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NRL REPORT 3500

Annual Technical Report

Fiscal Year 1949

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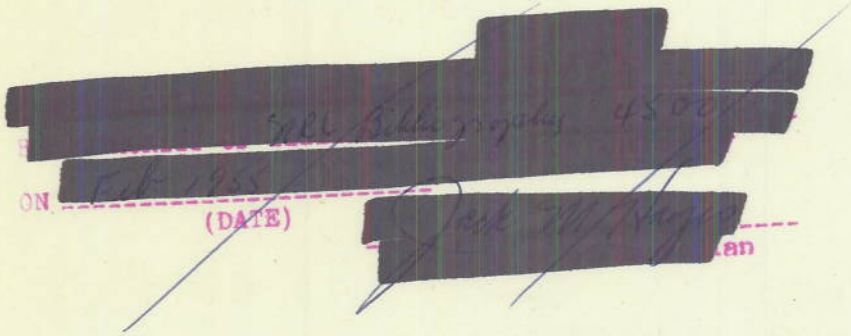

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CAPTAIN F.R. FURTH, USN, DIRECTOR.

Washington, D.C.

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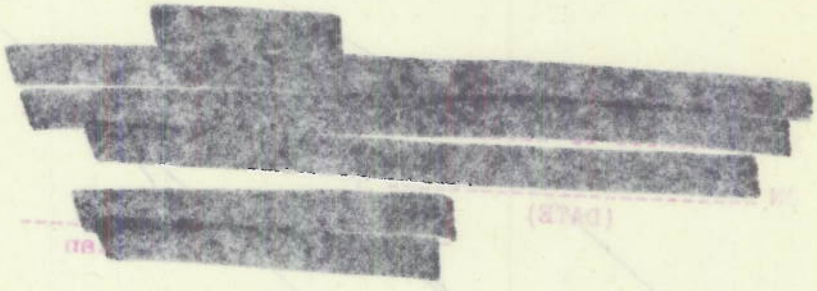
Annual Technical Report



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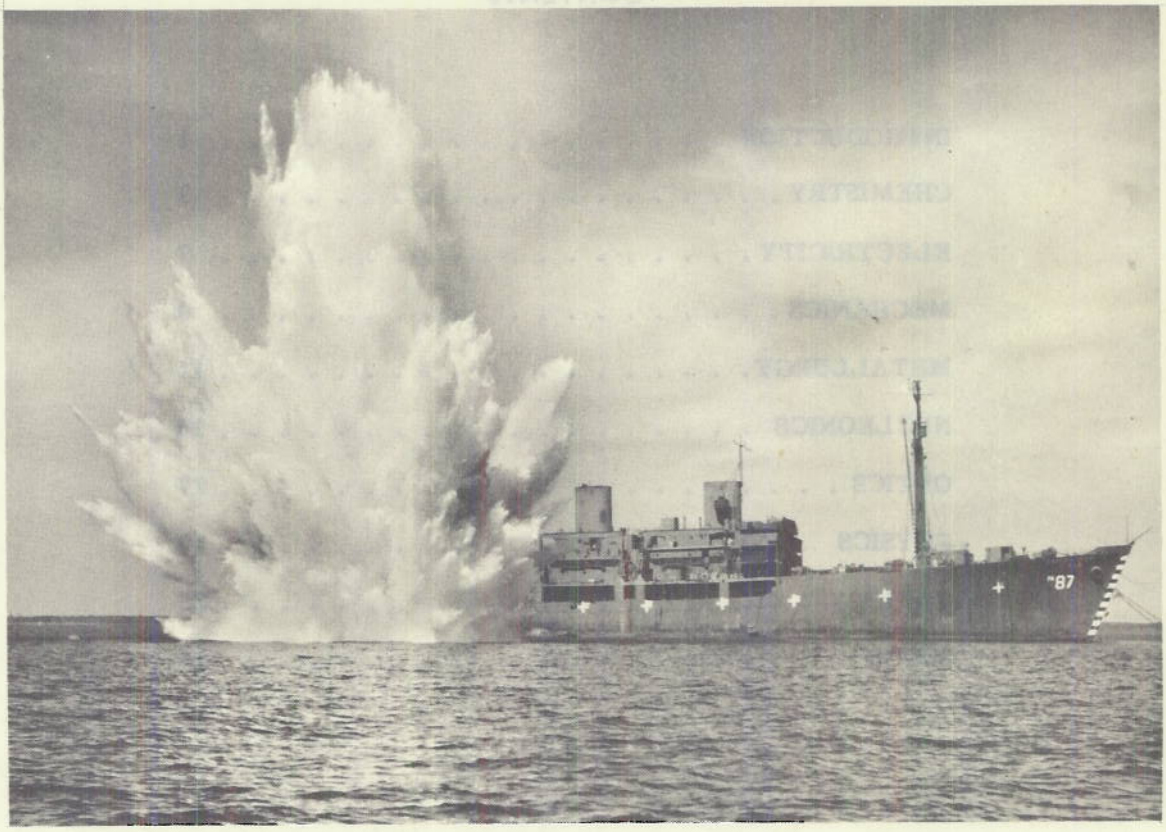

Typical plume from an underwater explosion in shock and vibration studies in the Chesapeake Bay area. This spectacular photograph was obtained in the course of a series of field investigations of the effects of shock on ship structures and interior equipment.

ANNUAL TECHNICAL REPORT
FISCAL YEAR 1949

INTRODUCTION

For more than 25 years, the Naval Research Laboratory has been occupying a place of progressively greater responsibility in U.S. Naval affairs, its broad objective being always, as originally defined, "to increase the safety, reliability, and efficiency of the Fleet by the application of scientific and laboratory experimentation to naval problems." In the course of steady growth from a modest five-building installation (1923) to one of the largest research units in the Navy, NRL has been a pioneer in hundreds of developments—in communications, in detection and ranging, in guided missiles, in underwater sound gear, in physical optics, in hydraulic fluids and lubricants, in fire-fighting equipments—now accepted quite ordinarily in both military and civilian circles.

Fiscal 1949 marked the beginning of the Naval Research Laboratory's second quarter-century of service to the Fleet, but the program of research during that year showed little fundamental deviation from the traditional pattern so successful heretofore. Although by integration toward long-term goals there was the continued reduction, begun postwar, in the number of problems, the scope of the Laboratory's function was, if anything, broadened by the continued pursuit of several programs of special interest to the National Military Establishment as a whole. Beginning with 600 research, development, and test problems on 1 July 1948, the Laboratory accepted 133 new problems and closed out 288 existing problems during fiscal 1949, a net decrease for the year of 155 problems. But, again, this reduction in total number of problems resulted from a careful study by the Scientific Program Board aimed at elimination of all inactive problems and those considered non-productive.

Following established policy, the program for the year was conducted by ten scientific Divisions covering nine fields of science (chemistry, electricity, mechanics, metallurgy, nucleonics, optics, physics, sound, and radio). For those interested in detailed results on any aspect of the scientific program, attention is directed to the formal NRL technical reports (of which 148 appeared during fiscal 1949) available upon request by authorized persons. It is the purpose of this document to bring together in concise form a review of the significant scientific activities of the Naval Research Laboratory during the period 1 July 1948 through 30 June 1949.

CHEMISTRY

Basic research on chemicals which may have possibilities as new fuels continued. Laboratory tests of diborane, a light metal hydride which is a high-energy propellent fuel, are substantially complete and the fuel is now obtainable commercially. Manufacturing methods for aluminum borohydride, pentaborane, and borazole are now being studied on a laboratory scale; commercial concerns will investigate the most promising methods on a pilot plant basis. The Laboratory has produced enough aluminum borohydride to conduct a hydropulse evaluation of this fuel.

A solid slow burning fuel composed of nitroguanidine and guanidine nitrate was investigated for the propulsion of small gas turbines for short periods of time. Satisfactory cigarette-wise burning of the fuel cylinder for a four-minute period was demonstrated.

Turbo-jet engines require a lubricating oil which will withstand high temperatures. A synthetic oil of the aliphatic diester series was developed to meet these extreme requirements and will be used for large-scale engine tests. Systematic laboratory study has developed a number of excellent new high-temperature antioxidants, which are also needed.

Research on high-temperature greases showed progress. A program of lubrication of high-temperature electric-motor ball bearings is apparently nearing a successful conclusion. The greases withstood continued operation without lubrication for 3000 hours at 300° F. The Bureau of Ships has stated that the new grease will find extensive use in submarines and is preparing appropriate specifications.

Basic studies in the field of lubrication and surface chemistry continue on polar molecules and their absorption from aqueous and nonaqueous solutions, on monomolecular films, on optical light scattering and fluorescence methods for the study of colloidal properties of soaps and lubricant additives, and on the displacement of water from metal surfaces by polar compounds. Knowledge thus gained will probably form the basis for future advances in lubrication.

In the field of antifouling paints, it was found that the effect of the particle size of the toxic pigment on the antifouling properties of the paint is not as critical as hitherto supposed. Additional research examined the role of plasticizers and the effect of storage time on toxic paints.

Research on protective coatings for magnesium, centering largely on improving the chromate primers, shows that advantages result from replacing part of the zinc chromate with other chromates. Recently, attention was directed toward improving the adhesion of coatings to the magnesium leading edges of high-speed planes. Current coatings are reported to be unable to stand the ravages of flying through rain.

Studies of fungicides led to useful generalizations concerning the influence of molecular structure on the fungicidal properties of organic compounds.

Research is underway on the synthesis of new silicone monomers in which fluorine replaces the hydrogen to produce resins with increased resistance to heat.

Phosphate coatings on steel were the subject of basic studies. The kinetics of the reaction for the formation of the coatings was determined and the crystal structure of some of the reaction products established.

In the field of personnel protection, emphasis was placed on the detection and removal of harmful airborne particles. These may be liquid or solid and are known as "aerosols." For testing the efficacy of removal methods, an improved aerosol penetration meter is being assembled which has 30 times the sensitivity of the present instrument. Methods were developed for the formation and measurement of aerosols down to about 0.02 microns diameter, as compared with the previous limitation of 0.2 microns. Improved filters are under intensive study. Research on collective protectors demonstrates that the efficiency of electrostatic precipitators can be increased up to 99.995 percent through improved construction.

In relation to the decontamination of ships from chemical warfare agents by means of steam, the hydrolysis and oxidation of mustard at 100° C is being studied. Other projects involve certain aspects of the protective clothing problem and the physico-chemical reactions of adsorptive carbon.

Work on a gas analyzer for the air of submarines operating under long submergence is progressing well. An oxygen analyzer, based on paramagnetic principles, was developed and is undergoing tests, the results of which are so far quite favorable. Other analyzers for carbon dioxide and carbon monoxide are nearing completion and should be ready for evaluation during the next six months.

Research on storage batteries covered basic studies of the lead-acid cell, operational studies of the submarine storage battery, particularly under schnorkel operation, and research on the alkaline storage battery. The silver oxide zinc primary cell was also studied.

Sacrificial zinc anodes for counteracting the galvanic corrosion of ships' hulls are now undergoing service tests on destroyers.

The present sonar recording paper has certain intrinsic defects which limit the reliability and definitiveness of the intelligence received. The development of new types of recording films to improve reception is now the object of high-priority research. Several promising lines of attack are being studied.

A new rubber composition, suitable for use with embedded metallic conductors and capable of maintaining a very high vacuum, was developed and successfully applied in the construction of high-vacuum electronic tubes.

Because of the unique facilities of the fire engineering laboratory, continuous evaluation and consultation on naval fire-fighting problems continue. These include the study of liquid proportioners, high-capacity fog-foam systems, pressure-foam generators for subsurface oil tank fire protection, dry powder chemical extinguishing devices, and new fluorocarbon extinguishers. Looking forward to the possibility of a central foam generating station, basic engineering studies are being made of the flow of foam through pipe systems, especially with regard to foam stability, viscosity, and pressure drop.

New weapons sometimes present novel types of fire hazards. For instance, a full-scale V-2 rocket launching casualty test at White Sands Proving Ground demonstrated the severity of a liquid oxygen and alcohol explosion and led to a study of the explosibility of these materials. Explosions will occur, it was indicated, whether the alcohol be in the solid, liquid, or vapor phase. Means for combating the hazards of an accidentally toppled V-2 rocket are under investigation.

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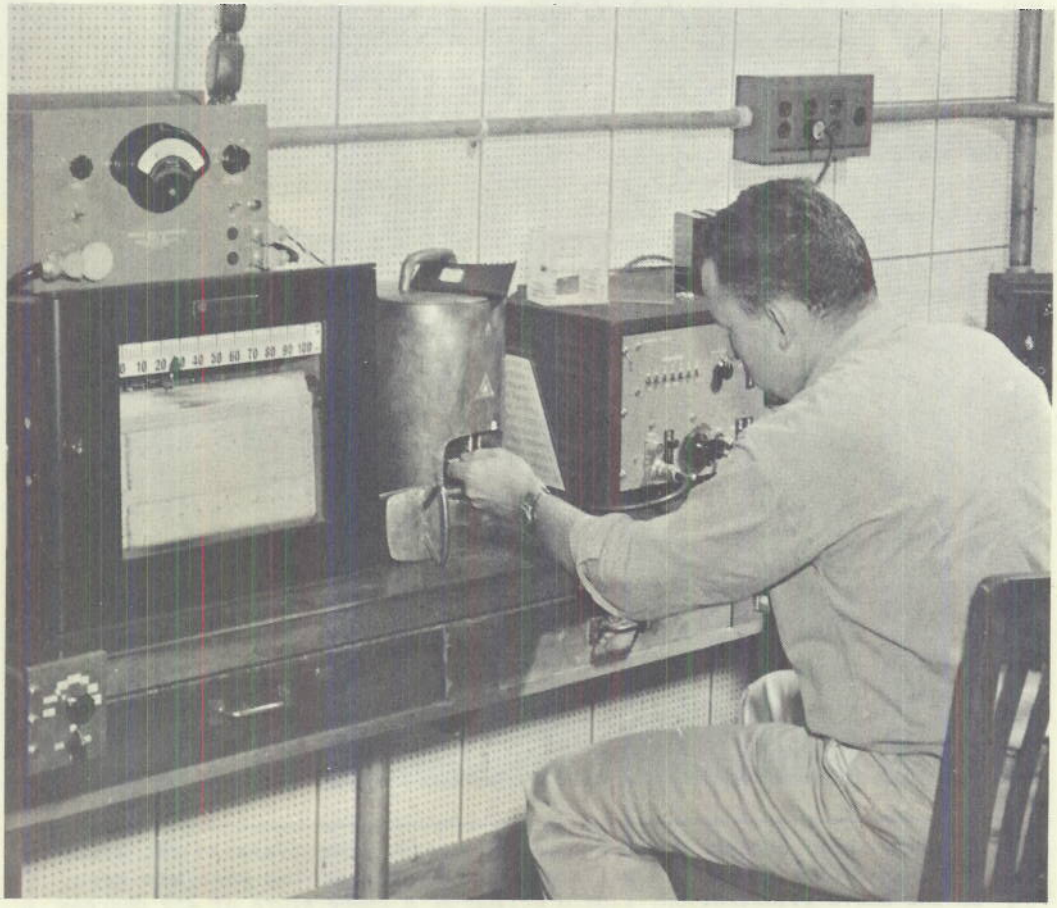

Measurement of radioactivity. A beta absorption curve is taken on a sample of neutron-bombarded sodium carbonate containing 14.8-hour sodium 24 to determine the purity of the sample used in a problem on sodium oxide solubility.

To understand better the behavior of metals, scientists at NRL study the properties of metals at temperatures approaching absolute zero. In the above illustration, liquid helium at a temperature of 452 degrees below zero Fahrenheit is being transferred from the liquefier into a dewar containing experimental samples. Studies of thermal and electrical conductivity, specific heat, and superconductivity are being pursued.

ELECTRICITY

The electricity programs of the Laboratory involve investigation of electrical power systems and equipment, operational equipments, and conversion to electrical energy.

Long-range studies of shipboard and airborne electrical power systems, and investigations of protective requirements for aircraft electrical systems necessitated detailed research into many problems. Design of anticipated submarine electrical systems required a complete understanding of short-circuit currents and flashover characteristics of d-c machines. Experiments on a mock-up of a submarine electrical system showed that peak short-circuit currents may be as high as 8 to 10 times the rated machine currents and that flashover occurs when armature current reaches approximately 5 times the rated current.

Extreme environmental conditions frequently contribute to breakdown or "tracking" across the surface of the insulation separating power conductors aboard submarines. Research led to a theoretical explanation of the phenomenon and will result in recommendations for the minimum spacing of conductors in high-voltage submarine systems.

Similarly, studies of aircraft electrical systems should aid in the design of appropriate systems for modern military aircraft. The installed capacity has steadily increased, bringing about increased hazards from accidental electrical faults. A new protective system will give adequate overvoltage protection and more sensitive differential current protection. It will minimize equipment-damaging and fire-inducing hazards resulting from solid electrical faults, that is, a broken conductor which has welded itself to the frame or skin of the aircraft. Research began on arcing faults, those caused by a frayed or broken conductor making intermittent contact with the aircraft skin. Investigation of life-temperature characteristics of class A and B insulation indicates that the life of these materials may be considerably longer at high temperatures than had been thought, which would result in specifying smaller light-weight motors which could operate at higher temperatures. Permanent magnet alternators now being studied may replace existing generators because of their freedom from sliding contacts which are troublesome at high altitudes.

Shipboard servo systems capable of handling the large amounts of power required to position heavy gear such as radar antennas are increasingly required. To improve the performance of these three-phase servo systems, the Laboratory developed a simple system which uses saturable reactors and provides improved control with low power loss. The application of a magnetic fluid clutch was also investigated for this development and it promises to provide a system having much better response characteristics than the servo motor.

Several new types of operational equipment were developed, for example: (a) A magnetic amplifier type of frequency control unit for use with an 80-volt-amp dynamotor, having no moving parts and maintaining the frequency of the dynamotor output within 0.15 percent at 60 cycles per second under severe operating conditions. (b) A new type of fire-alarm thermostat together with a shock mount

for shipboard installation, which can at times serve as an alternate for the currently used fragile mercury-in-glass thermostat. (c) Rugged indicator lamps and resilient fixtures for showing vital information such as power availability, equipment conditions, and battle information. These lamps will stand up under severe shock of battle conditions and may be installed in existing switchboards with a minimum of modification. (d) A small colored indicator light with self-contained transformer, which is resistant to high-intensity shock. As it requires only slightly more than one square inch of panel space, it is particularly suited for damage control boards. (e) A foolproof multiport valve which provides safe, positive air venting of a submarine's log under submerged conditions. (f) Two types of tank-level indicators, one for gasoline and water, the other for any single liquid or any two immiscible liquids. Both types provide remote indication at several locations simultaneously and result in improved accuracy and reliability for shipboard applications. (g) Basic electric computer elements for application to an aircraft jet-thrust computer and a carrier barrier cable accelerator.

* * *

MECHANICS

The mechanics programs include research on shock and vibration, strength of solids, and penetration and aerodynamic ballistics. During the year, work was done on: (a) propagation of mechanical shock in simple beams and plates, (b) electrical resistance changes during elastic and plastic extension of metal wires, (c) an extension of the NRL plan for absolute calibration of electromechanical vibration indicators, and (d) use of ultrasonic detection techniques. A study of noise isolation characteristics of shock mounts was started.

During the summer of 1948, in cooperation with other Navy groups, there was conducted an extensive series of trials of shock effects propagated through a ship's structure. Noncontact underwater explosions near the USS NIAGARA APA87 were employed. Study and analysis of the data continues.

Research on the strength of solids included studies of plastic flow and fracturing, armor materials, strength of metals under shipboard shock, and effects of permanent deformation upon internal damping.

Motion picture photography with appropriate lighting and speeds up to 3,000 frames per second proved effective for recording and demonstrating results of the model studies of plastic flow and fracturing. Models which used soap bubbles provided qualitative information, and the centrally slotted foil fracture model technique developed last year continued to supply quantitative as well as qualitative data.

Several new research tools for pulling metal wires and plastic fibers at constant true strain rates were successfully completed and tested. An effect of water molecules upon strength of oriented nylon was investigated over a wide range of strain rates. X-ray line broadening techniques were also used in studying the deformation of nylon filaments. Maximum preferred orientation occurred approximately at the inflection point of the load-strain curve. The subsequent portion of the deformation resembled plastic deformation of crystalline metals in its effects upon azimuthal and radial line broadening.

Applied research on armor materials disclosed excellent performance in certain preparations of titanium as armor. A report was made on a method of improving ballistic resistance of aluminum alloy armor by "cool forging" and heat treatment. Investigations of plastic fiber armors continued.

The relative ability of certain common metal structural materials to withstand severe mechanical shock was measured.

Experimental work was resumed, using the precision optical chronograph, on the measurement of force as a function of time during penetration at ballistic speeds. The impulsive pressure in closed aluminum boxes during impact flash was studied and comparison with other impact flash data indicated that about as much of the impulsive wall pressure is due to fast particles of debris from the penetration as to gas pressure. Establishment of an experimental procedure for

comparing relative gunfire damage vulnerability of aircraft structural components proceeded slowly.

Development continued on the momentum trap method for measuring aerodynamic forces on objects in free flight at high Mach number. Comparisons of air-drag data for spheres indicated that the method as now applied gives values about six percent low relative to results obtained with spark photography range and counter chronograph techniques. Exploratory trials of longer periods for the ballistic swing of the momentum trap indicate long-period seismograph-type suspensions may be required. A 37-mm gun is being installed for this work.

The Shock and Vibration Centralizing Activity held its twelfth symposium on 16 February 1949, with attendance exceeding 300. A sub-committee completed a report on nomenclature and definitions in the field of shock and vibration which was submitted to the American Standards Association for study. A nation-wide survey of research and development on shock and vibration was prepared for distribution by the Research and Development Board.

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METALLURGY

To the Navy, to the Armed Forces in general, and to industry, there is a need for expanded knowledge of the factors which affect high-temperature performance of metals. As a first step in this direction, a research group was organized and appropriate equipment was assembled to carry out evaluations of grain size influences on creep rupture properties, and to study the influence of environment, strain rate, and fluctuating stresses on the nature of fracture and on flow at elevated temperatures. Attention is first being centered on single phase metals and alloys; later extensions will be made to more complex alloys. Future work will involve a study of transformations that occur in some of the more common high-temperature alloys.

Because of its importance to ship steels, an investigation of the effect of alloying elements on the temperature-brittleness relationship is being conducted by studying steel specimens of about 50 different compositions. Base compositions of approximately .30% carbon and 1.00% manganese, all steels having similar microstructures of coarse pearlite, are being examined, and correlations are being made between composition, microstructure, strength, and notch toughness. Inasmuch as evidence indicates that ferrite properties largely influence structural steels, facilities are being assembled for the preparation and detailed study of pure ferrites.

Toughness or ductility of steels was also investigated through the study of austenite formation at normal temperatures used for tempering. By carrying out this work on a steel of .10% carbon, 3.5% manganese, and 2.5% nickel in the range of 900° - 1250° F, it was found that (a) austenite increases above 900° F and (b) the temperature at which martensite forms on cooling increases as the tempering temperature and holding time increase. Correlation is now being made between mechanical properties and quantity of austenite retained in tempered and untempered martensite; future work will involve austenite formation during tempering for other alloys.

High-purity titanium was prepared by the thermal decomposition method and was so ductile that, without intermediate annealing, it could be reduced from 0.25 inch to 0.015 inch in diameter. Apparatus was prepared to make titanium-oxygen alloys by diffusing oxygen through heated titanium, and a method was developed for the analysis of oxygen in titanium, which appears to give more satisfactory results than other known methods. Work continues on the preparation and investigation of this metal and on the equilibrium diagram of the titanium-oxygen system to a composition of ten percent by weight of oxygen. A number of different refractory materials were investigated for use in melting titanium. Graphite, pure carbon precipitated from organic solutions, beryllia, zirconia, and cerium sulfide were all tried without finding a satisfactory material; research now continues on such materials as refractory carbides and borides in both high vacuum and inert atmospheres. As a means of making small melts of titanium, experimental arc-melting equipment was installed.

According to a theory that particle size of metallic flakes might be a factor in their role as high-frequency wave absorbers, a study was made of permalloy

powder in various sizes starting at 0.5 microns. Within the range studied, however, the particle size appeared to play no important part. Other work on electric and magnetic alloys continues on an examination of an iron-aluminum alloy, Alfer, which might prove to be a very good magnetostrictive alloy, and of silicon as a rectifier possibility. An investigation of electrode influence on transient electrical discharges upon interrupting a current will be reactivated.

The Laboratory is attempting to establish scientific facts concerning foundry methods, which have largely been evolved by trial and error. Investigations were made on the effect of melting practices, on methods of introducing liquid metals into molds, on the feeding range of risers, and on sands. By studying the effect of atmospheres on copper alloys known to be sensitive to melting conditions, it was found that oxidizing and reducing conditions produced differences in the castings. Dry nitrogen treatment improved castings melted only under extremely reducing conditions.

The momentum of a pouring metal was found to be an important disadvantage during flow in step and finger gates. Several methods were found which reduced this momentum, and step gates were designed which produced a desired flow sequence. As the design of risers has always been controversial, experiments were performed to determine limiting sizes of steel castings that can be made from specific risers with the plane of the casting, its thickness and design varied. The expanse of sound metal produced by a single riser was found to be surprisingly small, and studies are now under way to determine the cause.

Necked-down risers may cause hard spots and cracks in steel castings just below the riser cut-off section. Research showed that these may arise from carbon segregation, which can be minimized by the use of wider and shorter riser necks and by making the riser core from exothermic materials. Special insulating materials for ferrous risers were investigated as they promise to offer considerable economy of casting material.

In thermal expansion studies of investment mixtures for precision castings, it was found that the extent of expansion is largely controlled by the refractory and binder used. Promising results appear possible with properly sized particles of calcined and crushed fire clay with ethyl silicate binder.

A simple general formula for mold washes was developed for various metals and consists of silica flour (optimum size of 20 microns) as the refractory which is mixed with bentonite, dextrine, sodium benzoate, and water.

Research was initiated on the effect of alloying elements on graphite shape and distribution in cast iron. During this investigation, nodular graphite was produced through a magnesium alloy more safely and economically than by any other known alloy.

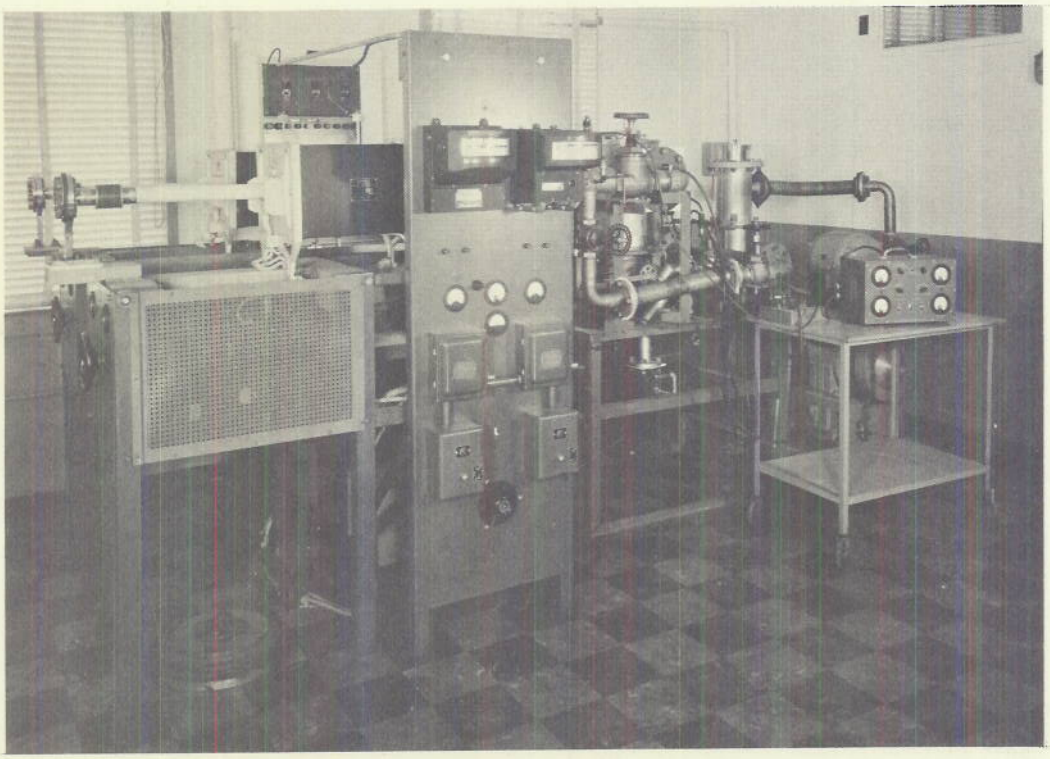
Most of the test and evaluation problems under the general subject of welding which were carried over from the war were completed, and new welding problems were initiated to obtain more fundamental information concerning welded joints. The new problems are concerned with the welding of high-strength aluminum alloys, high-temperature alloys, and high-tensile steels.

Of the test and evaluation problems brought to a conclusion, one dealt with the evaluation of laboratory tests of large-scale specimens such as a welded box

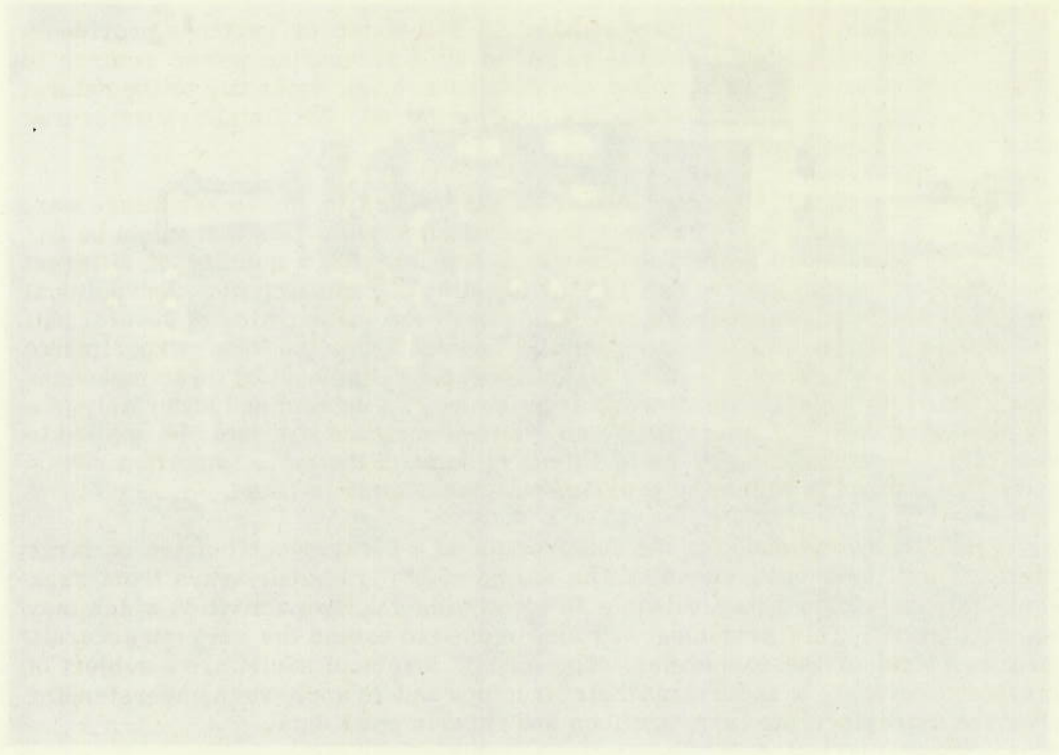
girder. This work was carried out in collaboration with the Welding Research Council and the National Bureau of Standards. Performance evaluation, it was found, depended on the definition chosen for transition from ductile to brittle behavior and was also found to be beyond the capabilities of any simple laboratory specimen.

In studying the effect of titanium and vanadium on the weldability of low-alloy steels, it was discovered that (a) small changes in these metals had a marked effect on transition from ductile to brittle behavior, (b) welding adversely affected both steels especially at higher percentages of the alloy, and (c) in order to have minimum notch sensitivity, carbon and titanium in combination should not exceed 0.15% and 0.25% respectively, and carbon and vanadium 0.15% and 0.10% respectively.

The low strength of welds in high-strength aluminum alloys 24S-T and 75S-T results less from the welding heat than from the low strength of the filler alloys normally used. By using 75S-T alloy as a filler, a commercial alloy not generally so used, joint-strength efficiencies of welded 75S-T sheet were increased as much as 20 percent.



High-vacuum, heat-treating apparatus. In this equipment, NRL metallurgists can heat-treat such gas-sensitive metals as titanium without appreciable contamination from atmospheric gases. Pressures of the order of one billionth of an atmosphere are required to prevent embrittlement of the metal upon prolonged heat treatment.



NUCLEONICS

Research in nucleonics includes four general programs in the fields of nuclear constituents, structure, motive power, and technology.

During the fiscal year, activities and reports were completed on Operations Fitzwilliam and Sandstone, which involved the testing of atomic weapons and observations of nuclear phenomena at the Atomic Energy Commission proving ground on Eniwetok Atoll in the Marshall Islands. These two large undertakings were the only occupations of the newly formed Nucleonics Division until about September 1948. After their completion, the Division undertook twelve problems within its four programs.

The first comprehensive study of Multiple Compton Scattering demonstrated, for example, the futility of attempting to devise gamma-ray instruments to detect the bearing of an atomic bomb explosion, when that explosion takes place at any distance over a few hundred yards.

Measurement of the activity induced in sea water by neutrons provided a basis for estimating the shielding required by a submarine power reactor to escape detection. The background counting rate in sea water due to the natural activity of the potassium present was also measured. Artificial sea water was used in these experiments.

Because radioactivity may appear in diversified forms in any future war, means must be devised to identify the radioactive materials that might be encountered. Identification may require the measurement of a number of different quantities, one of which is the half life, or duration of radioactivity. Conventional measurement requires an experiment extending over the duration of several half lives, which from a military standpoint is frequently far too long. Experiments are underway which may lead to a considerable refinement of these measurements so that the half life of weak samples may be determined accurately in a fraction of a half life interval. These refined methods will later be applied to an accurate determination of the half lives of some of the more important radioactive substances in which the experimental uncertainty is large.

Plans are being made for the construction of a β-ray spectrometer of large aperture for the measurement of the energies of β-ray and γ-rays from weak samples, these data being valuable in identifying unknown activities which may be encountered. This instrument will also be used to extend the very few accurate measurements of these energies. The energy levels of nuclei are a subject of great controversy; to understand their structure and to apply such understanding requires more accurate investigations and experimental data.

As another approach to the problem of obtaining detailed knowledge of nuclear structure, the Laboratory acquired and installed a two-million electron-volt electrostatic generator (Van de Graaff machine) and is making preparations to study the precise interactions of nuclear particles with each other and with other nuclei.

When the energy with which nuclear particles interact with nuclei is raised from the million to the billion electron-volt region, entirely new effects are observed. Nuclear explosions of great violence occur and new particles (mesons) are created. Although study of these phenomena has only begun, scientists unanimously feel that this is the area in which the future of nuclear technology lies. Accordingly, after study, a recommendation has been made to ONR to construct a machine (proton-synchrotron) to accelerate particles to energies of the order of approximately one-billion electron-volts. In the meantime, a minor study is being made of the high-energy particles found in cosmic radiation as they interact with matter.

Scientists know little about the effects on matter of electrons and γ-rays with energies above a few million electron-volts. With increasing use of high-energy accelerators industrially and experimentally, this information is much needed. Using the 20 MEV NRL betatron, the Laboratory initiated this work and has published a short notice concerning the radioactivities induced by high-energy γ-rays in a variety of substances.

To reach higher energies of electrons, a cheap and compact design for an electron sychrotron is being developed.

The Laboratory has been active in the field of mass spectroscopy for some time because instruments to measure the relative isotopic abundances of samples are of fundamental importance in nucleonics. A small mass spectrograph is being devised for use in high-flying rockets to measure the argon-nitrogen ratio throughout the whole depth of the atmosphere. A precision mass-measuring spectrograph is being planned and probably will be built during the next year. This should enable accurate mass measurements for elements in the middle of the periodic table where data are now lacking.

Work was instituted in health physics, an essential part of any nucleonics program. At present this involves only the monitoring of radiation received by personnel—monitoring accomplished through the processing of film badges and the calibration of dosimeters and monitoring instruments. Another essential service function is the design of special nuclear instruments, such as remote manipulators for strong radioactive materials.

Because it is very frequently necessary to concentrate or extract radioactive isotopes by chemical means and because these materials are often encountered in extremely dilute solutions, studies will begin on the chemical reactions of (infinitely) dilute systems. The chemistry of such dilute systems differs from that of more concentrated systems and is not at all adequately understood.

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OPTICS

As part of the research into optical properties of materials, the Laboratory extended the development of reflection-type interference filters. With these, measurements in the infrared spectrum can be restricted to a selected band of wavelengths without employing spectrometers. The filters, which are simply constructed, are essentially selective reflecting mirrors that produce interference fringes similar to those of a soap film except that they are much more brilliant. One of their uses is in the isolation of the 4.4-micron emission band of certain jet-engine exhaust flames.

A basic limitation to communication by optical radiation, whether in the ultraviolet, visible, or infrared region, is atmospheric interference. Measurements were made of the frequency distribution and wave shape of the fluctuations in background illumination and atmospheric transmission, with the aim of determining optimum communication carrier and modulation frequencies.

The operating range of a thermal detector is similarly determined by (a) the amount of radiation emitted by the target, (b) the amount and character of the background radiation, and (c) the amount and character of absorption in the intervening atmospheric path. To evaluate these factors, an experimental target consisting of an aluminum block 36 by 36 by 6 inches fitted with shore-controlled electrical heating units, was erected on a tower on a level with the detector location, 4,500 yards offshore at the Chesapeake Bay Annex of the Laboratory.

One aspect of upper-air research was the measurement of the brightness of the daytime sky at altitudes from 10,000 to 38,000 feet. Values of solar illumination were substantially lower than comparable data previously obtained between sea level and 10,000 feet. Consequently, work is continuing on clarification of the apparent discrepancy.

The brightness of the night sky, the natural night illumination near the surface of the earth, is being surveyed in latitudes higher than 45 degrees, which was previously the limiting boundary of such studies. Photometric observations are being made regularly at several locations scattered over North America.

A program of systematic measurement of the radiation transfer between earth and sky as a function of wavelength, zenith angle, time, and weather, was recently initiated. The work relates to a problem on infrared detection of aircraft for fire-control purposes.

One problem in long-range missile-guidance systems is the establishment of a stable vertical which can be accomplished by optical methods. Measurements at sea level indicate that by both day and night the horizon is sharply defined by a thermal radiation discontinuity. Special airborne infrared equipment was developed for use in a B-29 aircraft to investigate the infrared radiation from the horizon as viewed from high altitudes. Measurements made during three flights showed sharp thermal discontinuities at the unobscured earth-sky horizon at all altitudes up to 36,000 feet, and less sharp discontinuities produced by clouds.

As part of the study of infrared detection of jet-powered missiles or aircraft, a determination was made of the transmission coefficients of carbon dioxide present in the atmosphere for 4.4-micron infrared radiation emitted by hot carbon dioxide in flames. The result indicates that infrared detectors such as lead telluride cells may be useful in detection, guidance, or control devices against targets emitting slightly luminous flames.

Installation of a vacuum ultraviolet monochromator inaugurates a program of quantitative spectrophotometry in the little explored extreme ultraviolet spectrum.

Research on night vision in the field of physiological optics produced new data on the spherical aberration of the eye at several stages of accommodation. Study continued on the best use of radioactive self-luminous markers and fluorescent materials on decks, on instrument dials, and in other applications on darkened ships.

Since atmospheric absorption limits the operational range of an optical communication system, it is desirable to increase the output of the transmitter. However, for reasons of security, the average output of visible light must be kept low in comparison with the useful radiated output. One means of obtaining the desired ratio is pulse-time modulation, and a project was conducted to provide a better source of code-transmitting radiation capable of incorporation in a pulse-time system. Gaseous discharges excited externally by pulse-modulated radio frequencies offer advantages in optical communication systems by virtue of very high peak output and low visible output. Excitation of this type also enables convenient study of emission spectra in the presence of a steady background of very similar spectral quality. Square pulses of radiation of any pulse length can be generated.

Research on the difficult problem of detecting schnorkelling submarines led to advances in the measurement of the thermal radiation emitted by the Schnorkel and the wake of the vessel. Infrared detection equipment, the Passive Bearing Finder, designed for use by submarines against surface targets, was mounted in a blimp and surveyed the USS DOGFISH under various operating conditions at night. The infrared radiation from the schnorkel was detectable at an altitude of 2,000 feet, and the radiation from the wake was detectable from the same altitude three miles astern. In consequence, infrared equipment expressly designed for airborne use was devised. It has performed well in preliminary blimp flights from Naval Air Station, Lakehurst, N. J. and will be used in more extensive tests in the warmer Key West waters where the thermal nature of wakes may differ.

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PHYSICS

ELECTRICAL AND MAGNETIC PROPERTIES

An extensive program of theoretical and experimental research in the fundamental electrical, magnetic, thermal, and mechanical properties of matter is carried on. The studies are concentrated in the fields of low-temperature research, surface phenomena, and the interaction of the nuclei and electrons of solids with their surrounding lattice.

Because many unexplained phenomena occur at extremely low temperatures (in the vicinity of 4° K), the interdependence of these properties at these temperatures is under investigation both theoretically and experimentally. As one phase, the low-temperature behavior of an assembly of particles was studied. Accumulation temperatures for an assembly of particles obeying the Bose-Einstein statistics are the basis for predictions of the accumulation temperatures to be expected for bi-electron and deuteron gases within solids. Experiments will test the validity of the theoretical predictions.

To subject the London Theory of Superconductivity to a critical test, a study of the diamagnetic susceptibility of suspensions containing superconducting spheres is being carried out. Experiments show that increasing the volume concentration of superconducting spheres results in decreasing the experimentally determined value of their diamagnetic susceptibility. Accordingly, corrections for the proximity effect must be made before attempting any theoretical interpretation of the susceptibility measurements.

To examine the applicability of electrodynamic theory to multiple-connected superconducting systems, the theoretical expression for the magnetic field about a superconducting torus was derived. An experimental determination of the field distribution was made, and it confirmed the theoretical predictions.

The development of fundamental theory of elementary particles requires an understanding of solid-state phenomena at low temperatures, and one of the problems is to unite the theories of the gravitational field with the quantum theory. The limitations set by the uncertainty principle on the measurement of the curvature of space were investigated theoretically by examining the behavior of a small test particle passed around a geodesic triangle. Results led to the conclusion that, in any theory which attempts to unite quantum theory with the general theory of relativity, the relation of the matrix to the energy momentum tensor must appear only in the large and in a statistical sense, that is, for large regions of space and large numbers of elementary particles.

Surface electrical behavior was the subject of several studies, one of which developed a method of predicting the generated noise voltage of a parallel set of electrical contacts from simultaneous resistance and voltage measurements on one contact. Another study indicated that, at least for the simple contact used, and for current densities less than 300 amperes per square centimeter, field emission currents do not contribute appreciably to the current carried by the

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contact. A velocity analyzer for slow electrons was required, and such an instrument was built using 180-degree deflection in a uniform magnetic field. It is used to investigate secondary electron emission from semi-conductors. A graphical method was developed for determining the transmission factor of the analyzer as a function of the velocity of the incident electrons.

Investigation of interatomic forces—interaction of the magnetic moment of the electron and nucleus—is being studied by measurements of the relaxation time and line breadths of nuclear resonance absorption. The lattice-ion interactions in paramagnetic salts are being studied through electronic resonance experiments.

Studies of the behavior of lead and tin resonant cavities were continued on specimens made of the pure metals and having a single soldered lid. Excitation was carried out so that no current flow took place across the soldered joint. By measuring the resistance of the material at microwave frequencies through measurements of the decrement, it was found that loaded Q's were recorded at 9,000 megacycles and at 1.95°K as high as 3.5×10^6 for the lead and tin. The unloaded Q's are of the order of 10^7.

Research on ferromagnetic properties of metals at radio frequencies continued. Emphasis was placed on improvements of technique for the measurement of the complex permeability at very high frequencies. Major improvements included development of a stable and powerful source of CW at frequencies up to 3,000 megacycles and advances in the design of cavity resonators. It is anticipated that completed experimental work and theoretical studies will permit use of improved apparatus for securing a wide range of interpretable data on the complex permeability of unusually pure metallic specimens having well-defined surface properties.

ENGINEERING PHYSICS OF MATERIALS

In the operation of the Human Centrifuge, there was required the transmission of small electroencephalograph signals, 10 microvolts or less, through a rotating joint. Noise voltage generated by sliding contacts interfered, however, and various materials and contact arrangements were evaluated in order to select a device producing low generated noise.

ATMOSPHERIC ELECTRICITY

A program has approached completion on the development of special antenna hardware for the reduction of precipitation static on aircraft. This type of static, which interferes with radio reception, is caused by flight through rain, snow, or sleet. By covering the antenna system with a material of high dielectric and insulation strength and by other changes, interference is reduced to a tolerable level.

HEAT POWER

Because of the high noise levels, heat power experimental work on pulse-jet engines has been conducted at the Chesapeake Bay Annex of the Laboratory. One

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of the chief limitations of the engines is the short service life of the vibrating reed valves upon which the simplicity and automatic functioning of the engine are contingent. After much experimentation, a ribless valve box completed an endurance test of 40 hours on a six-inch-diameter engine 63 inches long operating at 105 cycles per second. With the newly designed valve box, the engine generated a maximum thrust of 80 pounds compared with a 50-55 pound maximum with the old style valves. The new valve box has laminated vanes striking one upon another rather than upon fixed seats, a "keeper" to provide structural reinforcement, and neoprene "bumpers."

A compact, experimental, high-frequency engine, 6 inches in diameter and 32 inches long, operating at 160 cycles per second, was developed in a size suitable for rotor tip application. The tip-mounted pulse-jet may be used as a helicopter engine because of its high thrust per unit of engine weight, reasonable fuel rate, and elimination of heavy, complex drive gear. To provide a dynamic test for high-frequency engines, a whirlstand apparatus with rotating arm and suitable instrumentation was built. It is expected that this equipment will supply a means for correlating static test data with flight performance.

METEOROLOGY

Meteorological work has led primarily to the development of special instruments either for operational use or particular research problems.

An aerograph for use on aircraft was developed to provide an improved method for recording true air temperature, static air pressure, and water vapor pressure.

A balloon is being developed which will rise to and remain at a predetermined altitude for a period of several days. It will probably be a closed-appendix type with a nonextensible envelope and will serve both operational and research uses.

Design and construction is nearly complete on a whirling device which will impart velocities exceeding the speed of sound to test specimens. It will rotate the test body at the end of an arm about a vertical shaft driven by a suitable power plant. A speed of Mach 1.3 at sea level atmospheric pressure should be obtained with a 2,000 horsepower engine. Special instrumentation will permit continuous observation of the test object while in flight, and electrical leads will make possible electrical measurements. The device will provide information on frictional electrification and aerodynamical factors under actual atmospheric conditions.

Special electronic apparatus was devised to utilize the microseismic method of detecting and tracking hurricanes or typhoons at sea. It permits rapid determination of the direction of propagation of the earth motions which originate in the vicinity of the storms and which are detectable for hundreds of miles. Experimental stations using this equipment will be in operation at Chesapeake Bay Annex and at Miami during the hurricane season of 1949.

UPPER ATMOSPHERE

The Laboratory was the principal research agency in two V-2 flights and participated in several others. Under the category of "firsts," the first NRL

Aerobee was fired in August 1948, the first Skyhook balloon experiment was conducted in September 1948, and the first Viking was successfully fired in May 1949.

As borne out by cosmic-ray cloud chamber photographs taken during a V-2 flight, particles with greater charge and mass than the proton are present in primary cosmic radiation. In later flights there were found no differences in intensities of ionizing and soft gamma radiations in the upper atmospheres by day and by night. It appears that very little gamma radiation in the range of 0.08-5 MEV comes from the sun. Soft X-rays were discovered above the atmosphere during two rocket flights; however, the intensity appears to fluctuate widely.

A theoretical study of counting with Geiger counters was made, in which, under simplifying assumptions, the coincidence rate of a two-counter telescope was obtained for the case of isotropic radiation and also for the case in which the radiation varies with zenith angle in accordance with a cosine-squared law.

Atmospheric pressure measurements were made in the first Aerobee flight, in a V-2 flight, and in the first Viking flight; ambient temperatures were derived by calculation. These results corroborated earlier findings, but measurements above 50 kilometers (31 miles) were still crude and it is expected that future firings will produce more accurate data through new techniques which were developed.

The first Viking flew successfully in May 1949 at the White Sands Proving Ground. It reached a velocity of 3450 feet per second after 54 seconds of powered flight, at which time power cutoff occurred, and the rocket reached a maximum altitude of 50 miles. Though the missile's aerodynamic design and control system performed favorably, improvements in the power plant, control system, and operational procedures are being made. These improvements are expected to allow the rocket to reach altitudes of 190 miles. A shipboard launching is anticipated during the coming year.

The Naval Research Laboratory Rocket Impact Computer was installed at White Sands early in 1949 and has performed successfully several times. A new NRL telemetering system usable in the Viking and the V-2 has proven itself. It operates on 1025 megacycles, has 30 channels, a sampling rate of 312-1/2 per second on each channel, a range of 250 miles, video recording, and an accuracy of ±1 percent. Telemetering systems were also developed for balloons and Aerobee rockets.

A phosphor of calcium sulphate and manganese sulphate known to be thermoluminescent after exposure to extreme ultraviolet radiation of wavelength shorter than 1300A was found to be sensitive to X-rays as well. Samples of this phosphor were carried in V-2 rockets on November 18, 1948 and February 17, 1949 to altitudes of 90 and 79 miles respectively, and exposed to radiation from the sun for approximately three minutes. Some were bare and some covered with filters. The results indicate the presence at high altitudes of a considerable intensity of solar radiation in wavelength regions between 1300A and 1230A, 1230A and 1100A, and below 1100A; the presence of X-rays is also indicated.

PHOTON AND PARTICLE COUNTERS

Two types of self-quenching Geiger counter tubes with simple gas fillings, and proportional counters for use in alpha, beta, and gamma ray survey meters were developed.

ELECTRON MICROSCOPY, X-RAY, AND ELECTRON DIFFRACTION

Studies in the basic structure of matter have continued with electron diffraction experiments using 40-kilovolt electrons. These studies together with the use of a newly constructed diffraction machine make possible more accurate determinations of molecular dimensions and the internal motions of the atoms of a molecule.

CRYSTALS

Nonmetallic crystals have wide application in many components of radar, sonar, and optical devices. A broad program has been continued, therefore, on the development of new methods of growing synthetic crystals, on the application of new materials for specific applications, and on the fundamental investigation of crystal properties.

As one of the applied investigations, efforts were directed toward the development of a simple, inexpensive, and rugged device for measurement of nuclear radiation using phosphors in conjunction with photomultiplier tubes. Alkali halides of the proper texture and impurity content hold promise in this connection. More promising as scintillation counters than the alkali halides are single crystals of the tungstates $CaWO_4$, $CdWO_4$, and $ZnWO_4$. From the measurements of the comparative "figures of merit," synthetic $ZnWO_4$ crystals appear superior to the other two tungstates and thallium-activated potassium iodide.

A survey of the infrared photoconducting properties of crystals was started as a means of finding new materials which can be used as detectors of infrared radiation. The investigation thus far has been concerned with the relation between the infrared absorption and the spectral response of photoconduction.

One phase of the work on single crystals for special applications was concerned with a study of synthetic rutile (TiO_2). Preliminary research indicates that reduced rutile crystals may have application as impedance-matched rectifiers, crystal triodes, or waveguide terminators.

In the search for improved materials for sonar gear, this search being concerned chiefly with barium titanate ceramics, it was found that thick specimens of the ceramics (1 to 2 cm) can be prepared having the same high value of the coupling coefficient as found in thin sheets. A study of the breakdown of ADP (ammonium dihydrogen phosphate) crystal transducers showed that failures occur in the castor oil and not in the crystals. At present, then, the crystals are not the limiting factor in applying higher voltages to transducers.

Two additional methods for preparing single crystals were added to the crystal-growing facilities. The first, the flame-fusion process, was used to prepare rutile and the tungstates; the second, the gas-phase process, was found to be essential for preparing the crystals of ZnS, CdS, and similar materials used in the investigation of photoconductors.

Fundamental investigations of crystal properties resulted in several significant contributions. Experimental work on the mechanism of crystal growth from water solution led to the discovery of two significant facts: (a) the growth rate

of crystals in solution is dependent on surface area, and (b) good crystal growth occurs most readily in systems having a large supersaturation. It was further found that by the addition of additives such supersaturation could be induced in systems which do not show large supersaturation in the pure state.

Considerable progress was made in clarifying the concepts underlying the relationship between optical properties of crystals and molecular structure. By correlating the results of photoelastic and thermo-optic studies carried out at the Laboratory, it was possible to explain the change in refractive index with temperature in terms of the change in molar polarizability and the corresponding shifts of the absorption frequencies due to density and temperature effects. These studies together with an investigation of the Cauchy relations in NaCl and CsCl-type crystals led, also, to a better understanding of the influence of homopolar bonding on the elastic, optical, and dielectric properties of crystals. Further evidence for the role played by the deformability of atoms in infrared absorption was demonstrated in the case of diamond which is completely homopolar and which would never exhibit absorption on the basis of anharmonic vibrations.

Electron trapping by impurity ions in crystals plays an important role in breakdown phenomena, photoconductivity, and luminescence. Studies of color-center formation by X-ray irradiation in impurity-containing crystals clarified many of these phenomena.

A significant contribution to an understanding of the mechanism of dielectric breakdown was made in an investigation of the breakdown patterns in non-centro symmetric crystals. The patterns in such crystals as ADP and $NaClO_3$ were found to lack a center of symmetry, which indicated that the simple Brillouin Zone Scheme employed by other investigators was insufficient.

Important results originated from the fundamental investigations of luminescence. With single crystal specimens of the tungstates, it was possible to make improved measurements which showed that photoconductivity does not exist and that free electrons are not produced in the absorption of energy. A thorough study of the Mn^{++} activated luminescence in the zinc beryllium germanate system of solid solutions was carried out. Interpretation of the excitation, absorption, and emission depends upon the coordination number of the manganese rather than upon the relative number of single and paired manganous ions.

APPLIED MATHEMATICS

In the field of applied mathematics, the possibilities of making computations and model experiments through the use of analog devices were further explored. This led to the development of an improved differentiating circuit and the formulation of an equivalent circuit for a beam vibrating in flexure, including both shear and bending motions. Installation of an electronic differential analyzer is nearing completion. Mathematical studies on continuum theories have produced three extensive reports which will serve as important reference works in this field.

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RADIO

COMMUNICATION

Improved methods for minimizing multipath propagation limitations resulted from experimental studies of long-range facsimile circuits employing multi-channel multiplex techniques. A system employing eight tone channels contained within a single octave makes it possible to operate at speeds at least three times faster than have been attainable with a sequential system under multipath conditions of average severity. Modulation difficulties were alleviated by the development of a phase modulating system of improved frequency stability and simplified tuning adjustments.

The development of a self-aligning communication system permitting the use of directive antennas in a mobile microwave communication circuit progressed to the operational experiment stage. By means of suitable electronic controls and servo mechanisms, the antennas at the terminal points of the system remain properly aligned regardless of changes in the relative position of the terminal stations. This system permits mobile stations to attain the advantages inherent in directive point-to-point communications.

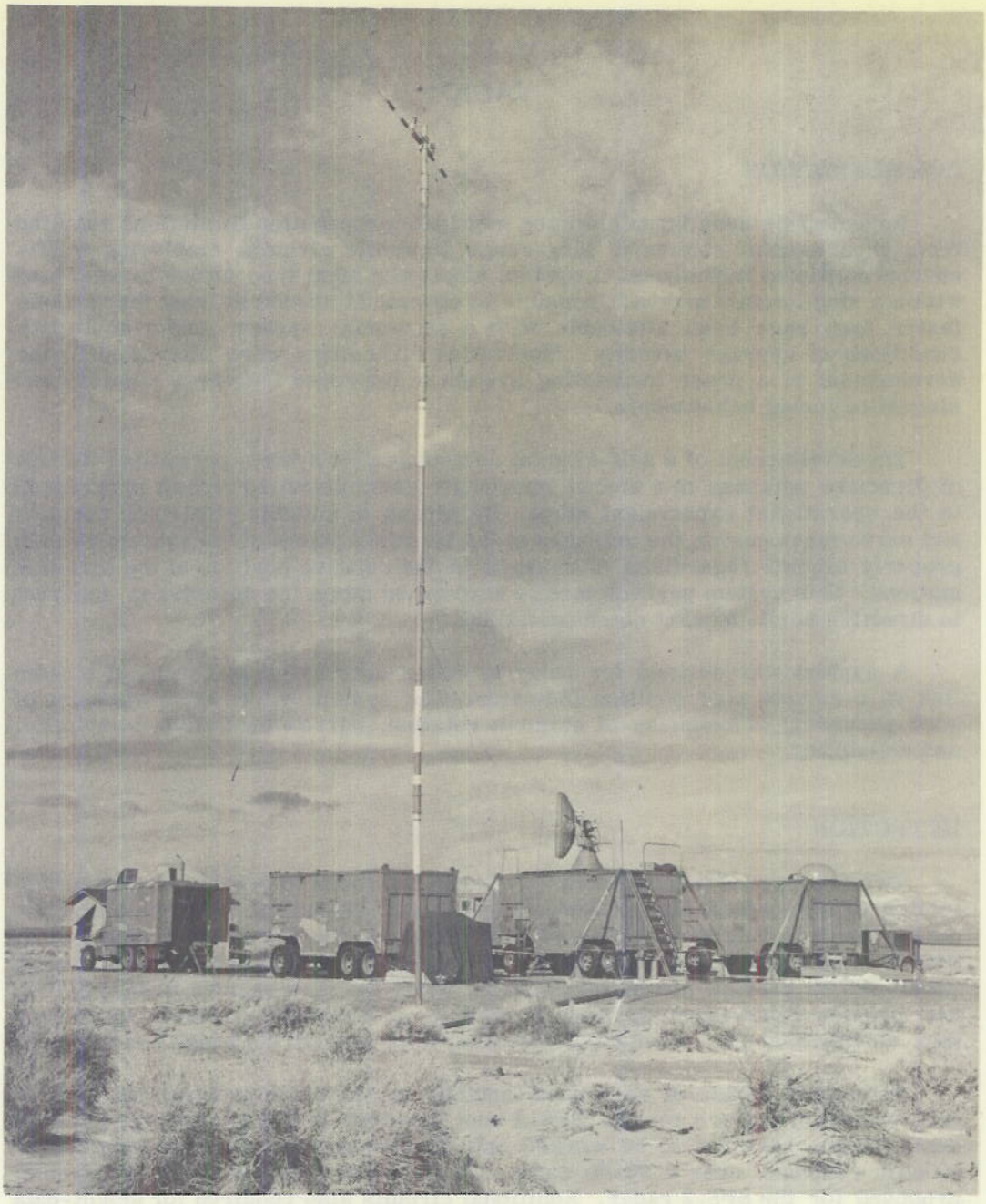
A system was devised for relaying radar information by means of a radio link to a remote plan position indicator. The system offers the advantages of good accuracy, smoothness of azimuth rotation, narrow bandwidth, simplicity, and reliability.

DETECTION

Two new types of radar systems are being developed to provide improved detection of high-speed high-altitude targets, and substantial progress was made during the reporting period. One of these systems, the Very Long Range Radar, SPS-2, is intended primarily to extend the range and altitude coverage of search radar and to provide height information, while the Hemispheric Radar, SPS-3, will provide rapid-scanning, high-resolution, close-range coverage up to very high elevation angles, furnishing elevation data as well as range and azimuth.

Successful design of an X-band antenna model which provides the desired multiple-beam pattern for the SPS-2 was achieved in the laboratory, although some details have yet to be worked out. Receivers were developed with logarithmic response over a 90-db range, as required by the height-data system proposed for the SPS-2 radar. Additional circuits also required for height-data presentation were devised, and progress was made on various other phases of the project. The Bureau of Ships is negotiating a contract for construction of two prototype equipments to be completed in two to three years.

A wooden-inner-cone model of the Foster Scanner for the SPS-3 Hemispheric Radar was tested and proper scanning action demonstrated. Delivery of a precision-built magnesium cone for further tests is expected soon. The type-G



Lark SP-1M Radar at the Naval Ordnance Test Station, Inyokern, California. This ground-control and data-taking system, designed and constructed by the Naval Research Laboratory, is used for beam-rider guidance of the Lark during mid-course flight.

three-dimensional display system was developed to a usable degree in the laboratory, and further improvement is expected when recent types of storage tubes are made more reliable and more available for experimental work.

In the field of Moving Target Indication (MTI), a laboratory tool was developed and constructed which permits analysis of the performance of experimental MTI systems under accurately simulated shipboard conditions. This is an ultrasonic device known as the "Water Plow." It consists mainly of an ultrasonic radar operating in a tank of water. The MTI system for the SR-3, SR-6, and SPS-6 radars, incorporating velocity-compensation for own-ship's speed, was completed and satisfactory performance demonstrated by use of the Water Plow. Sea trials will be made, and future work will then be directed toward providing MTI for the SPS-2 radar.

Studies continued on the detection of weak signals in the presence of noise on a PPI indicator, and extensive studies were conducted on the training of personnel for detecting schnorkel against sea return. As a result, the Bureau of Aeronautics is proceeding with the development of a trainer and the Laboratory is investigating the possibility of including in the APS-20 a dark-trace tube and modified B-scan indicator using rectangular pattern of azimuth versus range.

NAVIGATION

The development of a ground velocity indicator, to be used for determining the absolute velocity of an airplane in flight over land and sea, was continued. Velocity is obtained from the Doppler frequency shift which occurs when microwave radiation from an airborne transmitter is scattered by the earth's surface and returned to the airplane. For a given system and altitude there is an optimum angle from the vertical at which the airborne antenna may be positioned for maximum useable signal. Measurements made from the Golden Gate Bridge at the entrance to San Francisco Harbor under several conditions of wind, tide, and wave height, indicated that the optimum antenna angle is 15 to 20 degrees from the vertical. A relatively simple system for use in a blimp to indicate distance travelled, with an accuracy of two or three percent in normal flight, was developed. It may be possible to scale this apparatus to K-band for use in a helicopter.

Plans for the next year call for development of a prototype Ground Position Indicator which will use components of the existing Air Position Indicator. It will be provided with two antennas, one to right and the other to left of the plane axis. Signals from receivers connected to these antennas will be fed to a computer, the output of which will provide true ground speed and drift information to a latitude-longitude computer.

In undertaking the basic research for the Navy's Carrier All-Weather Flying Program (CAWF) and in analyzing the scope of this investigation, the Laboratory emphasized three major phases of the program: (a) the development of a Data Relay Navigation (DARN) system, (b) application of DARN techniques to the existing Carrier Controlled Approach (CCA) System, and (c) the study and development of equipment for automatic carrier aircraft approach and landing operations. The DARN system proposes to supply in the aircraft a display of homeship PPI information to implement air navigation and traffic control. Electronic and mechanical components for laboratory system analysis and test of DARN are now

complete. Through use of the DARN technique, an airborne pictorial display of the final approach can be provided by relay to the aircraft of radar information presently available aboard ship as a part of the CCA system. All components were developed that are required for ground simulation of the airborne CCA display. Under the automatic aircraft approach and landing project, preliminary studies are being made and equipment developed to determine practical possibilities in the design and operation of such a system.

CONTROL

As the complexity of instruments applied in modern warfare increases, it becomes more and more necessary that as many operations as possible be made automatic. The Laboratory has undertaken extensive work in the control field, principally directed toward the development of integrated systems for the automatic control of gunfire, guidance of missiles, and gathering and analysis of equipment-performance data.

Operational evaluation of gun-fire control systems Mk 56 and Mk 63 are now substantially complete, whereas analysis of the Mk 40 Mod 0 target designation system was completed. Research on techniques of computation and data-taking instrumentation resulted in improved equipment being applied in the field evaluation of fire and missile-control systems. A recently completed laboratory equipment, Digitar, precisely translates into digital form and records high-speed shaft position and motion. A large-scale digital computer, to be used as a laboratory research tool, is now being planned.

Findings of such basic studies as system noise, missile kinematics, and low angle and jet gas effects, are prerequisite to the design of usable control systems. These and other fundamental studies contributing to the science of missile guidance and control have continued. The theoretical work was supported by controlled flight experiments aggregating some three hundred hours of aircraft flight plus numerous evaluation flight tests in missile airframes. A total of 12 hours, or 2200 miles, of guidance in full automatic control of the aircraft were flown.

The Lark SP-1M Radar, a trailer-borne control and data-recording equipment for both beam-rider and command guidance, was completed at the Laboratory and is now in operation at the Naval Ordnance Test Station, Inyokern, California. Two Lark-missile flight tests of the mid-course guidance system were conducted with limited success.

The Laboratory's contribution to the Kingfisher E guidance program included the development and demonstration of the command guidance equipment. This equipment uses a modified Mk 25 radar and command pulse coding devices on the surface and a receiver, decoder and beacon control equipment in the missile. Aircraft demonstrations of the system are the first known successful flights applying command guidance in full automatic control.

The design of mid-course command and terminal homing guidance equipment for the Skylark missile is complete in preproduction form. Piloted flight experiments are being conducted by the prime contractor. With continued development and refinement, both the mid- and end-course guidance systems for Skylark should become satisfactory.

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Several products have evolved from the subminiaturization program for missile-borne electronic equipments. An ultra-small radar beacon provides means for increasing the tracking ranges of missiles over that which radar reflection permits. Operating at S-band and weighing only three pounds ten ounces, the beacon is approximately one-tenth the weight of previous reliable designs and occupies less than one-twentieth the volume. In performance, it is equivalent to its predecessors. Reliable miniature missile telemetering equipment was also developed.

COUNTERMEASURES

The task of countering enemy electronic signals is twofold. The enemy signal must first be intercepted, and if possible its source located and frequency determined; then the enemy's efforts must be neutralized by active countermeasures such as jamming or returning confusing signals.

To improve the facility with which naval direction-finding nets can intercept and obtain a fix on a short-duration transmission, a system was devised to control several direction finders from a single remote point. The time required for obtaining a fix on such transmission may then be greatly reduced by combining the bearings rapidly from the direction finders constituting the net.

In order to provide submarines with means of detecting the presence and direction of approaching enemy radar-equipped units while still beyond their radar range, a direction finder covering the frequency range of 2300 to 10,600 megacycles was developed. In a preliminary test at the Chesapeake Bay Annex of NRL, the experimental model, designed to withstand the high pressures of deep dives, indicated bearings of radars in the 3000-megacycle band for a distance of twenty miles beyond the eleven-mile radar range.

Shipboard operational tests demonstrated the superior effectiveness of pulse analyzers, based upon a multigun cathode-ray indicator system, recently developed at the Laboratory for the analysis of short-duration "flash" type signals.

In the operational use of countermeasures against high-speed enemy signals, the necessity for covering wide frequency ranges in a short time makes manual control impractical. As an initial step in the development of automatic search and jam systems, a control unit was devised to tune a receiver over a desired frequency range, stop it on a received pulse signal, automatically set a jammer to the same frequency, and provide periodic monitoring of the victim signal during jamming.

Plans in the countermeasures field include continued development of automatic search and jam systems. Also projected is further development of automatic position-indicating systems requiring the synchronized tuning of the receivers of the several controlled direction-finder stations and the automatic presentation at the control point of the bearing from each direction finder in the net. Further enlargement of the frequency range and increase in the probability of signal interception by submarines are vital problems on which additional work is planned.

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SYSTEMS INTEGRATION

As a primary function, naval electronic systems must provide information for the rapid and accurate exercise of command. For maximum utilization of this information, the several electronic systems must be combined into a coordinated and integrated whole. The Laboratory is actively concerned with the problem of systems integration as related both to existing electronic systems and to those in a development stage.

Illustrative of research in this field is a statistical study of the response of a radar beacon to multiple interrogations - a situation which exists in aircraft homing. An experimental multiple-pulse generator which simulates as many as 300 independent pulse sources or interrogators was developed and will be applied in this study.

The problem of designating targets from a single search radar to several gun fire-control systems is a difficult one. A new method was proposed that detects the polar coordinates of any point on a conducting surface by touching the point with a conducting stylus. With this technique, a gun director may be placed on a target by touching the target echo that appears on the face of a radar PPI indicator.

ELECTRON TUBES

Activity during the past year was concentrated on three research projects, chosen because of their potential value to the Navy. These are cathodes for ultra-high-frequency tubes, storage tubes, and microwave tubes.

Research on cathodes has as its object the development of high current density cathodes for use in tubes operating at extremely high frequencies. A hot pressing technique was utilized for fabrication of high density ceramic thoria cathodes. Cathodes of pure thoria and mixtures of thoria and conducting material were formed in a carbon mold applying pressure (2.5 tons per square inch) and heat (2000°C) simultaneously. It was found that the hot-pressed cathodes have characteristics similar to cathodes prepared by cold pressing or slip casting, but are easier to fabricate. The life of thoria cathodes operating at high temperatures appears to be limited primarily by the evaporation of the material. One of the most promising conducting materials was found to be tantalum carbide, whose rate of evaporation was found to be about 2 mg/cm^2/hour at 2000° C as compared to titanium nitride's rate of 50 mg/cm^2/hour at 1750°C.

Considerable effort was again devoted to signal storage tubes with the ultimate object of developing electronic signal storage tubes needed for important problems in radio communication, radar, identification, countermeasure, and computer systems. A considerable improvement in contrast, resolution, and control of persistence was achieved in the Image Intensifier Memory Tube.

An outstanding success was achieved in devising and demonstrating a method for recording, storing, and reproducing half-tone pictures. This tube, a modification of The Memory Tube, has as the essential feature a storage surface consisting of dielectric particles sprayed over a glass surface (such as the face of the tube) with a conducting transparent coating. Its advantages include high signal

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output, negligible "angle" effect, good stability, and uniformity of persistence over the entire target area. It is believed that this "screenless" Memory Tube is the first electronic storage device which can store and faithfully reproduce half-tone pictures for any desired period of time.

New electronic methods of generation and amplification of microwave energy are being explored, particularly methods suitable for the millimeter wave region of the radio spectrum. The electron wave-tube characteristics received special attention. This device, originated at the Laboratory, makes use of the interaction of space-charge waves which result in amplification of microwave energy. Net useful gains as high as 60 decibels were obtained in experimental electron-wave tubes operating at 3000 megacycles.

ANTENNAS

The principal effort in the microwave antenna research program was concentrated in a few areas of particular current interest. The continuing problem of rapid scanning of the antenna beam was attacked as an optical problem of moving a feed with respect to a focusing device (lens or reflector). This led to a study of wide field-of-view focusing devices, of moving-feed and extended-feed systems, and of artificial dielectrics as lens materials. The possibilities of a microwave iconoscope consisting of a lens and a 12 x 12 array of feed horns were explored experimentally. Artificial dielectrics, both the metal-plate and the metal-loaded types, were the subject of a continued study.

The useful simultaneous lobing (monopulse) principle for precision location system antennas stimulated the development of a compact r-f circuit for lobe comparison and for the investigation of the effect of illumination on significant antenna performance characteristics. The r-f circuit employs directional couplers between the guides leading from the four parts of the simultaneous-lobing feed horn to obtain compactness.

A number of antennas were developed for specific applications: circularly-polarized, hemispheric search antennas for the BLR-1 system and three shaped-beam antennas for the SPS-6 system. The effect of the curvature of the earth on the equal energy pattern for airborne bombing antennas was calculated.

The principle of common antenna working, which was applied to the very high and ultra high frequency ranges during the previous year's program, was further utilized to encompass the high frequency range. This is part of the general program to reduce the number of shipboard communication antennas and to improve their radiation characteristics.

Broad-band antennas having characteristics suitable for multiple-frequency operation were devised. Antennas of the cylindrical sleeve type were designed to incorporate portions of the ship's superstructure into the broad-band radiating system.

In support of the antenna program, emphasis was placed on a program of instrumentation for microwave antenna measurements. Some of these instruments include: (a) a low-inertia automatic plotting recorder for antenna radiation patterns, (b) a direct-viewing standing-wave instrument and a direct-reading instrument for impedance measurement of microwave antennas, (c) an automatic

computer for directive aperture antennas, (d) instruments for measurement of electromagnetic properties of dielectrics under free-space conditions, and (e) a simplified technique for frequency stabilization.

CIRCUITS, COMPONENTS, AND INSTRUMENTATION

An absolute method was devised for the measurement of power at a level greater than 100 microwatts, suitable in both the microwave and millimeter wave ranges. It has a threshold sensitivity of about two microwatts and yields an accuracy of about two percent at a level of 100 microwatts. The method employs adiabatic microcalorimetry, making use of the temperature rise of an absorbent matched load upon which impinges the energy to be measured.

A continuously variable decade frequency generator having a range of 100 cycles to 25 megacycles was developed. It demonstrated accuracy of plus or minus 1 cycle throughout the range, based on a 100-kilocycle standard frequency source.

Techniques and instrumentation were developed to permit measurement of capacitance increments of the order of 0.001 micromicrofarad for use in studies of the stability of components and for use in related researches.

The causes and effects of capture of a weak signal by a stronger one in frequency modulation and amplitude modulation communication systems were exhaustively studied to provide quantitative limits upon which to base design and operational planning for communication systems.

Standards laboratories are required by the Navy at convenient points for the servicing and recalibration of electronic field-type test equipments. To meet a portion of this need, self-contained console-type recalibration equipments, complete with standards and power supplies, were developed. These will be used for the recalibration of moving-element meters operating from dc to 1600 cycles per second. Circuit research and development was completed on extremely stable frequency multipliers and dividers applicable to the frequency standard portion of this requirement.

Extensive future use of such new airborne and shipborne equipments, presently under Navy procurement or development, as the AN/ARC-19 creates an urgent need for frequency meters and signal generators of greater accuracy and frequency range. In anticipation of this need, a program of development is under way for a precision portable frequency meter to measure frequencies in the range 10 to 500 megacycles to an accuracy of 0.001 percent. The basic design of the frequency meter, and the development of the major and most difficult circuits is complete.

PROPAGATION

A model range was developed and placed in operation at Chesapeake Bay Annex for determining the radar properties of various types of targets by making measurements on scale models. Such measurements are useful for exploring

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the detailed characteristics of the radar reflection as a function of target orientation. Measurements of this type can be used to explore the mechanisms of reflection and to interpret the results of full-scale dynamic flight measurements. This type of comparison is being made with models of naval shells which were observed in actual flight at the Naval Proving Ground, Dahlgren, Virginia.

Extensive investigations are being continued of the properties of sea clutter of radar echoes from small targets, and of the discrimination of small targets in the sea clutter background. Complete instrumentation for airborne measurements of radar signals was installed in a PBM aircraft to accumulate fundamental data from which the basic mechanism of sea clutter will be explored. Because part of this study will be the role of the sea and targets in depolarizing the signals, special antennas were designed for this work.

In analyzing the effects of rain and other precipitation on radio transmission, the two major effects found are attenuation of waves transmitted through the rain, and radar signal masking caused by scattering from the rain. Experimental measurements of microwave attenuation by rain disagree with theory which neglects action of raindrops with each other. In the analysis of this interaction, some new mathematical formulas were developed which are useful in problems involving scalar and vector wave functions corresponding to acoustic and electromagnetic waves scattered by particles small compared to the wavelength.

In order to correlate attenuation and back-scattering of radio waves produced by rain and other forms of precipitation, an airborne instrument which is flown through the precipitation region was developed for measuring size and size-distribution of raindrops. This instrument, known as the Disdrometer, showed a sensitivity accurate enough to detect and record raindrops from 0.5 mm diameter and up — the range of drop size causing the greater part of scattered radar energy. In order to evaluate the effect of the precipitation in the range of drop sizes below that which can be measured by the Disdrometer, it is customary to make a measurement of the total water content of the space being investigated. This led to the development of a "mercury-filament" flow meter consisting basically of a mercury-platinum contact so composed as to provide a record of mercury position versus time, thus giving directly the rate of flow of water as the latter collects in a glass capillary.

Nonresonant, very-broad-band absorbers were developed by tapering the absorbent material. A fairly light-weight (12 oz. per sq ft), very thick (4 in.) material was developed for use in microwave darkrooms and other laboratory installations. This material is a good absorber for S, X, and K-band radiation, 99 percent of the incident power being absorbed at all frequencies in this region for radiation at normal incidence. The material is, furthermore, fairly insensitive to angle of incidence and polarization of the radiation.

A somewhat thinner (3/4 in.), heavier (2-$\frac{1}{2}$ lb per sq ft), but more flexible broad-band material was also developed; it absorbs 95 percent or more of normally incident radiation throughout S, X, and K bands. This material should be very useful for the radar camouflage of schnorkels, tanks, and other objects where weight and thickness requirements are not too stringent.

Measurements on the intensity of radio-frequency radiation from the sun at 10,000 and 35,000 megacycles were taken, and an analysis was made interpreting

the results in the light of the conditions in the sun's atmosphere where the radio-frequency radiations arise. This investigation will give a better understanding of peculiarities in radio communication due to ionospheric variations and will lead to a better understanding of conditions in the atmosphere of the sun.

The very narrow beamwidth (0.18 degrees) obtained by using a 35,000-megacycle receiver in conjunction with a ten-foot diameter antenna made it possible to scan the surface of the sun and to establish the fact that some active areas radiate much more intensely than the general background. On July 29, 1948, an intense radio-frequency disturbance from the sun was detected at 10,000 megacycles and the intensity rose to many times its normal value. These disturbances, called outbursts, are usually associated with the presence of a solar flare and with the accompanying sudden ionospheric disturbance. The outbursts have been measured at lower frequencies many times before, but until this time had never been observed at this high frequency.

Investigation of jet-gas and low-angle effects upon the propagation of electromagnetic radiation is of primary importance in the development of missile guidance equipment. The nature and extent of adverse propagation characteristics together with incidental modulation of radiation incident upon flames was the subject of intensive study. It was determined that, in the case of the Lark acid-aniline motor the jet flame will not compromise performance of the beam-rider guidance system. Beam-rider guided-missile targets will usually occur at less than 3 degrees radar elevation angle and such low angles introduce noise effects the nature of which must be known for effective control-component design. An examination of the field intensity distribution of the beam-rider radar beam at various low elevation angles was undertaken in connection with the study of low-angle propagation effects. Flight testing beam-rider guidance equipment in aircraft was accomplished at low elevation angles (average about 1 degree). Guidance error-signal analyses resulted in circuit modifications that now appear to make practicable automatic beam-rider guidance at low elevation angles.

PRECISION LOCATION

This program is concerned with investigations of radar techniques and components for precision automatic tracking of targets or missiles and techniques for obtaining extreme target resolution. Precision tracking radars could be improved by reducing the effects of noise on tracking smoothness, and higher resolution could be obtained by improving the generation, amplification, and presentation of extremely short pulses.

Two basic types of tracking-radar systems were constructed and tested. One, which used sequential lobing techniques may be operated at conventional lobing rates, at high rates and at aperiodic rates; the other used simultaneous lobing comparison or "monopulse" techniques. Comparative experimental evaluation of these systems was inconclusive since test results determined only total noise which in these systems under the necessary test conditions is large compared with the effects of amplitude noise. Accordingly, the present effort was placed on direct evaluation of the various noise components. Amplitude noise spectra have been obtained. Angle noise is to be determined in the near future by direct measurement of the angle of arrival between a target echo and a reference

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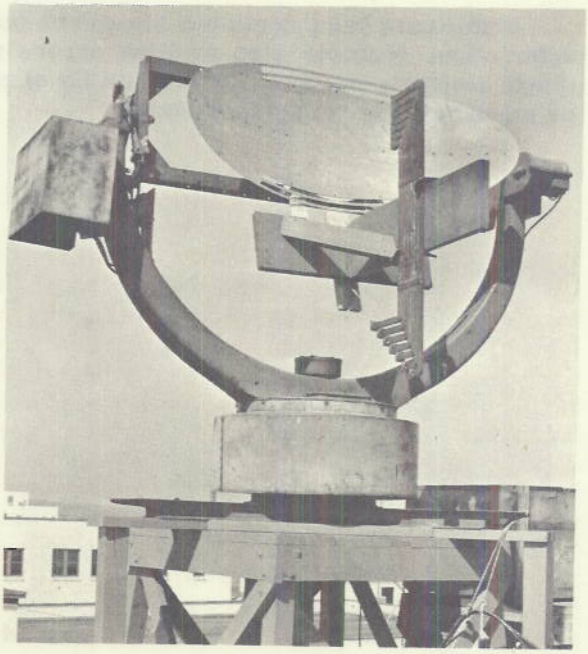
beacon carried by the target. A knowledge of the various noise components will permit the evaluation of the probable tracking dispersion obtained in any given system under any assumed tracking conditions.

The generation of short pulses requires circuits having extreme bandwidth. A modulator was designed and constructed capable of generating high power pulses of 0.01, 0.025 and 0.10 microseconds at pulse repetition rates controllable from 60 to 3700 cycles per second. Video amplifiers with bandwidths of 160 megacycles and i-f amplifiers having a bandwidth of 120 megacycles centered at 1000 megacycles were also built. A test oscilloscope with sweep speeds up to 100 inches per microsecond is in operation. Short-pulse generators and indicators require extremely stable delay circuits in order to avoid time jitter. Successful operation of high-power gas tubes and sweep generator circuits was obtained which show no perceptible time jitter at the maximum sweep speed. Upon completion of the circuit and component development, an experimental system will be constructed for evaluation of the range-resolution capabilities of a short-pulse system.



Experimental radar antenna mounted for evaluation. For convenience, radar antenna design is carried out utilizing this 5 by 2 foot model. The corresponding production antenna would be scaled to 35 by 14 feet, the largest yet developed for Naval radar and over ten feet wider than the German "Giant Wurzburg."

PSYCHOLOGICAL RESEARCH

The reliability of automatic equipment often depends at some point upon the "human element." The human operator of a power-controlled equipment in a sense constitutes one element in a complex servo mechanism and many practical advantages might be gained in control-equipment design if the transmission characteristics of the "human link" were subject to treatment by techniques of linear-servo analysis. Measurements were made of human motor responses to step-function inputs of position in which position, rate, acceleration, and other aspects of output were treated as functions of varying input amplitude. The human appeared to be nonlinear in several different ways. It was found that the correction response was made in a period of time shorter than the human reaction time, so that once started, the response does not appear to be controlled by visual feedback. This and other evidence suggests that man is intermittent in his tracking behavior.

Studies are being continued to explore further the human transmission characteristics. Multiple step-position errors are now being employed as well as single step rate errors. The possibility of response control by muscle feedback or kinesthesis is being investigated.

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SOUND

Under the general program of "sound," the Laboratory conducts research on transducers, sound propagation, location of small objects, recording and reproduction, sonar electronics and systems, bio-acoustics, countermeasures, and harbor, fleet base, and coastline defense.

Research into improved means for converting electrical and other forms of energy into sound or vibration, and vice-versa, included the building and testing of a new crystal array or transducer devised specifically for phase comparison methods of bearing measurement. It has an improved directivity index and operates well at two vibration modes. Study of piezoelectric crystals continued, and the properties of Alfer, a magnetostrictive alloy of aluminum and iron, were tested. Methods of construction of magnetostriction transducers were advanced, and two improved "broadcast" projectors using a new technique were built for the Blimp Sonar.

Vertical thermal gradients in the upper layers of the ocean have for some years been recognized as an important factor in the propagation of sound in the sea. Superimposed on this large-scale thermal structure are small temperature irregularities now being studied as a probable cause of some anomalous propagation phenomena. A sensitive and quick-acting thermopile was built, mounted on a submarine, and used to collect records of temperature fluctuations in waters near Cuba. Temperature variations in the isothermal layer near the surface caused a small amount of ray-bending compared with those in the thermocline or deeper temperature-changing layer.

To further the knowledge of sound transmissions through the sea, measurements were made by projecting sound signals from a submerged submarine to a string of hydrophones suspended at several depths below a surface vessel. From the data, sound-intensity cross sections for a deep layer were constructed to supplement earlier measurements of shallow layers.

The effects of high-intensity sound waves in heterogeneous liquid media are incompletely known. Several studies are now in progress to clarify the nature of these effects.

Short-pulse sonar equipment developed at the Laboratory and installed by the Army at Fort Monroe, Virginia, has been used for some time to make a statistical study of the detection of small objects (mine cases) anchored at various depths and at ranges of 15 to 1100 yards.

A magnetic recording unit is being prepared to obtain underwater sound transmission data. To offset the possibility that the response-frequency characteristics can change over long periods of time, a specially constructed calibrating device supplies a known signal after each recording.

A two-frequency echo-ranging system which may improve recognition differential in sonar is being investigated. Comparative tests showed that a preliminary model performed better than standard sonar equipment in river water.

In deep water, it was superior in detecting echoes in the presence of propeller noise.

Data are being assembled upon which to base new detection systems and to evaluate methods of improving recognition differential in sonar. To appraise very-narrow-band sonar reception in the presence of various background noises, compact, narrow-band filters were constructed. Other equipment is being used for comparing the detection of pulsed signals by the human ear with electronic detectors having bandwidths down to about one-tenth that of the ear. Also, a program was planned and the instrumentation begun for the recording and analysis of reverberation and target echoes in various ocean conditions and areas.

As an interim part of the Ship Sonar Research program, work on the Type-A Integrated Sonar was directed toward the study of system parameters as they apply to shipborne sonar systems. The Type-A was originally designed according to basic searchlight techniques but containing unique modifications necessitated by war experience. The resulting integrated system was a new research tool useful for obtaining operational data on varied problems. Instrumentation was included for the analysis of operator techniques to reduce as far as possible personal errors in interpretation. Improved Sector Scan Indicators, a reengineered attack director, and a depth tracker to be used alternately with a depth-computing device provided greater efficiency. Repairs during a run were possible without loss of target contact by simply plugging in a new sub-unit.

The advent of the high-speed submarine greatly increased the need for a sonar vehicle having a high search rate and freedom from underwater attack. A low-flying helicopter or blimp could tow a trailing sound transducer in the sea. A helicopter-sonar unit, AN/AQS-1, made contact with targets at ranges to about 3800 yards by echo-ranging and ultrasonic listening when passing freighters were used as the targets. Sonic listening was inferior to ultrasonic detection; this is probably caused by the disturbance of the sea surface by downwash from the rotor blade of the helicopter hovering at about 60 feet. An entirely different sonar equipment for blimp use was constructed and is being tested.

The feasibility of ship-towed sonar is being investigated to eliminate some of the inherent disadvantages of normal shipboard sonar, such as noise induced by the ship, vibration effects, turbulence and air bubbles produced by the motion of the ship, shallow thermal gradients, cavitation effects at high speed, and noise induced by the screws. Equipment is being assembled for test runs of a ship-towed sonar at a depth of about 50 feet.

New techniques were developed for spot-welding structural members in reinforced rubber domes. Stresses in the new 60-inch rubber dome due to sea forces during operations were measured by means of strain gages embedded in the dome.

The calibration phase of the XDG submarine-sonar equipment on the sound barge was completed and it is ready for installation on a submarine.

Work on a long-range search sonar system progressed in some phases to the engineering stage. The first transducer (a 10-kilocycle crystal transducer) and the training gear and programming mechanism were designed. Progress

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has been made in the design of a high-power long-pulse driver and in electronic detection equipment with improved recognition differential.

A technique for measuring the sound velocity and absorption in animal tissue and its physiological effects was developed; tests showed slight variation in velocity from that in water.

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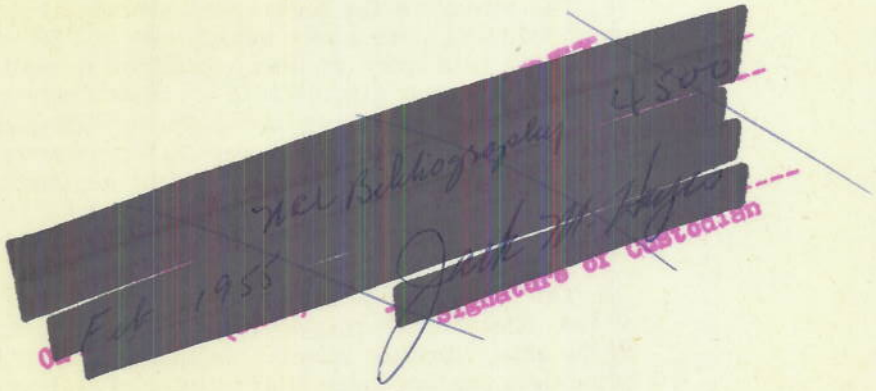

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