among legislators and scientists. Shown here are Eldon I. Nowstrup, supervisor of NRL's reactor (left), Dr. Joe O. Elliot, Head of NRL Reactor Branch (second from right), and CAPT A. E. Krapf, Director of NRL (right) with panel members Cong. Robert Kastenmeier (D.-Wisc.), RADM Lewis Strauss (USNR-Ret.), Sen. Maurine Neuberger (D.-Ore.), Cong. Chet Holifield (D.-Calif.) and William Lawrence, of the New York Times.*




*NRL exhibit, demonstrating some of the accomplishments in the field of astrophysics, shown at the Seventeenth Annual Instrument-Automation Conference and Exhibit of the Instrument Society of America in New York City, October 1962.*

# PART V
# BEHIND THE SCENES

"-- *excellent service from supporting groups.*"

Behind the scenes in every great endeavor are the unsung heroes who "grease the wheels" and "feed the hoppers." NRL ended the fiscal year with a civilian population of 3272. Of this total 2210 were administrative personnel of one kind or another. They form the supporting groups which operate and service the Laboratory, leaving the scientists free to pursue their research efforts unencumbered by management problems.

To describe in detail each individual service would require a separate publication. Instead there is presented here a brief account of how the administrative divisions, quietly and without fanfare, perform their respective roles in the conduct of research.

## PERSONNEL

### Highlights in the Employment Area

All of the positions of division superintendent and above in the Research Department have been placed under Public Law 313, which makes a total of eighteen such positions at the Laboratory. During the 1962 fiscal year, twenty-one branch heads in the Research Department were promoted from GS-14 to GS-15. As of June 30, there were eleven branch-head positions at the GS-14 level, many of which will be upgraded to GS-15 during the 1963 fiscal year.

During the 1961-62 academic year, 114 colleges and universities and four scientific meetings were visited for the purpose of recruiting scientists and engineers. As a result of this effort, 1081 applicants were interviewed, 457 applications were received, and 49 offers of appointment were made. It is anticipated that approximately the same number of colleges and scientific meetings will be visited during the 1962-63 academic year and that possibly 200 or more offers of appointment may be extended.

### Incentive Awards Program

The Naval Research Laboratory encourages the highest individual effort by its employees and provides official recognition through its Incentive Awards Program. A noteworthy appraisal of the program occurred recently when it was cited by the U. S. Civil Service Commission as one of the best in the Federal Government. Also, an Invention Awards plan under the program was started in November 1957. This was the model for the Navy-wide plan which was adopted in August 1961. Details of the awards and distinctions received by NRL employees during the past year appear on page 69.

### Superior Accomplishment Awards

Fifty-two individual employees received certificates and monetary awards for superior accomplishments in three categories: (A) Sustained Superior Performance, (B) Superior Achievement, and (C) Special Act or Service. The number of employees, the sum of monetary awards in each category, and the savings to the Government were as follows:

| Category | Recipients | Amount | Savings |
|---|---|---|---|
| A | 42 | $7,800 | |
| B | 6 | 7,200 | $6,227,000 |
| C | 4 | 1,200 | 70,000 |

Awards for adopted beneficial suggestions (including 110 invention awards) were made to 115 individual employees and 47 separate groups at NRL during the year. The sum of payments for new and useful ideas was $7,335. Total savings resulting from these amounted to $10,125.

*CAPT A. E. Krapf, Director of NRL, presents an Incentive Award to Gordon Ridings, of the Public Works Division, for sustained superior performance. This was one of 52 such awards granted to employees of the Laboratory during 1962.*

## PUBLIC WORKS

NRL's Public Works Division is far more than just a building-maintenance and grounds-keeping unit. It is frequently involved in architectural design and engineering and often acts as the contractor in construction of new buildings and facilities. The Division also supports in several ways the Laboratory's field activities by surveying and clearing sites for construction, designing and erecting foundations, furnishing and operating huge tractor-trailer trucks and cranes, and awarding contracts.

Accomplishments by the Public Works Division during the year included:

- Completion of a high-level-radiation laboratory for studying the effects of nuclear radiation on engineering materials. (See p. 12)
- Completion of a high-temperature physics laboratory for exploding-wire experiments.
- Construction of a new main gate house and access roads to the new Anacostia Freeway.
- Construction of a hypervelocity accelerator facility for research in hypervelocity impact phenomena. (See p. 10)
- Design and construction of the "brick and mortar" portions of an additional hypervelocity facility at the CBA, consisting of magazines, target storage area, and a gun mount and barrel for firing projectiles.
- Acquisition of a site at Dresden, on Lake Seneca, New York, for a deep-water calibration facility, including the conversion of a railroad car float into a mobile transducer-calibration platform.

## TECHNICAL INFORMATION

The Technical Information Division administers the Laboratory's program of disseminating the results of its research through official publications, exhibits, films, and news media channels. It furnishes technical support services to both NRL and ONR in areas of documentation, editing, printing, presentations, and photography. It operates the Navy's largest and best integrated technical library.

*One of the book stacks in NRL's technical library. Here scientists may find a careful selection of material in all branches of the physical sciences, including current and past issues of nearly 1000 periodicals, both domestic and foreign.*

## ENGINEERING SERVICES

The Engineering Services Division, as its name implies, provides the Laboratory with the necessary support services of engineering, design, drafting, and manufacture of research equipment and developmental and prototype models of equipment generated by research projects. To provide this direct support service to research, the Engineering Services Division is staffed by engineers, designers, planning and production analysis personnel, and skilled artisans of many trades. The shops include machining facilities, sheet-metal-working facilities, pattern shop and foundry, plating and electro-forming, structural and plastics, electronics model shop and coil winding facilities, and, most recently, a printed-circuit facility.

The Engineering Services Division, which recently marked its fourteenth anniversary, is required to design and manufacture a never-ending variety of electronic and mechanical devices. Seldom is a particular task repeated, and the work can vary in size from an item which requires the assistance of a microscope to be seen to a hoist assembly which may weigh up to twenty-five tons. The variety of materials used also is extensive. Plastics, adhesives, metal alloys, and a variety of chemicals are all needed to satisfy specific requirements of function and environment as dictated by research.

In addition to the direct engineering support provided for research, the Engineering Services Division maintains an instrument repair shop where all Laboratory electronic and mechanical instruments are calibrated and maintained. Also, this Division provides skilled personnel to assist scientists in their field operations.

## HEALTH PHYSICS

More than 1500 sources of ionizing radiation are used at the Laboratory in various projects. These include a research reactor, particle accelerators, x-ray machines, and radioisotopes. Approximately one-third of the Laboratory's employees work directly or indirectly with sources of ionizing radiation.

The Health Physics Staff is responsible for radiological safety at NRL. This responsibility is threefold:

1. To the Navy, by assuring, in the most economical manner, that all operations where ionizing radiation is used are safe and in compliance with all pertinent federal regulations.

2. To the employees, by providing conditions, instruments, and assistance which will guarantee radiological safety in the performance of their duties and by instructions in methods for protecting themselves against radiation hazards.

3. To the public, by assuring that radiological operations at the Laboratory will not endanger the health, safety, and well-being of the surrounding community.

*Health physicists were on hand to monitor and supervise the handling of a SNAP-7E nuclear generator during the entire period it was at the Laboratory for hydrostatic tests.*

Professional and technical services by the Health Physics Staff include the evaluation of potential radiological hazards associated with the use of ionizing radiation in Laboratory operations; the supply of personnel monitoring devices and services, protective equipment, and calibrated radiac monitoring instruments; and the responsibility for waste disposal and decontamination. Thus, the over-all Health Physics program assists the scientists in accomplishing the many and divergent missions in radiation research by evaluating radiation hazards, providing adequate controls, equipment, and guidance, and assuring that working environments are safe.